Report of the great earthquake of 12th June, 1897

Richard Dixon Oldham

MEMOIRS

OF

GEOLOGICAL SURVEY OF INDIA

VOLUME XXIX.

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MONUMENT TO GEORGE INGLIS, CHATAK.

(The part left standing is about 45 feet high.)

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PREFACE.

ON SOME GENERAL PRINCIPLES OF SEISMOLOGY.

(The memoirs of the Geological Survey of India usually assume a certain previous knowledge of the subject they treat of, and do not attempt to recapitulate the elementary principles which will be found in any text-book of geology. In the case of the earthquake of 12th June 1897, which has attracted more general attention than is usually given to the labours of the Geological Survey, more elementary details than customary have been introduced, but even so there are some points which it is necessary to understand, and of which a sufficiently exact knowledge is by no means common. These could not have been treated in the body of the report without great interruption to its continuity and the introduction of a large amount of matter which would only embarrass those to whom it was already familiar.

For this reason an introduction dealing with certain general principles has been prepared and printed as a preface to the report. It is not intended as an introduction to, or as a primer of, seismology in general, but only of such parts of the science as is necessary for the comprehension of the following report, or as have not been treated with sufficient fullness in the body of the report. Those who desire to pursue the matter further should refer to the two volumes of the International Science Series, 'Earthquakes' and 'Seismology' by Prof. J. Milne, F.R.S., which between them practically cover the whole range of the science.

A special index is appended to this preface to serve the purpose of a glossary of the technical terms used in the report.)

I.—The nature of wave motion.

1. When a stone is dropped into a pool of water a series of concentric ripples are formed, which travel outwards in ever widening circles till they reach the edge of the pool, or, if it is large enough, gradually die out. But though we speak of the ripples, or waves, as travelling, it is important to remember that the water of which they are composed does not travel; each separate particle of it moves in a certain orbit, whose size and shape determines that of the wave, but ultimately returns to its original position. The travel of the wave is due to the fact that all the particles of water do not move at the same time, each one starting and finishing a little later than the one behind and a little earlier than the one in front of it, on the course the wave is travelling.

2. The shape of the orbit in which the particles of water travel changes gradually as the wave progresses, as may be seen in the gradually changing form of the waves as they travel outwards, but the change is slow and, for any given spot, the tracks in which all the particles of water move may be regarded as similar, and the nature of the *wave motion* can be defined by the shape of the track followed by each particle involved in the wave. Hence comes a term which will be frequently employed, the *wave particle:* by this is meant no

specific individual particle of matter, but any one taken at random at a chosen place, by the extent, form, and rate of whose movement the nature of the wave motion at that place is defined.

3. The particles referred to are *molecules*, the ultimate portions of matter reached by continual subdivision till a limit is reached where no further division is possible without a change of character and properties. Hence the movement in a wave is called *molecular*, while a bodily displacement of the water or other substance may be distinguished as *molar*. When a kingfisher dives into a pool it makes a splash, and then from the splash a series of concentric ripples travel outwards in ever widening circles. In the splash the movement of the water is *molar*, in the ripples it is *molecular*. So too the general movement of the water of a trout stream may be regarded as *molar*, that in the ripples formed by the rising trout as *molecular*.

4. *Gravitational waves.*—Waves are of several kinds; of these it will be well to take first that which is most commonly known, such as may be seen or started on any sheet of water. In these the course of the wave-particle is elliptical, or circular, as is diagrammatically represented in fig. i. The wave-particle is at its highest point as the crest of the wave passes over it, and at its lowest when the trough occupies the same position. When any one particle is at its highest the one in front has not yet risen to its highest point, while the one behind has begun to sink again. By the time the one in front has reached its highest point the one we were considering has begun to sink; and so it is that the wave travels.

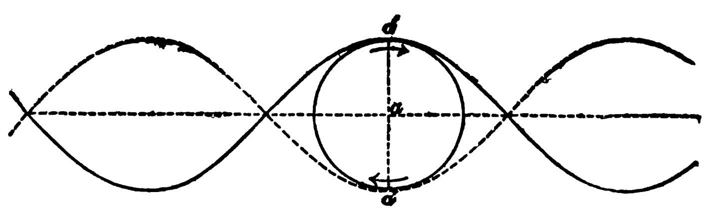

Fig. i. Diagram of movement of wave particle in a gravitational wave.

5. Wave motion of this nature is quite superficial, and where waves are set up in deep water it is only that near the surface which is affected. As we descend from the surface the extent of movement of the wave-particle rapidly diminishes, the shape of its track becomes a more elongated ellipse, till, at a comparative short distance from the surface, there is only a slight to and fro movement which becomes less and less till it vanishes.

6. If in fig. i the firm and broken curved lines are taken to represent the outlines of a wave when its crest and trough respectively are over the same place, and the horizontal dotted line the normal level of the surface of the water; then the *length* of the wave is the distance from crest to crest or trough to trough. The distance *a a'* is the *amplitude* of the wave, or the distance the wave-particle moves up or downwards from its normal level; double this, or *a' a'* is the *height* of the wave from trough to crest.

7. If the track of the wave-particle as drawn in fig. i is examined, it will be seen that the movement can be divided into two *phases*: one of forward, and one of

backward, movement, if the dividing line is horizontal, and one of upward, and one of downward, movement if the dividing line is vertical. Moreover, by the intersection of these two dividing lines we get four *semiphases* in which the motion is (1) upward and forward, (2) downward and forward, (3) downward and backward, (4) upward and backwards, thus completing the cycle.

8. Waves of the kind now being dealt with are known as *gravitational* waves, as in them the moving force is the attraction of the earth. The water which has been raised above its normal level in a wave, is brought back by gravitation and communicates the energy so developed to the water in front, by which it is raised above its normal level, only to fall back and cause the rise of fresh water in front. In other words, it is the weight of the water in a wave which causes it to sink, and in doing so to make the water in front rise as the continuation of the same wave.

9. *Elastic waves.*—Besides gravitational waves there are other molecular movements which, by analogy, are called waves, and, being propagated in virtue of the elasticity of the substance through which they travel, are called elastic waves.

The elasticity of a piece of indiarubber or cane is familiar enough; in the sense used here it may be defined as the capacity, possessed by all substances to a greater or less extent, of recovering their original bulk or shape, if these are altered by the action of an external force. It is of two kinds, one, common to both solids and fluids, is the power of recovering the original volume, which has been altered by change of pressure, when the original pressure is resumed. The measure of this is the *bulk modulus* of the substance. The other kind of elasticity can only be possessed by solids, and is the power of recovering the original form, if this is changed by the action of an external force, when the force is removed. The measure of this is known as the *rigidity* of the substance.

10. A perfectly elastic substance would completely recover its original bulk and form, and in doing so give up exactly the same amount of energy as was absorbed in producing the change. So far as bulk is concerned a gas may be regarded as a perfectly elastic substance, but no solid can be regarded as such or even nearly such, except within comparatively small limits. A bar of iron bent slightly will spring back to its original form, but if bent further and strained beyond the *limit of elasticity* will remain bent. So all solids, if strained within their *limit of elasticity* will recover their original form, but if strained beyond that limit will either remain permanently bent or break.

11. Within these limits elasticity is measured by the force required to produce a given amount of change in bulk or shape. The greater the force that has to be applied, the greater that which the substance will exert in regaining its original bulk or shape, and the one is equal to the other. Measured in this way the elasticity of steel or glass is very high, while that of the typical elastic band is very small; for, though the limit of elasticity is much wider, the force required to produce a small change of shape is much smaller.

12. *Waves of elastic compression.*—Corresponding to the two kinds of elasticity there are two kinds of elastic waves, one of which, depending on the resistance to compression, can be propagated in solids and fluids alike. This form, which will be considered first, is that of those known as *waves of elastic compression* or more briefly *condensational* waves. In these the movement of the wave-particle is

directly forwards and backwards in the direction of travel of the waves, hence they are sometimes called *normal* waves.

13. To understand the nature of the movement in a wave of this kind let o, fig. ii represent the normal position of a molecule when undisturbed. Suppose it to become involved in a wave of elastic compression travelling in a straight line from left to right; then, starting from o it will move outwards passing successively through the positions 1, 2, 3, till at 4 it reaches the extreme limit of its movement. From 4 it returns with an ever-increasing speed, till at 8 it passes on through its original position and, gradually slowing down, comes to a stop at 12; from this it commences its return journey through o to 4 and so on. The movement is in fact just like that of the bob of a pendulum, assuming the direction of travel of the wave to be that of the swing of the pendulum. Returning to the diagram fig ii, the distance from o to 4 is the *amplitude* of the wave, or the extreme distance which the wave-particle reaches from its normal position; 4 to 12 is the double amplitude or *range of motion* of the particle, and the time taken by the wave-particle in travelling from o out to 4 and back through 12 to o is the *period* of the wave.

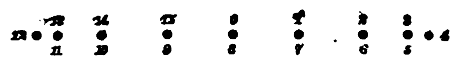

Fig. ii. Diagram to illustrate the successive positions occupied by the wave-particles at equal intervals of time during one complete undulation of a condensational wave.

14. As in the water wave, the movement of the wave-particle may be divided into two *phases*, one of movement in the direction the wave is travelling, the other in the reverse direction. Each of these can again be divided into *semiphases* according as the movement of the wave-particle is inwards, towards, or outwards from its normal undisturbed position.

15. To understand what is meant by the wave length in a wave of this nature we must consider how the arrangement of the molecules is affected by them. In fig. iii, let o represent a molecule which at the movement is passing through its

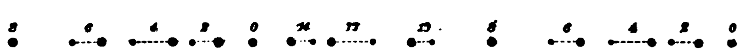

Fig. iii. Diagram to illustrate the distribution of matter in a condensational wave.

normal position; the next molecule behind it, the wave being supposed as travelling from left to right, is in a slightly more advanced stage of the wave motion, the next still more so and so on till we come to one where the wave-particle has reached the stage marked 2 in fig. ii. The small dot numbered 2 in fig. ii. may be taken to represent the normal position of the molecule and the heavy dot its position at the instant under consideration. Passing still further backwards along the wave path we come to molecules occupying respectively the positions 4, 6, and 8, or normal and behind that again 10, 12, 14, and so on to position o. Now if the momentary disposition of the dots is considered they will be seen to be crowded together at o and widely separated at 8; that is to say there are definite zones in the substance through which the wave is travelling where its material is alternately condensed and rarified. We may regard the point of maximum condensation as analogous o the crest of a sea wave and the point of maximum rarefaction to the trough. The *wave length* becomes then the distance o to o, or the length of the complete undulation is analogous to the length of sea waves measured from crest to crest.

16. It is to be noticed that the points of maximum condensation or rarefaction are those of junction of the semiphases of movement towards and away from the normal position of the molecule; that of greatest condensation is where this point is passed in the phase of motion in the same direction as the wave is travelling, that of greatest rarefaction where the same point is being passed in the opposite phase of motion. It may also be noticed that the tracts which are in this latter phase are longer than those in the former, the difference being four times the amplitude.

17. As has already been remarked waves of this nature can be transmitted through fluids as well as solids; in the latter they travel faster than any other form of elastic wave. It is waves of this nature which, if the period is not too small or too great, become sensible as sound.

18. *Waves of elastic distortion.*—Another form of elastic waves is due to the rigidity of the substance through which it is transmitted, or to that form of elasticity which causes a substance to resist a change of its original shape, by the action of an external force, and to regain it when this is removed. These waves, which are necessarily confined to solids, and cannot be transmitted by fluids, are known as *waves of elastic distortion* or *distortional waves.* In them the motion of the wave-particle is still in a straight line backwards and forwards, but this line lies at right angles to, instead of along, the direction in which the wave path is travelling, the displacement being alternately to one side and the other of the normal position of the wave-particle; hence these waves are sometimes distinguished as *transverse.* The motion of the wave-particle may, in fact, be likened to the motion of the bob of a pendulum, the direction of travel of the wave being vertically up or down. This form of wave motion is represented diagrammatically in fig. iv. The figures opposite the dots having the same significance as in fig. ii, the *amplitude* is the distance o to 4, and the *period* is the time taken to travel through the complete cycle. As before, there are two principal *phases* of the movement, in two opposite directions, and these are divided each into two *semiphases* according as it is towards or away from the normal position of the particle. The *wave length* is the distance between two points where the wave-particle is at the same extremity of its displacement at the same instant, these extremes corresponding to the crests and trough of a gravitational wave.

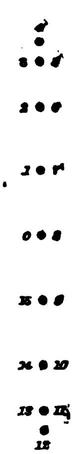

Fig. iv. Diagram of movement of wave-particle during one complete undulation of a distortional wave.

19. *Elastic surface undulations.*—When waves of either of the last two kinds after travelling through the interior of a body reach its surface, they might produce disturbances of form which would simulate the surface undulations of

gravitational waves. Apart from this there are, however, as has been shown by Lord Rayleigh, true surface undulations, closely simulating gravitational waves but propagated elastically. In these the path of the wave-particle is an ellipse whose major axis is vertical and from one and a half to twice the minor. The horizontal displacement extends but a short way into the mass, disappearing at from one-eighth to one-fifth of the wave-length from the surface. Below this there is only a vertical movement. It does not appear that the existence of waves of this nature has ever been demonstrated, and they have certainly not as yet been separated in the complicated disturbances of an earthquake, but the possibility of their existence may be taken as demonstrated, and time and the collection of fuller details will doubtless lead to their recognition.

20. It may be noted here that whether the surface undulations noticed in great earthquakes are of the nature of Lord Rayleigh's waves or not, there can be no doubt of their existence. They have been observed too often for this to be doubted, and ample proof of their reality will be found in the pages of the following report. It must, however, also be noticed that there are apparently two distinct types. Firstly, there is the long, low, quick travelling wave, which first begins to be distinctly noticed in the area where the earthquake has ceased to be destructive, or where the destruction wrought has become much less than in the epicentral tract. These waves cannot be seen; they are recognised only by a successive tilting in one direction and then in the opposite, and their rate of travel, 100 to 120 miles a minute, is that of the earthquake shock. Secondly, there are the much shorter and steeper sided waves which can be seen and recognised as such; these may vary in length from 20 feet to 200 yards and in height from a few inches to 2 or 3 feet, and travel at a rate of 3 to 8 miles an hour.

21. Whatever may be the nature of the laws which govern the movement of the wave-particle in these surface undulations it is hardly possible that they can be the same in the case of waves which differ so much in size and rate of movement as the two forms of surface wave referred to in the preceding paragraph This conclusion appears to be supported by the absence of any passage from the one to the other, but on this point further observation is required.

22. *Complication of waves.*—If the earth were a perfectly homogeneous globe, then, supposing elastic waves of one of the three classes were set up by a disturbance at any part of it, they would be propagated without change. If the waves of all three classes were set up, they would separate as they travelled, the waves of elastic compression, travelling at the greatest speed, would outrace the others; then at a gradually increasing distance behind would come the waves of elastic distortion, while lagging more and more behind would come the elastic surface waves, which not only travel slowest, but have to travel round the surface of the globe, while the others can take a short cut through it.

23. In the case of the disturbances which are registered by sufficiently delicate instruments at a long distance from the place they start from, and have consequently travelled through the comparatively homogeneous central core of the earth, something like this has been observed. In the case too of artificial disturbances, such as are produced by explosion of gun-cotton, something of the kind has been observed where the disturbances have been measured at comparatively small distances and have travelled through fairly homogeneous material.

24. In the case of earthquake waves in the region where the shock is severe enough to be felt, nothing of the sort has been recognised and nothing of the sort is to be expected, seeing how heterogeneous are the materials of which the outer crust of the earth is composed.

25. The rate at which elastic waves are transmitted depends only partly on the elasticity, whether that measured by the bulk modulus, or the rigidity; the density of the materials is also a controlling factor. A wave may, consequently, preserve the same rate of propagation, even when it passes from one medium to another of different density and elasticity, provided that the changes are in exactly such proportion that the new density combined with the new elasticity give the same rate of propagation as before. Usually, however, there will be a change in the rate of propagation; and when a wave of either elastic compression or distortion passes from one medium into another, in which it has a different rate of propagation, not only is its direction of travel changed, in other words, not only does it undergo *refraction*, but it is also split up and partially converted into elastic wave motion of the other kind.

26. Seeing how very heterogeneous are the materials of which the earth's crust is composed and how frequently waves travelling through it must pass from one medium to another in which they have a different rate of travel, it is easy to see that, even if the motion in an earthquake wave was simple to start with, it would soon become extremely complicated.

II.—Definition of seismological terms.

Having treated of the various possible forms of wave motion, we are ready to go on to a consideration of the observed facts of earthquake movements, but before doing so it will be necessary to explain the meaning of certain special terms which will be frequently used.

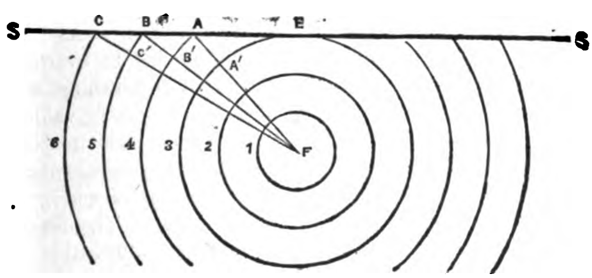

Fig. v. Diagram in explanation of seismological terms.

27. Whatever be the cause of an earthquake, the disturbance starts from some place within the crust of the earth. This may be so small that it can be considered as a point, or more usually have considerable extent. Whatever its size or form, it is known as the *centrum* or *centre*, or, if regarded from another point of view, as the *focus* of the earthquake. For convenience we will assume it to be a point, F, in fig. v, which represents, diagrammatically, a vertical section through the

crust of the earth, S S being the surface. Then a straight line drawn vertically from F to E is the *seismic vertical*, and the point E is the *epicentre*. Where the centre, instead of being so small that it may be considered a point, is of considerable size, then the *epicentre* increases in size to a corresponding extent, and we have an *epicentral* or *epifocal area* or *tract*.

28. From the centre F the earthquake waves radiate in every direction. To the epicentre they travel straight upwards; away from it they reach the surface at a less and less angle as we get further away. Let F A represent one of these wave paths: then the angle E F A is the *angle of emergence*.

29. The front of the disturbance travels at a definite rate, and if the rate of propagation is equal in every direction it will at any given moment have reached the same distance from the centre in every direction. The circles drawn in fig. v may be taken to represent the wave front at successive equal intervals of time and are known as *homoseists*. They are surfaces, which appear as lines where they are cut by the ground level, and if we had a perfectly homogeneous earth and a perfectly level ground, they would appear as circles. In practice neither condition holds good and the *homoseists* or *homoseismic lines* are irregular in form.

30. As the earthquake radiates from the centre it becomes less and less violent, and it is possible to trace lines of equal violence of shock which are known as *isoseists* or *isoseismic lines*. If a condition of perfect homogeneity prevailed in the crust of the earth they would coincide with the *homoseists*; but as the violence of the shock is much more influenced by the nature of the surface deposits than the rate of propagation, they are in practice found to pursue an even more devious and irregular course.

31. The actual violence of the shock doubtless decreases outwards from the epicentre, but its destructiveness does not necessarily do so. At the epicentre the thrust, if we are dealing with a wave of elastic compression, is straight upwards; there is no sidelong push, and consequently no tendency to overturn walls. As we recede from the epicentre, and the angle of emergence decreases, the sidelong motion increases, and there is an increasing tendency to overturn walls and buildings; the violence of the earthquake is, however, diminishing, and there is a point where the increasing value of the one and the decreasing value of the other lead to a maximum of destructive effect. The line along which this takes place is the *meisoseismic line* or circle; according to the view we take of the rate at which the violence of an earthquake diminishes the angle of emergence to which the meizoseismic circle corresponds becomes 45° or 54° 44. Theoretically, then, the depth of the focus from the surface should be equal to, or rather over, half the diameter of the meizoseismic circle.

32. Within the meizoseismic circle the variation in destructiveness of the earthquake is found to be much less than should be the case if the movement were purely that of a wave of elastic compression. This is in accordance with what has been said regarding the impossibility of one form of wave motion reaching the surface unaccompanied by others. In practice it is generally found that there is an area over which there are comparatively small variations in the destructive force of the earthquake. This lies within the meizoseismic circle, which is not always recognisable, while outside it there is a much more rapid decrease of destruction. This inner area is known as the *pleistoseismic area*.

33. The greater destruction in the pleistoseismic area, as well as the comparatively smaller variations in the amount of destruction, are probably due to a radical difference in the nature of the motion of the ground. Above the focus it is probable that the ground is lifted bodily and that, besides the *molecular* motion of the elastic waves, there is a certain amount of *molar* motion of the whole of the rocks lying between the focus and the surface. This would not be confined to the region vertically above the focus, but would extend outwards; what the exact limit may be is not known, but it is probable that an angle of 45° from the vertical would include all that was so affected. For this mass of rock the term *core* of the earthquake has been suggested, and it affords a convenient, and apparently true, distinction between the central *core* on the one hand, in which both molar and molecular movement takes place, and the *area* or *region of propagation* on the other, in which we have only elastic waves, set up by the earthquake and travelling outwards with a decreasing energy and violence.

34. The term *seismic area* was applied by Mallet to the region over which the earthquake was felt; of late years, when the improvement of instruments for recording earthquake movements has rendered it possible to detect the disturbance caused by a great earthquake at long distances, beyond the utmost limit at which it can be recognised without the assistance of these instruments, the term *microseismic* has been applied to these unfelt movements and the seismic area of Mallet has sometimes been distinguished as *macroseismic*. The terms seem inconvenient and hardly appropriate, for some of the waves in the area where the disturbance would be described as *microseismic* are larger in size than any of those in the *macroseismic* area. It seems consequently best to retain the terms *seismic area* in its original sense and to describe the movements that take place outside it as *cryptoseismic* reserving *microseismic* for those minute earthquakes which nowhere become sensible to unassisted observation.

35. Two more terms may be explained with advantage, though they are not specially seismological, and these are the words *resultant* and *component*. If a body is acted on simultaneously by two distinct forces, the final result will be the same as if each force acted singly and successivelv. Where the two forces do not act in the same or opposite directions, this leads to the construction known as the parallelogram of forces; in fig. vi let O represent a body acted on by two forces in the directions A and B, and let O A and O B respectively represent the magnitude of the forces, that is, the distance through each singly would displace O in, say, one second of time; complete the parallelogram O A R B, then R represents the position which O will occupy at the end of a second, and O R will represent the direction and distance that O will travel in that time. In other words O R represents the direction and magnitude of a single force, called the *resultant*, which will produce the same result as the two separate and simultaneous forces O A and O B. Similarly, if we have a single force O R, it may be regarded as composed of two separate forces O A and O B which are called the *components*. Moreover, as

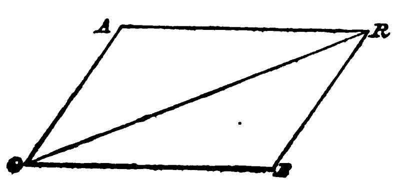

Fig. vi.

the distance to which a body, free to move, is displaced in a given time is a measure of the force affecting it, the same words are applied in a similar way to motion, which may be compounded into a single *resultant*, or resolved into one or more *components*.

The components are usually, but not necessarily, considered to be at right angles to each other, this being purely a matter of convenience or convention.

36. Though possibly self-explanatory it may be well to point out the sense in which the words *wave front* and *wave path* are used. The *wave front* is the same as a homoseist; it is the limit to which, at a given moment, the wave motion has reached. In a perfectly homogeneous medium this is everywhere at the same distance from the focus, but if the medium is like the material of which the earth is composed, such that the wave motion is transmitted more rapidly in some directions than in others, the distance of the wave front from the focus will vary from place to place. The *wave path* is a line along which the wave motion may be supposed to travel. There are an infinite number of such lines radiating from the focus, and each cuts the successive wave fronts always at right angles. From this it follows that if the wave motion is propagated with equal rapidity in every direction the wave paths will be straight lines, but if the wave motion is propagated more rapidly in some directions than in others, the wave paths will bend round, so that they shall always form a right angle with the varying direction of the wave front.

III.—Nature of earthquake motion.

From the earliest times the fact that there are distinct types of earthquake motion has been recognised in Italy. Earthquakes are there divided into four classes, *orizzontale* or horizontal, in which only a to and fro motion is felt; *onduloso* or undulating, in which the ground appears to be thrown into waves and the sensation is like that of a ship rocking on a gentle sea; *sussultorio* or palpitating, in which there is a distinct vertical or up and down motion; and *vorticoso* or verticose. The justification of this last distinction, which is based on the effect of the earthquake, has been questioned but it appears sound; the subject is discussed at length in Chapter XIV of the following report.

38. Though these distinctions, which are popular rather than scientific, have long been recognised, it is only comparatively recently that instruments have been devised by which the actual movement of the ground has been traced. Of the exact nature of the movement within the core of a really destructive earthquake, or even of that same earthquake outside the core so long as it retains a high degree of destructive power, nothing detailed is yet known. In these circumstances the instruments and their records are alike lost in the ruins of the building which contained them.

39. Beyond this region of extreme destruction, but where the shock might still be described as destructive, records have been obtained. It is found that the earthquake sets in with minute rapid *preliminary tremors* which increase in amplitude and period till they suddenly give way to one or two very much larger movements, and these again are succeeded by a series of waves of longer and longer period.

40. Leaving, for the moment, the consideration of the preliminary tremors and of the long slow afterwaves, and confining attention to the central parts of the disturbance, which constitutes the sensible shock, it seems necessary to distinguish the character of the movement in small and great shocks. In those which nowhere reach a degree of violence sufficient to cause alarm, and much less any actual damage, it is probable enough that the motion is largely due to elastic vibration propagated directly from the focus to the surface through the substance of the earth. In the case of severe earthquakes, this form of motion is also present, but overpowered by waves of a different character, which are probably analogous to the elastic surface undulations of Lord Rayleigh, and originate at the surface, within the epifocal area, whence they spread outwards in every direction.

41. A peculiarity of this sensible earthquake motion is that, as the disturbance radiates, its duration at first increases and then appears to diminish. This was very noticeable in the case of the earthquake of 1897; within the epicentre the duration of the great shock did not exceed two minutes; at Calcutta it was certainly 5 or 6, and the maximum duration seems to have been at about 500 miles from the centre, reaching some seven minutes. From here the reported duration diminishes till at the furthest limit, in Ahmedabad, it is reported to have been but a second or two. This does not, however, mean that the disturbance of the ground only lasted for that period, but that, except for a few seconds, the movement was too slow and gentle to be felt.

42. In the area of propagation of an earthquake, this movement, which can be felt, and to which the damage done is due, is quite superficial. It has been found by experiment in Japan that an excavation of only 20 feet in depth is enough to reduce the wave motion of an earthquake to a very small fraction of what it is at the surface. Another fact, pointing to the same conclusion, is the rarity with which an earthquake is felt underground in mines, even where these are shallow. In the rare cases where an earthquake has been felt underground, like that referred to in Appendix H to the following report, it is probable that the mine lay within the core of the earthquake, and that the motion felt was due to those molar displacements of the ground which have been referred to in para. 33. The 1897 earthquake was not felt underground in the mines of the Bengal coalfields; it was felt and caused some damage in the coal mines at Makum in Upper Assam; but these mines are really over ground, being driven into the side of a hill and not descending below the general surface level, the conditions are, therefore, not strictly comparable to those of a mine sunk in open and tolerably level country.

43. If the felt earthquake wave is of the nature of Lord Rayleigh's elastic surface undulations, the restriction of the shock to the surface is in accordance with the theory, for at a short distance the range of motion would become too small to be felt below the surface. It may also be explained, in the case of purely elastic condensational or distortional waves, by the greater play which is possible at the surface than in the body of the earth. While the wave is being transmitted through the rocks which constitute the crust of the earth, the movement of each wave-particle is restrained by the resistance of those in front, to which it has to communicate its motion; but when the wave reaches the surface there is

nothing in front to restrain the movement of the wave-particle and it can consequently range further out from its normal position. The effect of this greater freedom and range of motion where the wave comes out to a *free surface* is very marked, and will be referred to in the chapters dealing with earth fissures and landslips.

44. To this greater freedom of motion at and near the surface of the ground we must, at any rate, to a large extent, attribute the more noticeable and destructive character of the shock at the surface of the ground. Of the nature of the movement, all that can be said here is that it is characterised by an extreme complication and intricacy of the path of the wave-particle. At one and the same time it is subjected to wave motion of varying amount and period, and of each of the three distinct types described in paras. 9 to 21.

45. In spite, however, of this complexity, a prevailing direction can often be recognised, which may or may not change during the period for which the earthquake lasts. As a rule there is no relation between the direction of this movement and the direction in which the epicentre lies, that is, from which the shock is travelling. In the case of very severe earthquakes it may happen that many of the buildings and monuments overthrown point in a direction towards, or away from, the epicentre. Where this is so they may be used for determining the position of the focus, but the method, as referred to in Appendix D, requires both care and skill in its application.

46. So far reference has only been made to what can be observed without instrumental aid. If the same disturbance is studied with the aid of seismographs it is found that the duration is about double of what can be felt, and that it follows the same law. That is to say, it first increases as the epicentre is receded from, and then decreases, only a smaller and smaller fraction of the whole disturbance being of a character which can have any effect on the instrument. What takes place may in fact be likened to the changes that take place in the band of ripples set up in a pond by a stone falling into it. As they spread outward the width, not only of each individual wave, but of the whole band, increases, and then, if the pond is large enough, one wave after another may be seen to grow so long and flat that it ceases to be discernible, and finally the pond resumes its originally undisturbed condition.

47. This spreading out of the waves is very conspicuous in the records obtained by the delicate instruments specially designed to detect the movement which takes place at distances beyond where the earthquake ceases to be recorded by ordinary seismoscopes. In these the *preliminary tremors* which have a duration to be measured in seconds within the seismic area, outrun the larger waves by periods which may range up to half an hour. They are probably due to elastic vibrations propagated through the body of the earth, and in the case of the earthquake of 1897 it was possible to recognise that they present two phases which may be interpreted as being due to the arrival of the condensational, and of the slower travelling distortional, waves respectively.

48. This division of the *preliminary tremors* into two phases had not been definitely recognised before 1897, but it seems probable that it may be found in the records of other earthquakes when they come to be re-examined in the light of the distinction recognised in the case of the 1897 earthquake. It lends such

support to the hypothesis that the preliminary tremors are transmitted through the earth, as almost amounts to proof. Were they transmitted through the superficial crust of the earth, a separation of the two classes of waves would be impossible for the reasons given in para. 25, but, in the more homogeneous matter constituting the central core of the globe, such a separation is what would inevitably happen, through the more rapidly travelling condensational waves outracing the slower travelling distortional. Moreover, it is only at great distances, where the portion of the wave path which lies within the surface crust, or, say, the outermost 30 miles, of the earth, forms but a small fraction of the total wave path, that such separation could take place. If, as seems probable, this hypothesis stands the test of further experience, it is certain that in the majority of cases the preliminary tremors of distant earthquakes, as recorded by the instruments in present use, are those due to the distortional waves, those due to the condensational being ordinarily too feeble to be recorded.

49. Following on these preliminary tremors come the great surface waves so well shown in the diagram on Plate XLI. which have expanded from a length of 2 to 3 miles and a period of 2 or 3 seconds to a length of 30 miles and a period of 25 seconds, while their duration, instead of being a few minutes, ranged over half an hour, or, if the slighter and less distinctly recorded waves are included, of several hours.

IV.—The elements of earthquake motion which can be measured.

There are certain elements of the motion of an earthquake which can be measured and expressed in figures. These are: (1) the *rate of transmission* or velocity with which the wave motion travels from place to place, (2) the *amplitude* (3) the *period*, (4) the *velocity* of movement of the wave-particle, and (5) the *acceleration* of the wave-particle.

50. The *rate of transmission* is readily determined if we have accurate records of the time of arrival of the earthquake at different places, whose distances apart are known. Theoretically, if the time of arrival at three places is known, it should be possible, provided the times are not simultaneous, to determine the rate and direction of travel of the earthquake wave. In practice, however, it is not possible to obtain records of sufficient accuracy, and this apart from any fault of the observations or records. The wave motion is not a simple one, and to compare the times it would be necessary to be certain that they referred to one and the same phase of the movement. From what has been said of the constant variation of the character of the wave motion from place to place, it will be seen that this is impossible; consequently, it is only possible, in practice, to obtain a fairly accurate estimate by combining a large number of records from many different places.

51. Another element of uncertainty in all determinations of the rate of transmission of the earthquake waves lies in the fact that all we can obtain by direct observation is the *apparent* rate of travel along the surface of the earth, which may be very different from the *true* rate of travel through the interior of the earth. In fig. v, for instance, if the successive circles represent homoseists at intervals of one second, then the *true* distance travelled by the wave in the first second after

the earthquake reaches the surface is represented by A'A while the distance it would appear to have travelled along the surface is represented by E A; similarly, B'B and A B represent the *true* and *apparent* distances travelled in the next second, and so on.

52. It will be seen from this that not only will the *apparent* rate of travel along the surface be different from the *true* rate of travel through the earth, but that it will vary as the distance from the epicentre varies. This will be true of the waves which are transmitted through the earth whether the wave paths be straight lines, as represented in fig. v, or curved, as is more probable. In the case of those great earthquakes which have been exhaustively examined, no such variation has been recognised; on the contrary, the rate of transmission seems to be practically uniform, and it is this which has led to the conclusion that, in the case of great earthquakes at least, the movement which can be felt is due to waves propagated along the surface, and that in their case the apparent and true velocities are identical. In the case of the preliminary tremors, on the other hand, the apparent rate of transmission varies largely according to the distance from the epicentre, and this leads to the conclusion that they are transmitted through the earth, and that in their case the true and apparent velocities are not the same.

53. The *amplitude* of the wave has already been explained (paras. 6, 13, 18); it is usually expressed in millimetres or in inches; double the amplitude is the *range of motion* of the wave-particle, or more correctly would be, if the motion was a simple harmonic one. The error introduced in practice by assuming the amplitude to be half the range of motion is, however, in all probability immaterial.

54. The *period* of the wave has also been explained, and need not be further treated. It is usually expressed in seconds of time.

55. The *velocity* of movement of the wave-particle is a quantity which varies from moment to moment. Each particle as it starts from a position of rest commences moving slowly, then moves more and more rapidly, till it attains its *maximum velocity*, after which this decreases till the particle once more comes to rest before commencing its return movement, in which the same succession of a gradual increase of the rate of movement up to a maximum and a subsequent gradual decrease takes place. The velocity of movement at any moment is expressed in feet, inches, or millimetres per second, and does not mean that the particle actually travels so many feet in one second, but that, if it were to continue moving at the same rate for a whole second, it would then have travelled the given number of feet, inches, or millimetres.

56. As a rule, we are only concerned with the *maximum* velocity of the wave-particle, that is to say, the most rapid rate of movement attained; like all the lesser velocities of wave-particle it is only momentarily attained, but is the only one to which a numerical value can be given which is independent of time. The lesser values vary from moment to movement and from zero to the maximum; but it is obvious that there can be but one maximum value, and that this value can be given, and remains true, apart from any statement of the exact instant at which it was attained.

57. The *acceleration*, or rate of change of velocity, of the wave-particle is one of the most important elements to be determined, for on this depends the violence and destructiveness of the earthquake. As explained, in para. 55, the velocity

of the wave-particle is never the same for two successive instants: it is constantly changing, but the rate of change is not constant. Like the velocity, it is nothing at one point of the path of the wave-particle, increases to a maximum, and then decreases again, being zero when the wave-particle is at rest or at its maximum velocity, and attaining a maximum four times in each complete wave period, at positions half way between the maximum and zero velocity, which are reached twice only in each complete undulation.

58. As it is important that there should be a clear understanding of what is meant by *acceleration*, a brief explanation may not be amiss. Suppose a body, such as a railway train, is standing still, and that, by the action of an external force, such as a locomotive, it is set in movement, and that at the end of the first second it is moving at the rate of one foot per second, at the end of the next second at the rate of two feet per second, at the end of the third at the rate of three feet per second; then the *accceleration* of that train is one foot per second per second. That is to say, at the end of each second its velocity is one foot per second greater than at the beginning.

59. The instance taken is a very simple one, where the acceleration is supposed to remain constant for at least three seconds; in the case of a wave-particle, on the other hand, it does not remain constant for two successive instants. Just, however, as it is possible to define the *velocity* at any instant, so the *acceleration* at any instant may be defined as being so many feet, inches or millimetres per second per second; by which it is not meant that the given rate of acceleration is maintained for a whole second, or for any finite fraction of a second, but that, if the actual rate of change of velocity at the given instant were maintained for a whole second, the velocity would at the end of it be so many feet, inches or millimetres per second greater than at the commencement.

60. It is important that the distinction between the *velocity* or rate of movement, and the *acceleration* or rate of change of velocity, should be clearly understood. It is possible to have a high velocity combined with a low acceleration, or a low velocity with a high acceleration, the two being quite independent. It may also be necessary to state that the word acceleration is, in this connection, equally applied to what would ordinarily be regarded as retardation: a body which, moving at the rate of 10 feet per second, slows down at the rate of 5 feet per second per second is said to have that *acceleration* equally with one that increases its speed at that rate. The word is in fact used as equivalent to rate of change of velocity, and irrespective of whether the change is one of increase or decrease.

61. As in the case of the *velocity* of wave-particle, it is only the maximum *acceleration* whose determination is ordinarily necessary or attempted.

62. *The intensity of an earthquake.*—Besides the elements above mentioned, to which numerical values can be given, attempts have been made to define in a similar manner a vague and uncertain quantity called the *intensity* of an earthquake. The best known and most often used of these so-called *scales of intensity* is that known as the Rossi-Forel, which, because it is so frequently used and because in the absence of anything better it may be better than nothing, is given below. Of it, all that may be said at present is that, though to a certain extent it may serve for the comparison of different earthquakes, each being taken at its maximum intensity, it does not serve as a scale for the gradual dying out of a

severe earthquake. For instance, degree IV specifies, as a part of its characters, the disturbance of doors, etc.; in the case of the 1897 shock, this was recorded at Sehore in Central India and at Bangalore, yet these places were beyond the region where the earthquake could be distinctly felt, and would fall, at the outside, in degree I of the Rossi-Forel Scale. Another objection is its limited range. The area which, in 1897, was covered by the maximum degree, No. X, of the Rossi-Forel Scale is as large as England, and within it there were variations of violence, or, as ordinarily called, intensity, which would require the scale to be extended for at least another 5 to 10 degrees.[1]

63. The fact is that the word intensity as ordinarily used, and as it is attempted to be defined in these scales—which were intended to serve in seismology the purpose which Moh's scale of hardness serves in mineralogy—is altogether too vague and indefinite a term to be used in scientific description. Prof. Mendenhall has pointed out that there are three distinct quantities which have been or may be used as measures of the so-called intensity at a given locality. They are—

(1) the maximum *velocity* of wave-particle,
(2) the maximum *acceleration* of wave-particle,
(3) the *energy* of the earthquake, which may be measured by (*a*) the energy contained in a unit volume of rock set in motion by the wave, (*b*) the rate at which energy is transmitted across a unit area of the wave front.

Of these, (3) in one of its forms is the most rational and scientific equivalent to be represented by the word *intensity*, and, of the two forms, (*b*) is that which Lord Rayleigh has adopted in his "Theory of Sound" as the measure of intensity of radiation.

64. Unfortunately the intensity, in this sense, is incapable of direct measurement, and, so far, has not been satisfactorily determined in the case of any earthquake. As ordinarily used, the word is applied to the greater or less impression produced by the earthquake on the senses or the greater or less destruction wrought by it.

[1] The *Rossi-Forel Scale of Intensity*.—Translated by Dr. C. Davison.

I. Recorded by a single seismograph, or by some seismographs, of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
II. Recorded by seismographs of different kinds; felt by small number of persons at rest.
III. Felt by several persons at rest; strong enough for the duration or the direction to be appreciable.
IV. Felt by persons in motion; disturbance of moveable objects, door, windows, cracking of ceilings.
V. Felt generally by every one; disturbance of furniture and beds, ringing of some bells.
VI. General awakening of those asleep; general ringing of bells, oscillation of chandeliers, stopping of clocks; visible disturbance of trees and shrubs. Some startled persons leave their dwellings.
VII. Overthrow of moveable objects, fall of plaster, ringing of church bells, general panic, without damage to buildings.
VIII. Fall of chimneys, cracks in the walls of buildings.
IX. Partial or total destruction of some buildings.
X. Great disasters, ruins, disturbance of strata, fissures in the earth's crust, rock-falls from mountains.

This is now recognised to be due to variations in the rate of *acceleration* of the wave-particle, and this might be used as a measure of what has been called the intensity, but that the degrees of the scale depend to some extent on the *destructiveness* or destruction produced by the earthquake, while the acceleration is more properly a measure of what Mendenhall has called the *destructivity* or power to destroy. The word proposed is, however, an awkward one, and the simpler word *violence* seems more suitable; of this the rate of acceleration of wave-particle is a measure, and in proportion as this increases the earthquake becomes more distinctly sensible and more and more destructive. Yet the destruction actually caused must not be taken as a measure of the *violence* without observing proper precautions, for it is determined both by the power of the earthquake to destroy and the power of the object to resist destruction. This is equally true whether we have to deal with buildings overthrown, landslips from hills, or fissuring of the ground, and consequently, in attempting to compare the violence of the earthquake at two different places, we must consider not only the effects actually produced, but the particular local circumstances governing their production.

65. Bearing these considerations in mind the word *violence* may well be used instead of acceleration in all those cases where there is no possibility or desire of giving it a precise numerical value. The word will, in fact, be used in the following report as substitute for *intensity*, the latter word being reserved till the time when, as the means of seismological observation improve, it can be used in its more proper sense.

V.—The means of measuring earthquakes.

66. The most satisfactory and trustworthy means of obtaining the values of the elements of earthquake motion which are capable of measurement is that of instruments specially designed for the purpose. These fall into three classes according to their purpose; *seismoscopes*, which merely record the fact of an earthquake, of sufficient severity to affect the instrument, having occurred; *seismometers*, which are intended to measure one or more of the elements of the earthquake motion; and *seismographs*, which record in greater or less detail the actual course of that motion from the commencement to the close of the shock.

67. In principle the instruments may be classed according as they consist of (1) a mass which is set in motion by the earthquake; (2) a mass which is so supported as to remain more or less steady, while the earth moves underneath it; and (3) an arrangement by which the actual tilting of the surface is measured. Two or more of these may be combined in the same instrument, and on one or more of these principles a vast number of instruments of varying design have been constructed or proposed. To attempt a description of them here would occupy too much space, and for an account of them and the capacities of the various types reference should be made to Prof. Milne's two books.

68. Apart from special instruments, much information may be obtained from observations made at the time of the earthquakes, or from the effect produced by it; in the case of very violent shocks this is the principal source of information.

69. The *rate of transmission* is obtained from observations of the time at which it was felt, and it is necessary that these should be accurate at least within one minute of time, even in the case of earthquakes which are felt over a large area. In the case of lesser earthquakes an even greater degree of accuracy is required if the results are to be of any value, yet even here, if the observations are sufficiently numerous, a much greater degree of accuracy in the result can be obtained than the errors of each individual observation would appear to justify.

70. Another necessary precaution is to compare similar phases of the shocks, and in practice the only phase which can be identified, with even an approximate degree of accuracy at different places, is the commencement. When a sufficient number of trustworthy observations are available, they may be treated either by means of the mathematical process known as the method of least squares, or in the simpler method adopted in Chapter III, which will usually give results as accurate, though less precise, than those obtained by the more elaborate method.

71. The replies to circulars issued after the earthquake of 1897 showed that the stoppage of clocks is popularly supposed to be a particularly accurate method of recording the time of an earthquake. This, however, is not the case; not only is there no means of determining the particular phase of the shock to which the stoppage was due, but in some cases the clock may not stop till some time after the earthquake has ceased. One authentic case is on record—the earthquake of 24th June 1870 at Athens—where the pendulum of an astronomical clock was observed to be knocked against the clock case by the earthquake, yet the clock only stopped some five minutes after the earthquake had ceased.

72. The *amplitude* of the wave and the *velocity* and *acceleration* of the wave-particle can be determined, in the case of earthquakes of sufficient violence to cause damage, by observation of its effects. The methods and formulæ in use are sufficiently explained in Chapter V and in Appendix C.

VI.—Earthquake effects.

73. Cracks in the walls of buildings are probably in large part due, and in lesser degree fissures in the earth, to the bending of the surface, as it is thrown into undulations by the passage of the earthquake wave. With this exception, all the effects of an earthquake, whether they take the form of visible damage or of the sensations produced at the time, are entirely due to *inertia*.

74. Everything tends to remain in the same condition of rest or motion in which it is at any moment, and is only by the action of an external force that a change can be produced. A pillar, standing upright, has no tendency to fall over, but when its base is suddenly displaced, as by the motion of the ground in an earthquake, the mass of the pillar tends to maintain its original position and a strain is set up at the base. If this strain is great enough the pillar will be tilted up on the edge away from the direction in which the base was moved, and if the movement be great enough the pillar will topple over.

75. If, from the form of the body affected, it is not free to fall or bend in the direction from which the motion starts, the velocity of movement of the wave-

particle will be communicated to it, and, when the next semiphase of wave motion sets in, its *inertia*, or, as commonly expressed, momentum, will tend to make it continue to move with the direction and velocity which have been imparted to it. A strain will consequently be set up, just as in the case considered in the last paragraph, and in this way not only may pillars be overthrown but the ends of walls may be shot off, or the soil resting on a hill side, or even the face of a cliff, be dislodged, as described in Chapter VII.

76. The magnitude of the strain set up is governed, not by the velocity, but by the *acceleration* of the wave-particle. This is easily illustrated experimentally. Let a match-box, preferably full, be stood on end on a sheet of paper resting on a table; if one edge of the paper is taken hold of, the paper and match-box can be moved over the table and, if the speed of movement be only gradually increased, it will be found that the motion may become quite rapid without causing the match-box to overturn; if, on the other hand, the sheet of paper be put suddenly in motion, the match-box will fall over backwards, or if after having been put in rapid motion it is suddenly stopped, it will fall over forwards. Similarly, if a train is started or stopped gently it is very difficult for a passenger to recognise the moment of starting or stoppage, but if an unskilful, or careless, driver is in charge of the engine, the stoppage, or starting, may be a jerk that is very noticeable. In both these instances it is not the rate of movement, but the rapidity of change of rate of movement, that is to say, the *acceleration*, which produces the effect. Similarly, in the case of an earthquake the sensation produced, or the damage done, is due to the greater or less suddenness of the movement and not to the actual velocity attained.

77. There is another way in which solid bodies may be affected by the earthquake wave, which depends, not on the acceleration, but on the velocity of the wave-particle. If, instead of a tall pillar, we take the case of a flat stone lying on the ground, it is obvious that any overturning is impossible. The motion of the wave-particle will be more or less completely imparted to the stone, and when the next semiphase of the wave motion sets in, the inertia or momentum of the stone will tend to make it continue moving with the direction and *velocity* which has been imparted to it. If the momentum imparted be more than sufficient to overcome the resistance of the attachment of the stone to its support, it will be projected through the air, and the distance to which it is projected is dependent on the direction and velocity with which it started on its way. Yet, even here, acceleration is not without its influence, for, where a body is projected upwards, whether vertically or in a slanting direction, the acceleration of the wave-particle must at least exceed that due to the action of gravitation, or the attraction of the earth on a free falling body near its surface.[1]

78. This statement may easily be illustrated by placing a small stone in the upturned palm of an open hand. If the hand is raised and then lowered slowly the stone will not leave it, but if the movement is made quicker and more quickly a limit will be reached when the stone leaves the hand and rises in the air; this means that the rate at which the stone increases its velocity of fall is less than

[1] This varies slightly from place to place, but may be taken as about 32 ft. per second per second.

that at which the hand increases its rate of downward movement. Once, however, that this limit is passed the distance to which the stone travels through the air is governed solely by its initial velocity and direction of movement, and if any two of these three is known the other can be calculated.

79. Though a consideration of the methods of construction, which should be adopted to prevent or lessen the damage caused by earthquakes, would be foreign to the purpose of this introduction, it may be pointed out that the foregoing paragraphs show that one of two principles should be used as a guiding one, either great strength or great lightness. Seeing that the strains set up are dependent on two factors, the inertia of the object affected and the acceleration of the wave-particle, we must, as we cannot control the second, either diminish the first, and so lessen the magnitude of the strains, or increase the strength of the structure so that it shall be able to withstand the strains set up; in other words, and to use Prof. Milne's simile, the ideal should be either the wicker basket or the steel safe.

VII.—The causes of earthquakes.

80. An earthquake may be produced by any cause, of the nature of a shock or blow, by which an elastic wave or waves are set up in the earth. The fall of a mountain, or even a house, the explosion of a mine or magazine, or the working of a large steam hammer, may set up a disturbance which can be felt as a earthquake within a certain distance of the origin. Excluding these disturbances, which originate naturally or artificially at or above the surface of the ground, and restricting the term to those natural disturbances which originate within the earth, earthquakes have been recognised as being produced by causes which divide them into three distinct classes, namely, (1) Rockfall, (2) Volcanic, (3) Tectonic.

81. The *rockfall* earthquakes are due to the falling in of the roofs and sides of subterranean hollows or caves. They are feeble, of very small extent and may often be only noticeable as sounds, and not as sensible shocks.

82. The *volcanic* earthquakes are those due to the activity of volcanoes, with which may be included earthquakes due to the rending open of fissures by the sudden development of steam under high pressure. This last cause has been inferred in the case of some earthquakes, but its reality has never been proved; volcanic activity is, however, well known to be associated with earthquakes, and these may sometimes be of very great severity, though always local in their extent. Within a very moderate distance of a town which has been laid in ruins the shock may be quite insensible.

83. To the class of *tectonic* earthquakes belongs by far the most preponderating majority of earthquakes and all those which can be classed as really great, on account of their violence or extent. They may be regarded as invariably due to the sudden relief of strain, as opposed to the volcanic earthquakes properly so called, which may be regarded as due to the sudden development of strain.

84. Leaving on one side all question of ultimate cause, the known facts of geology show that the rocks of which the crust of the earth is composed have been subjected to great deformations. In some places they have been tilted, bent and compressed till they only occupy half their original horizontal extent; in

others they have been broken through by fractures and one side raised by hundreds and even thousands of feet with respect to the other. All these deformations involve the exercise of great forces, which are opposed by the natural rigidity and cohesion of the rocks; where this resistance is small the deformation may go on gradually: where it is somewhat greater the strain will accumulate till the resistance is suddenly overcome and an earthquake is the result. The greater the power of resistance the greater will be the strain which accumulates before the final relief takes place, and the greater the resulting earthquake.

85. Tectonic earthquakes have been further classified according to the form of the disturbance to which they were due into *fault*, *heave*, *overthrust* and *fold* earthquakes. Leaving the last out of the question as a very doubtful class, the separation of the others appear to be of little use and to be rather fanciful than philosophical. All alike are the result of the sudden relief of accumulated strain, and the exact form of the fracture to which this is due appears to be an unessential detail; added to which the different forms of fracture accompanied by displacement to which the terms fault, heave, and overthrust are applied pass into each other without any defined line of demarcation. The term *fault* is used when both the fissure and the movement are more nearly vertical than horizontal; in a *heave* the fissure is also nearer vertical than horizontal, but the movement is more sidelong than up and down; while in an *overthrust* the plane of the fracture is nearly horizontal and the horizontal displacement consequently greater than the vertical.

86. It is important to note that the tectonic earthquakes are in no way connected with volcanic action, and the fears so generally felt in Assam and Northern Bengal that the earthquake of 1897 would be followed by the outburst of an active volcano were not only ungrounded, but opposed to all that is known of the action of the natural agencies by which earthquakes are produced.

VIII.—Secondary earthquakes.

87. All great earthquakes are accompanied by others which, as they are to a certain extent the result of the principal one, may be called *secondary earthquakes*. These are of two kinds, the first of which agrees more or less closely with the principal shocks as regards the position of the focus, though succeeding it in point of time, while the shocks of the other kind coincide with the principal one in point of time, but start from a different focus. A third class might be made out of shocks which to a certain extent combine the characteristics of the two first mentioned.

88. *Aftershocks.*—The shocks of the first sort are known as *aftershocks*; they succeed the great earthquake, at first with great rapidity, but the intervals gradually get longer and longer till the average number of earthquakes becomes normal once more. The cause of the aftershocks is not difficult to understand. Every great earthquake is accompanied by more or less displacement in the interior of the earth; this gives rise to a new distribution of strains, and the gradual relief of these new strains causes a succession of earthquakes, each of which again causes a redistribution of the strains, and the process goes on till equilibrium is more or less completely restored.

89. These aftershocks have been carefully studied in Japan, and it has been found that their decrease in frequency approximates to a definite law, such that if

two lines be drawn at right angles to each other, as in fig. vii, and divided

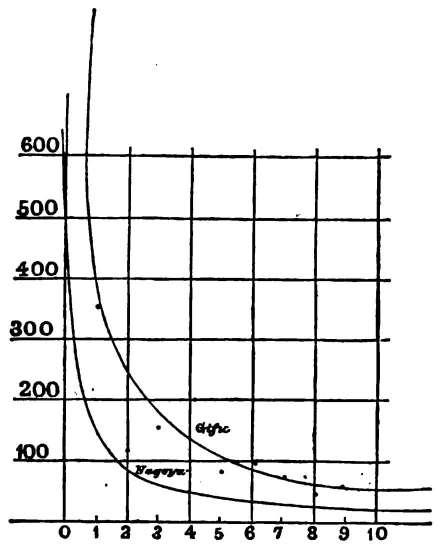

Fig. vii Curve of frequency of aftershocks.

into parts of equal length which shall represent equal numbers of earthquakes in the one and equal periods of time in the other case, and a series of points is plotted such that their distances from the one line represent the number of shocks felt in any given period of time—hour, day, week., etc.—and their distances from the other, the number of such periods that have elapsed since the great shocks, then the line joining these points will come close to a parabola which becomes asymptotic with the two lines at right angles to each other.

90. This will be better understood from an inspection of fig. vi, which represents the curves of frequency of the aftershocks of two Japanese earthquakes, as deduced by Prof. Omori. It will be seen that the frequency of the aftershocks is great at first, but the decrease in frequency is also great; as the absolute frequency diminishes the rate of decrease also diminishes, till, when the excess over the normal becomes small, the rate of decrease becomes also very small and the curve becomes almost parallel to the line representing the interval of time.

91. The actual course of the line representing the frequency of the aftershocks does not, however, follow the curve exactly, for among the aftershocks there will be some of greater severity than the average, and as each of these has its own series of aftershocks, superimposed on those of the main shock, there will be temporary increases of frequency above, compensated by temporary decreases of frequency below, the general average represented by the smooth curve.

92. *Sympathetic earthquakes.*—The existence of secondary earthquakes of the second class has never been positively established, but is probable. They are

independent shocks which originate from their own centres at or shortly after the passage of the main shock, and, as the time of their occurence is determined by that of the greater shock, they may be called *sympathetic* earthquakes.

93. It is conceivable that a portion of the earth's crust may be in such a state of strain that a very slight disturbance may be the determining factor in starting an actual rupture. In these circumstances it is possible that the molecular displacements due to the passage of an earthquake may be sufficient to determine the final fracture and so give rise to a sympathetic earthquake; that is to say, to an earthquake which is unconnected with the primary one, so far as the place and cause of origin are concerned, but is so far dependent on it that the moment of its occurrence is decided by the passage of the earthwaves of the greater shock.

94. There are many recorded cases of earthquakes which, occurring at the same time as greater ones, have been regarded as sympathetic, but it must be confessed that the connection has in no case been proved. As a rule, the coincidence in time is only approximate, and where it has been close enough to permit the supposition of a causal connection, there always remains the possibility of the coincidence being merely accidental. The existence of sympathetic shocks, though they are referred to and described in text books, must still be looked upon as conjectural rather than established.

95. *Sympathetic aftershocks.*—A third category might be made of shocks which, though they start from a centre which is neither identical nor contiguous with that of the great shock, yet follow it and are due to the alterations of strains caused by the displacements which accompanied the principal shock. In the case of the 1897 earthquake there were, during the autumn months of the year, a number of small earthquakes in the Darjiling district of the Himalayas, which evidently originated there, and did not spread into that district from a distant centre. The Darjiling district lay well outside the epicentre of the principal shock, yet these shocks, which originated there, and were much more frequent than the normal number of shocks occurring in that district, must have been indirectly due to the great shock; that is to say, the displacements of the earth's crust under the epicentre of the great shock caused a change and increase of the strains in the Himalayas outside that tract, which resulted in an increased number of earthquakes. These were not aftershocks in the ordinary sense of the word, for they did not originate from the same focus or from an extension of it, while they were equally not sympathetic earthquakes as defined above, for they occurred at a very different time; as they combine part of the characteristics of these two classes of secondary earthquakes, they may be distinguished as *sympathetic aftershocks.*

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to terms defined in the Preface (numbers refer to paragraphs).

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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Report *on the* **Great Earthquake** *of* **12th June 1897,** *by* **R. D. Oldham, A. R. S. M., F. G. S.,** *Superintendent, Geological Survey of India.*

CHAPTER I.—INTRODUCTORY.

At about quarter past five in the afternoon of the 12th June 1897, there burst on the western portion of Assam an earthquake which, for violence and extent, has not been surpassed by any of which we have historic record. Lasting about two and a half minutes, it had not ceased at Shillong before an area of 150,000 square miles had been laid in ruins, all means of communication interrupted, the hills rent and cast down in landslips, and the plains fissured and riddled with vents, from which sand and water poured out in most astounding quantities; and ten minutes had not elapsed from the time when Shillong was laid in ruins before about one and three-quarter millions of square miles had felt a shock which was everywhere recognised as one quite out of the common.

The earthquake found the geological survey in a manner unprepared for it. Of the officers available for despatch into the earthquake shaken tracks, there was but one who had paid any special attention to the subject of earthquakes, or had any knowledge of the nature of the observations required, beyond such as might be obtained from the ordinary curriculum of a geological student. The area affected was, however, too large for any one man to examine single handed, and the advent of the rainy season rendered it necessary that the work of examination should be undertaken at once. The four officers at headquarters, Messrs. T. D. LaTouche, H. H. Hayden, E. Vredenburg and G. E. Grimes, were accordingly despatched, with instructions to collect what information they could. Mr. LaTouche was entrusted with the examination of the Assam valley, and was subsequently instructed to visit and make observations at Shillong, Cherrapunji and Sylhet; Mr. Hayden examined the line of railway running north from Calcutta to Darjiling, and several of the more important towns in Northern Bengal; Mr. Vredenburg undertook the examination of the country to the west of this; and Mr. Grimes made a tour through Eastern Bengal and the Cachar valley. These investigations were confined to those districts where a considerable amount of damage was known to have been done. Mr. P. N. Bose was afterwards despatched to the eastern deltaic districts, from which the accounts, received at first, were meagre, and indicated a much less degree of violence than was at the time intelligible. The reports submitted by these officers, so far as they have not been incorporated in the text, will be found in Appendix A. Every attempt was also made to obtain information by means of letters and circulars; a large number of volunteer observers were interested in maintaining a record of the aftershocks; while the Local Governments and the Imperial Telegraph Department had been instructed by the Government of India to render all information and assistance in their power.

It is on the information obtained by these means, supplemented by a tour through the epicentral tract, which was made by the writer during the cold weather of 1897-98, that the following report is based. In accordance with the orders of the Government of India, it deals with the earthquake from a scientific point of view alone, and, except incidentally, the human aspect of the occurrence is not dealt with. No tales of hairbreadth escapes, of deaths, or rescues from death are recorded, nor is any reference to the manner in which the disaster was met and the complete interruption of communications remedied. These matters are dealt with in the official reports of the Governments of Assam and Bengal, in the Administration Reports of those Governments, and in the annual reports of the Imperial and Provincial Departments which were affected. Besides these an excellent summary of this aspect of the earthquake has been given, in an easily accessible form,[1] by Mr. H. Luttman-Johnson, formerly Commissioner of the Assam Valley Districts.

In the notices of the earthquake which have been published previous to this, it has been described as the Calcutta, the Assam, the Indian, or merely the, earthquake of 12th June 1897. The first of these titles is obviously inappropriate, for Calcutta was nowhere near the focus, nor was the earthquake so severe there as at many other places. The second title, though better, seems still too limited, for the province of Assam covers but a small proportion of the area affected by the earthquake, nor did the focus lie entirely beneath the area covered by the province of Assam. The term Indian is better, for, not only was it felt over a large part of India, but the greater part of the whole area over which it was felt, falls within the limits of the Indian Empire. Even this name is not, however, altogether unexceptionable, for more than a quarter of the area over which it was felt lies outside the limits of the Indian Empire, while not more than about a third can be said to lie within the limits of India proper.

In fact, it is not possible to adopt any geographical name which is altogether satisfactory, nor does this seem necessary in the case of the greatest earthquake of which we have any historic record. On the title page of this report I have referred to it simply as the Great Earthquake of 12th June 1897, and this appears to be sufficient to distinguish it from other, and lesser, earthquakes.

In dealing with the earthquake, I shall first give a selection from the numerous accounts received by me, which will indicate the

[1] The Earthquake in Assam. Journal of the Society of Arts, XLVI, 473-493 (1898).

nature of the shock at different places, and to some degree its extent, and shall then devote a series of chapters to considering the special aspects of the data that have been collected. The course of the investigation is sufficiently indicated by the headings of the successive chapters, but before proceeding to its description I must take this opportunity of expressing my obligation to the numerous correspondents whose names are mentioned in the succeeding pages, and to those many others whom it has not been possible to name individually. The information that each could give naturally varied much in value and importance, but, such as it was, it was willingly given, and what is more, subsequent correspondence and questions were freely answered in some cases, I fear, not without considerable trouble. But for this assistance readily rendered the information regarding the earthquake would necessarily have been very incomplete.

CHAPTER II.—NARRATIVE ACCOUNTS OF THE NATURE OF THE SHOCK.

In accordance with the general scheme of description proposed in the last chapter, we commence with the descriptions of the earthquake at Shillong, and of these I will first reproduce that of Mr. F. H. Smith, of the Geological Survey of India, who writes:

"Some tremors are said to have been noticed for a few days previously by sensitive persons; but if actually perceived they must have been very slight indeed. On June 12th the severe shock commenced without any warning whatsoever (some people say they noticed a rumbling sound for 10 or 15 seconds before the shock).

Personal experience.

"I was out for a walk at the time, and was standing on the road which passes the foot of the filtering tank of the Shillong waterworks, near the school. At 5-15 (according to the ordinary Shillong time, but it is not known how this compares with absolute Calcutta or Madras time) a deep rumbling sound, like near thunder, commenced, apparently coming from the south or south-west, followed immediately by the shock. The rumbling preceded the shock by about two seconds where I stood, and the shock reached its maximum violence almost at once, in the course of the first two or three seconds. The ground began to rock violently, and in a few seconds it was impossible to stand upright, and I had to sit down suddenly on the road. The shock was of considerable duration, and maintained roughly the same amount of violence from the beginning to the end. It produced a very distinct sensation of sea-sickness. The earth movement was exceedingly sudden and violent. The feeling was as if the ground was being violently jerked backwards and forwards very rapidly, every third or fourth jerk being of greater scope than the intermediate ones.

"The surface of the ground vibrated visibly in every direction, as if it was made of soft jelly; and long cracks appeared at once along the road. The sloping earth-bank round the water tank, which was some 10 feet high, began to shake down, and at one point cracked and opened out bodily. The road is bounded here and there by low banks of earth, about 2 feet high, and these were all shaken down quite flat. The school building, which was in sight, began to shake at the first shock, and large slabs of plaster fell from the walls at once. A few moments afterwards the whole building was lying flat, the walls collapsed and the corrugated iron roof lying bent and broken on the ground.

"A pink cloud of plaster and dust was seen hanging over every house in Shillong at the end of the shock.

"My impression at the end of the shock was that its duration was certainly under 1 minute, and that it had travelled from south to north. Several other observers agree with me in limiting the first and great shock to 40 or 50 seconds. I have heard since that its duration was timed roughly in Shillong and Gauhati, and put down at 2½ minutes; but I feel convinced that this includes subsequent tremors, which lasted some time. The violence of the shock may be imagined when it is stated that the whole of the damage done was completed in the first 10 or 15 seconds of the shock.

"The buildings of Shillong might, before the earthquake, have been grouped into 3 classes, which correspond now to 3 degrees of ruin:

Damage done.

"1. *Stone Buildings.*—It is not too much to say that every bit of solid stone work in the neighbourhood of Shillong, including most of the bridges, is absolutely levelled to the ground. The stone houses, and conspicuously the church, are now reduced to flat heaps of single loose stones, covered with torn and burst sheets of corrugated iron—the remains of the roofs.

"The walls do not show the slightest partiality in their direction of falling. The stones have in every case been shaken loose, and have collapsed equally on both sides of the line of the wall.

"Heaps of stones along the roads, broken for mending purposes, which stood 1 foot high before the shock, are now flat, roughly circular patches 3 or 4 inches in thickness.

"Two tall monuments of excellent cut stone work, about 20 or 30 feet in height, are in ruins; though in each case some feet of the masonry at the base still retain an upright position—the individual stones being shaken from each other. The ruins are scattered most impartially on all sides in a rough circle. The pinnacle of the larger (Quinton) monument has been thrown down bodily, and lies some feet from the centre of the stone work pointing N.-N.-E.

"2. *Ekra-built Buildings.*—A wooden frame work, with walls of *san* grass covered with plaster. About half the buildings of this description are ruined in the same way as the stone buildings. All the large ekra buildings are utterly ruined inside, the chimneys in all cases being of stone work, the whole of which has fallen with the plaster from the walls, and in many cases the roofs also.

"Small outhouses and villages of ekra-work have in some cases escaped with the loss of the plaster. Some of the new larger buildings would also have escaped, but for the stone chimneys, which have in every case wrecked the house.

"3. *Plank Buildings.*—Built on the "log hut" principle, a wooden frame work covered with planks, resting unattached on the ground. The only buildings of this description were stables or outhouses. In every case they have escaped untouched, except where the supporting stone work has been shaken away, when they have been slightly displaced.

"Trees in Shillong have not suffered much, two only were brought down by the shock, and as they were leaning over to begin with, their direction of falling does not give any evidence.

Country round.

"In Shillong itself the roads and hillsides are cracked in all directions, but the cracks merely show the lines of weakness in the ground, which has been simply shaken down by the violent vibration, which has apparently acted in every direction.

"Small banks of earth have been flattened everywhere, and the *band* of the artificial lake—a bank some 150 yards long and 30 or 40 feet high, made mostly of earth, gave way almost at once when the great shock began. The centre half of it has been carried bodily away down the valley below by the rush of water.

"On the hills round Shillong four or five considerable landslips can be seen. Patches of hillside debris have fallen from steep *nala* banks, carrying trees and undergrowth with them, and marked now as patches of red soil on the hill—the largest is about 300 feet in width and the same in height."

Another account which may be reproduced is that of the Assistant Superintendent of Telegraphs, Shillong Division, contained in his official letter No. 1473, dated 12th July 1897, Shillong, and addressed to the Director General of Telegraphs. According to this,—

"The shock which levelled Shillong was immediately preceded by a milder shock which did no damage, this was of a greater severity than the shocks usually experienced in Shillong. This milder shock seemed to die away, but without absolutely ceasing, it suddenly developed into a most destructive earthquake, which no building or structure withstood for more than a couple of seconds. The rumbling which accompanied the first shock increased in volume as the shock increased in severity. By that time I was outside, between my own bungalow and another one not 30 yards from it. The noise of the earthquake was so great that I could not hear the falling of the stone chimneys in either of the two bungalows, nor the noise of the fall of part of my bungalow. As soon as the shaking was over, I looked at my watch, and allowing for the error of my watch by that day's time, found the time was 5-16 P.M.

I estimate the duration of the whole earthquake to be about 1½ minutes.

Duration and direction of shock.

The first shock lasted about 10 to 15 seconds, so that the destructive shock lasted from 75 to 80 seconds.

The direction is more difficult to determine. Judging from the rumbling sounds, they appeared to come from the south. During the shock there were no undulating waves; there appeared to me to be no vertical motion. The hill I was on at the time simply felt as if it was being rapidly moved in a horizontal plane backwards and forward. This motion was so violent that I was unable to stand, but had to crawl on my hands and knees and hold on to a tree for support.

I examined several stone structures, the Church, Telegraph Office, Divisional Superintendent's and Sub-Divisional officer's offices, and found they had simply collapsed, owing to the stones being shaken out of their position, the debris remaining all round the site, with a slightly greater accumulation on the north side. The roof in all these cases has simply fallen almost exactly over the place where the supporting walls were. The Quinton Memorial, which was a stone spire, has collapsed, and the stones it was built of are simply lying piled round the base. The stoneware column which was at the top was lying south-south-west and north-north-east. This I take to be the true direction of the destructive shock."

One more extract, from an account given by the correspondent of the *Pioneer* newspaper in its issue of 3rd July 1897:

"As regards the movements of the earth's surface, I can furnish only the personal impressions of one who has had little, if any, scientific training. The movements seemed to me to be distinctly horizontal and undulating, the surface of the earth presenting the aspect of a storm-tossed sea, with this difference that the undulations were infinitely more rapid than any seen at sea. The depth of each wave seemed to me to vary from one to three feet, but this is the estimate of an unscientific individual who had never observed any similar phenomenon, and your readers must take it for what it is worth. I should also add that the earth's surface seemed to me to have a gyratory motion, as though each little area were moving in a whirl. It may be that the horizontal and gyratory movements cannot take place at the same time, and that the latter was apparent only, the impression formed in my mind being due to the rapid undulatory movements."

I have also received a number of accounts, both written and verbal, all of which agree in asserting that there was a very marked undulation of the surface of the ground. Different accounts place the length of these undulations at from 8 feet to 10 yards and their height at from 1 to 3 feet. It is probable that the highest of the former and the lowest of the latter values are nearest the truth, and we may take it that the waves were about 30 feet long and 1 foot high on the average, but that many may have been both shorter and higher. All the accounts also agree in showing that there was a very considerable vertical component in the shock, loose stones lying on the surface of the roads being tossed in the air "like peas on a drum," this vertical movement being accompanied by a more marked backward and forward movement of the ground, the sensation produced being generally expressed as being "shaken like a rat by a terrier." As will be seen in Chapter V, the range of this motion must have been at least 8 or 9 inches. As to the period, or rate of repetition, I was unable to obtain any really satisfactory evidence; in the face of so great and so unexpected a catastrophe, it could not be expected that attention would be paid to a matter which would not be regarded as important, but, by asking people to try and recollect their sensations at the time and to indicate the rate and extent of the movement, I found that there was a very substantial agreement as to the first, and that the rate must have been approximately one second for the double movement forwards and backwards. It may have been a little more rapid, but I do not think it would possibly have exceeded 1½ second.

All the accounts from the station of Shillong agree in stating that the first indication that was noticed was a rumbling sound, like that of a rapidly moving cart; but Mr. R. S. Strachey, who was riding at the time on the Peak, some 1,400 feet above Shillong, states that his attention was first attracted by the rustling of the leaves on the trees, and that the tremulous movement which caused this lasted for several seconds before he heard any other sound.

Passing westwards, we have the very interesting report by Captain A. A. Howell, Deputy Commissioner of the Garo Hills, of the earthquake as felt at Tura, of its effects, and also of the manner in which the administration of the district was carried on after the shock.

PART I—TURA[1].—

"1. To make this part of the report clearer, I have begun with a short description of Tura station, of which, too, a map (not printed) is herewith sent. In this map, only the portion south of the Ronkon stream has been accurately drawn. The contours are at 5 feet intervals. The rest was surveyed with a chain and compass, the contours being roughly put in, merely to show the general formation of the ground.

Short description of Tura.

"2. On referring to this map, it will be seen that the station is a very small one, and built mainly on three spurs running from east to west. The station has an elevation of about 1,300 feet above sea level. It is situated at the foot of the western end of the main range of the hills in this district, which rises immediately and steeply above it to a height of some 4,000 feet above the sea, and thence continues almost due east to the ranges of the Khasi Hills. The conformation of the spurs consists of a backbone of sandstone covered more or less deeply with a loose, reddish sandy soil, plentifully mixed with boulders of (what I am told is) gneiss.[2]. The crests of the spurs are broad and fairly level, but the sides are steep and occasionally precipitous. At the bottom of each ravine is a small (hill) stream flowing over a rocky bed.

The weather at the time of the earthquake.

"3. The week preceding the earthquake began with fine weather, a clear atmosphere, and not much rain. On the 10th there was a change. Heavy masses of cloud gathered round the top of Tura *pahar* (*i.e.*, the high hill above the station), and the air had a feeling of thunder in it, though there was no rain until noon of 12th, when a smart shower fell. This cleared off about 2 P.M., but was followed, after a vivid sunset, by heavy downpours lasting until the morning of the 13th.

The time of the earthquake.

"4. There being no telegraph wire to Tura, there is no means of checking our local time. We depend chiefly on a sun dial, but as it was inaccurately put up, the result is unreliable. The guard-room clock stopped at 5-5 P.M., and this was the time of the first shock by my watch.

The duration of the earthquake.

"5. The exact time the earthquake lasted was not noted by anybody in Tura. The consensus of opinion fixes it at five minutes or longer. The shock began with a sharp vibration, increasing in about 20 seconds to a violent rocking and heaving motion of the earth, which lasted about three minutes; in about two minutes more it gradually subsided to a gentle but distinct tremor. A few persons assert that the shock was preceded by a loud rumbling noise, but this is

[1] Reprinted, with a few trifling omissions, from the official report of the Assam Government, published in the *Assam Gazette* and also separately.

[2] The hills are composed of gneiss and other crystalline rocks, on which in places are patches of tertiary sandstone and shales.— R. D. O.

doubtful (personally I did not hear it). Everybody, however, agrees that such a sound was audible during the shock.

"This tremor of the earth continued almost without intermission through the night of the 12th June, increasing at irregular intervals of some minutes to a strong and jerky shake of sufficient force to make houses rattle and trees quiver. These shocks were, and still are, almost invariably announced by a distinct rolling sound as of far-off thunder.

Subsequent shocks.

"Nobody has kept any record of their number, but from several hundreds in the twenty-four hours, they have decreased to ten or twelve a day; even now some are nearly as strong as those immediately following the first and severest shock.

"6. The effects of the earthquake, as seen on the ground, are (1) landslips (2) cracks and fissures; (3) ridges and furrows; (4) depressions of the surface.

Effects of the earthquake on the ground.

(1) *Landslips*.—Landslips are now visible from the station in every direction, but are fewest to the north. They have occurred wherever the ground was steep and not formed of solid rock. In the station itself the southern spur has suffered most, and more on the south side than on the north. There is a large slip at the head of the *nulla* to the south of the Deputy Commissioner's bungalow. From this point, as far as the parade ground (on the western extremity of the spur, not shown in the map), the whole hillside has slipped more or less; on the northern face the landslips are both fewer and smaller. The small spur on which the inspection bungalow and charitable dispensary stand displays similar effects. On the south side, half the knoll on which the clerks' houses were built has come down, and there is a smaller slip within a few feet of the charitable dispensary. On the northern face, only a few rocks have fallen.

"The large spur on which the cemetery and Forest Officer's bungalow are situated has small landslips on both sides. The spur on which the mission compound lies has suffered least of all, there being only one small slip on its southern face. On the other hand, the high hill immediately behind it is scarred all over.

(2) *Cracks and fissures*.—Cracks in the ground are to be seen everywhere, but chiefly in the vicinity of landslips and along the upper edges of sloping ground. Their direction follows the line of the hills. Besides them, however, there are a good many on the level crests of the spurs far from any sloping ground and running in various directions. In some, a walking stick can be pushed down to a depth of 2 or 3 feet."

"(3) *Ridges and furrows*.—In the western portion of the southern spur and all round the Civil Surgeon's quarters to the distance of a mile down the Mankachar road, where the soil is sandy and the surface fairly level, the ground looks as if a steam plough had passed over it, tearing up the turf and throwing the clods in every direction, some up hill and some down, and in many cases turning the sods completely over, so that only the roots of the grass

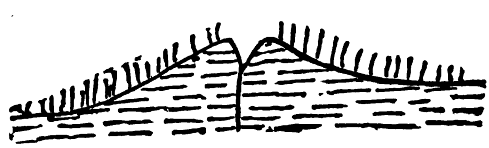

Fig 1.

are visible. In other places, the earth seems to have first opened and then closed again with great pressure, forcing up the turf along the line of cleavage into ridges, thus (Fig. 1).

" In other places, again, large pieces of turf are found lying on the grass with no mark or sign to show the place from which they had been torn.

"(4) *Depressions of the surface.*—Depressions of the surface of the earth are only a few inches deep and apparently of small area. Their edges at first were clearly defined, but now have become worn down by the weather and by the feet of men and animals. Those near sloping ground are due, no doubt, to the slipping of the earth or displacement of some large boulder below, but others occur in the centre of the most level places, and indicate perhaps an actual subsidence of some substratum of the spur itself.

" Trees have not, as a rule, been damaged, except on steep hill sides and in sandy soil, where in many cases the earth seems to have been shaken away from the roots.

" A stone on the parade ground, about 20 inches in diameter and 10 inches thick, partly imbedded in the ground, was thrown to a distance of about 3 feet, and turned upside down. A cylindrical metal rain-gauge on the Deputy Commissioner's lawn was also similarly displaced.

Damage to houses, etc.

" 7. All buildings in Tura, both Government and private, may be divided into four classes :—*First.*—Those built on wooden piles from 10 to 20 inches in diameter, driven several feet into the ground and reaching up to the roof. These have a raised board floor, mud and reed walls supported by timber battens, and a roof of thatch or corrugated iron. Of this class are the houses of the Deputy Commissioner, District Superintendent of Police, Forest Officer, and Sub-Engineer, the inspection bungalow, cutcherry, and the houses of the American Baptist Mission.

"The houses of the Deputy Commissioner, District Superintendent of Police, Forest Officer, and Sub-Engineer are damaged more or less severely in the same fashion. Several posts have sunk from a few inches to a foot deeper into the earth, causing the floor to buckle and the roof to sag. Many, too, are out of the perpendicular. At the point each post enters the ground, a cup-shaped depression, from one to six inches in depth and diameter, has been worn round it thus (Fig. 2) as though the post had been given a circular movement :

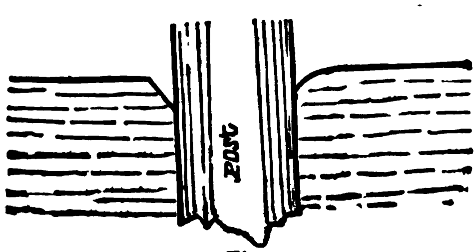

Fig. 2.

" Many of the timber battens supporting the walls have been wrenched loose, most of the plaster has fallen, and, where old and rotten, the reeds have come down with it. The bungalows of the Deputy Commissioner and District Superintendent of Police have suffered most. The former was built in 1872-73, the latter in 1875. The Forest Officer's bungalow was built about twelve years ago. Its walls have been badly damaged, and to a smaller extent, also the posts, floor, and roof.

"The Sub-Engineer's house was built in 1883-84; it has suffered in the same degree as the Forest Officer's.

"The inspection bungalows and cutcherry were erected in 1889 and 1889-90, respectively. They are both in fair condition as regards posts, floor and roof, but the walls have been almost destroyed.

"While Government buildings have fared so badly, it is curious to note that the houses of the American Baptist Mission have withstood the shocks with comparative immunity. The reason perhaps is that the posts, instead of being driven deep into the ground, mostly rest on stones almost flush with the earth, or flat on the earth itself. Their walls, too, on the sides exposed to the weather are protected with stout planks, which no doubt increase the strength of the structure.

"The second class of buildings differ only from the first in that they have a stone and cement plinth, instead of a raised board floor. In this class are the Civil Surgeon's house, the charitable dispensary, the post office, the treasury, and some shops in the bazaar. The most remarkable point about them is the manner in which the plinths have cracked and broken up. It is most noticeable in the treasury. This building stood on a gentle slope a few feet from the top of a steep hill-side. It had a strong frame of timber, walls and roof of corrugated iron, and a massive plinth of cement and large stones. The plinth was 70 feet long, and 32 feet 6 inches wide with a maximum and minimum height of 8 feet and 1 foot 6 inches, respectively. The floor was of concrete and cement to a depth of 9 inches. Solid as it was, it crumbled away like a pile of sand before the first shock had stopped. The stones rolled out on all sides, and the floor was broken into little pieces. The whole building tilted over towards the *khud*, wrenching the main posts in every direction, and uprooting or breaking the smaller ones which supported the verandah. The plinths of the other buildings also cracked up, and the sides fell away, leaving gaps under the walls, but they do not show signs of such violent action as the treasury. The frame and roofs are almost all sound; in the Civil Surgeon's house only, the thatch has parted along the ridges of the roof and slipped to the ground. The walls have been denuded of plaster and the battens have in some places been loosened. These buildings were erected as noted below:

Civil Surgeon's quarters	built in 1897.	Post office	built in 1887-88.
Charitable dispensary	„ „ 1890-91.	Treasury	„ „ 1887-88.

"The third class consists of buildings with the ground for the floor, timber or bamboo frames, walls of mat or reeds lightly plastered over, and roofs of thatch or corrugated iron. The out-offices of the different bungalows belong to this class. Being old and badly built for the most part, they have been reduced to ruins. Other buildings of this class, consisting of the police barracks, clerks' quarters, and the majority of the houses in the bazaar have stood well. Some have collapsed, owing either to their original ricketty condition, or to the ground having fallen away under them.

"The fourth class consists of the Garo's houses with a raised floor and built entirely of wood, bamboo, cane, and thatch.

"These houses, when on level ground and in fairly good repair, have not been at all affected by the shaking. Unfortunately, many of them were built (in a hilly district like this) on steep hill-sides, or at the base of cliffs, and numbers of them have been destroyed by landslips. In all the houses in the station, furniture was thrown about in great confusion, pictures fell, the pendulums of clocks were shaken off, chairs and tables shifted about like grains of rice in a winnowing basket. Almirahs and book cases were overturned; in short, no moveable article, however big and heavy, was left in its original place.

Station roads and bridges.

"8. The station roads and bridges had been badly damaged; that part of the road running past the District Superintendent of Police's house, marked A B C in the map, has slipped away altogether, and the path from the jail to the point marked D is covered by a landslip. The stone abutments of the bridges over the Ronkon and the Mafilkol have been shaken down, but the bridge over the Rengri has escaped untouched.

"To sum up. The damage done by the earthquake has been greater on the southern than on the northern sides of the spurs, while it is also most noticeable on the southern spurs, decreasing gradually towards the north. The small collection of houses near the mission compound, marked Chandmari in the map, shows no signs of any disturbance, nor do the bridle-paths to Rongrenggiri and Salmara for the first 3 miles from Tura. On the other hand, the cart-roads to Dalu and Mankachar are blocked with landslips right up to the station.

PART II.—THE DISTRICT.

"9. Owing to the difficulties and the deficiencies in the means of communication in this district, full reports of the damage done have not yet been received from all sides.

Damage in the plains.

"In the plains portions of the district deep cracks and crater-like pits appeared in the ground; one of the cracks is as much as a mile long, 2 or 3 feet wide, and 16 feet deep. The pits average about 6 feet in diameter, though one is said to be as much as 40 feet across. Through these fissures, jets of sand and water were thrown up to a height of 6 or 7 feet, in a few cases accompanied by pieces of coal, peat, resin, masses of semipetrified timber, and a black earth hitherto unknown in those localities. The bed of the Ganal was upheaved 20 feet, and so was the bed of the Jinjiram, but not so much. Both have since settled down again, though not to their normal level.

"Many houses sank into the ground bodily, the roof alone being visible, but no loss of life has yet been reported. Several villages were, and still are, partly submerged, and some thousands of *bighas* of cultivated land have been made useless. Of the crops, jute has suffered most; in some fields plants as high as a man have been completely buried in sand. The *ashu* crop has suffered a great deal less, and, where not destroyed, promises to be up to the average. Several *bhils* have silted up, and the newly-formed land is now being ploughed for *sali*; as the soil is excellent, good results are expected. The earthquake caused a regular panic amongst the plains people. Whole villages were deserted for days, while the inhabitants took refuge in the hills. A few Garos took advantage of this to loot their granaries. Considering, however, the extraordinary facilities for thieving afforded, very little crime was committed.

Damage in the hills.

"10. In the hills, landslips have caused a great deal of damage, granaries have been wrecked, and much grain lost. The cultivated slopes of the hills have cracked so as to injure the crop, and in some places the earth has been so severely shaken as to destroy it.

"It is generally stated that some hills have sunk bodily many feet while others have risen. In the case of two hills between Tura and Rowmari, this assertion is corroborated by the signallers of the Military Police, who have been constantly practising with the heliograph from these two places.

Mortality.

"11. I regret to say there have been more lives lost than was at first supposed. Up to date the number is 27, but as the reports arrive from the more inaccessible parts of the district, this number will, I fear, be considerably exceeded. The greatest loss has occurred in the lower part of the Someswari Valley in the circles of Bong and Damjing *Lashkars*; the latter with his whole family was buried in his house by the fall of the hill above it.

Attitude of the people.

"12. The Garos generally were thrown into a state of stolid bewilderment by the earthquake. They left their fields, and retired into their village houses to await further catastrophes. The Garo belief is that the world is a square flat body hung up by a string at each corner. There is a squirrel always trying to gnaw these strings, but to prevent it a demon was appointed. This demon, however, neglected his duty, and in order that his attention might not in the future be diverted from his work, he was struck blind. Now that he can't see, the squirrel of course has the best of it, and it is feared that when one or two of the strings are gnawed, the earth will be turned upside down.[1] Another story is that Her Most Gracious Majesty, not content with the last earthquake, has ordered another and more vigorous one to be followed by a cyclone. That it is in the power of the *Maharani* to do so is never doubted. One man asked for a *parwana* to forbid the hill behind his house from slipping down on to him. Had the houses of the European officials in Tura not been wrecked, the Garos would have made up their minds without doubt that the recent catastrophe was the work of the *Sahibs*, and excited by the wild stories in common circulation they might have given some trouble.

[1] I was informed that a number of Garo children, who were attending the mission school, convinced that this had come to pass, rushed underneath the platforms, raised above the ground, which formed the floors of the mission houses, so that, when everything was reversed, they might still have a solid floor to stand on.—R. D. O.

"13. The district roads have all been badly damaged; the cart-roads to Dalu and Mankachar were impassable for weeks, except by foot passengers. In the hills, they were blocked by landslips, in the plains embankments sank 2 or 3 feet for long distances, breaches were frequent, and bridges had nearly all subsided more or less. At the 22nd mile of the Mankachar road, a timber bridge, 80 feet long, was heaved up to a height of 8 feet above its proper level.'.

Roads.

To the north, in the alluvial plain at foot of the Garo hills, but still, as it would seem, within the area of the seismic vertical, we have the account of Surgeon-Major E. F. H. Dobson, Civil Surgeon of Dhubri, contained in a demi-official letter addressed to Mr. H. J. Cotton, C.S.I., Chief Commissioner of Assam.[2]

"On the 12th, I sent you a demi-official, and about four hours later, that is at 3 p. m., left the station by the ferry steamer, which landed me on the opposite bank at 4-15, and from there I drove to Jemadarhat, where I met my camp. There was a stormy sky ahead and a strongish breeze blowing whilst I was crossing the river; on reaching the opposite bank, had a few drops of rain, and, on the whole, had a cool and pleasant drive till I reached Jemadarhat, which is 3½ miles from the opposite bank of the river. The resthouse at Jemadarhat was burnt down some months ago, and my servants rigged up a small godown about 16'×8' for me to stay in during the night.

"At 5 P.M. came this terrible earthquake. I invariably sit out an earthquake, as I have always thought the worst is over before one has time to get outside a house, but though I was safe enough in the light shanty I was in, I had to rise, as the shock seemed never ending and a roar of water flowing near and the hum of voices compelled my geting up. The villagers were panic-stricken and fleeing from their houses to the Trunk Road. The ground I at once saw was everywhere cracked up, sunk, etc. Behind the old rest-house is the termination of a very long *bheel*. It was a wonderful sight, this *bheel*. The water rose steadily in it, and in two minutes must have risen at least twelve feet and then overflowed, and with this overflow, the whole country, as far as the eye could see on each side of the Trunk Road, was one sheet of water. The fact being that from all the innumerable cracks water had gone on spouting, and that, coincidentally with the overflow of this *bheel*, the water level had risen to the same height all over the surrounding country.

"In addition to the cracks from which the water welled up carrying the sand with it, innumerable jets of water, like fountains playing, spouted up to heights varying from 18 inches to quite 3½ or 4 feet. Wherever this had occurred, the land was afterwards seen to occupy a sandy circle with a depression in its centre. These circles ranged from 2 to 6 and 8 feet in diameter, and were to be seen all over the country. In some places, several were quite close together; in others they were at a distance of several yards apart. They had the appearance of

2. Assam Government report, Appendix V.

small craters. I have heard it said that the water from the cracks and these so-called fountains was warm, almost hot, but this must be due to some one's imagination: I had to wade through a good deal of water whilst the water level was rising, and had the temperature of the water been abnormal, it must have made itself felt to me. It must not be overlooked that the country had been water-logged days before the earthquake came, and that it must have been this water which was driven up with the subsidence of the land, as I believe the quake was due to a subsidence.

"In front of Jemadarhat resthouse the Garo Hills are within 5 miles, and behind it is the Brahmaputra at a distance of not more than 2 miles. The Trunk Road remained above water, but in certain portions, where it had subsided from 1 to 2 feet, the water flowed across it, and at these places where the panic-stricken villagers tried to run towards the direction of Lakhipur, which is 12 miles off in the Gauhati direction, the poor creatures got more alarmed than ever, for they found themselves sprawling about in the water, unable to realise what had barred their progress, and not knowing if they were going to get out of it again. At all these gaps or places, where the earth had subsided, or where fissures and cracks had formed, the rush of water from them all carried with it an immense quantity of sand, and this was what barred the progress of these panic-stricken villagers. This sand had a particularly quicksandish feel about it, but fortunately, as a rule, was not deep on the portions of the road that had subsided near the resthouse.

"The main shock seemed to me to have lasted nearly six minutes but perhaps in this I am wrong and perhaps I may have missed a cessation and taken two or more shocks as one, for certainly I noticed no cessation. It seemed as though death from drowning must have been the end of every one near me. Although the shocks went on being repeated incessantly at intervals of a few minutes, the rise in the water ceased after half an hour, and then the idea present to one's eye was that the country on either side of the road was nothing more than innumerable sand-*churs*[1] of different sizes, such as are met with in the Brahmaputra. This meant, of course, that crops were considerably covered by this sand. Most of the excavations made by the earth-cutters annually on each side of the Trunk Road to enable them to throw fresh earth on to it have been filled in by this sand, and the Public Works Department will not have quite such heavy rates to pay for earth-cutting, as the leads will be comparatively short when they begin work again; but for this, which is really no advantage to speak of, the loss to the province must be enormous.

"All the panic subsided by about 9 o'clock; the hut I was originally in was now under water, and I could not get back to it. Many of the villagers' houses and those of the Kayas had sunk a good deal, whilst others filled with two or more feet of sand through the doorways. My horse broke away towards the end of the first shocks, and made for home, the *syce* after her as hard as he could go, but on reaching a good strong wooden bridge, she was stopped by the bridge subsiding on the Dhubri side. Cattle seemed to find great trouble in extricating

[1] *i.e.* Sand-banks.

themselves from the sand and water, which but a few minutes before was their grazing ground. Villages were wholly vacated and refuge taken wherever high land was available. Almost everything is said to have its ludicrous side, and in the midst of confusion and the marked panic of the villagers, it was amusing to find my cook busy at work preparing dinner within half an hour of the occurrence. There he was, as though nothing had occurred, on the plinth of a burnt down hut only just above water and surrounded on all sides by it. I was very grateful to him later on for not having parted with his wits.

"As the rush of water ceased and order was to some small extent renewed, those who were able to do so scrambled to their huts, and brought out boxes and bedding, etc., etc., and, with their belongings, encamped on the road for the night. At about 10 it struck me I might have a roof over my head if I got near the ferry ghât, as there was a tumble-down serai there. I had gone half a mile when two men assured me it was impossible for me to progress, owing to a gap of several feet in the road through which water flowed, and across which they had just swum. On hearing this, I returned, and with my bed on the road, attempted to get at some rest. This was impossible, with the continuous and oft-repeated seismic shocks at short intervals, which, whenever the least bit strong, were followed by a wail of human voices. Cattle, goats, and dogs formed a goodly addition to those resting on the road for the night. At 2 A.M., a sharp drizzle came down, and with my umbrella over my face and a rug over my body, I weathered it out till 3 A.M. when my rug had got wet through. Close by was the resthouse well. I now transferred my head-quarters to it, by wading across 2 feet of water for about 15 yards, and then spread a dryish rug on the masonry platform of this well. The well and its platform had both been badly cracked at 5 P.M., and the water had risen to within 18 inches of the surface. It had a thatched covering over it, and this sheltered me during two hours of heavy rain.

"At 5 A.M. I rose finally, having had a fair night's rest under most extraordinary circumstances. Having had *Chota Hazree* at 6, I started to walk back to the ghât, having learnt that the road was impassable towards Lakhipur. As the road was heavy and my *syce* had developed strong fever, I left him the trap to drive in slowly. The whole Trunk Road from Jemadarhat to ferry ghât, which I had seen, had cracks running along it, which were in some instances over 100 feet long; in others the earth had subsided for a similar distance, and then, again, transverse cracks, depressions, etc., existed all along the road at distances of a few feet for miles; the same thing seemed to have occurred off the road side. The villagers stated that they had lost the grain they had stored in their houses. On arrival at the ghât, it is scarcely necessary to say it was much changed, the river having risen considerably since 4 P.M. However, after getting almost knee-deep in many places in very disagreeable soft sand, about which I was hopping for quite half an hour, I got safe on to the ferry, and returned to Dhubri at 9 A.M. Shortly before reaching the ferry ghât, my *syce* had sent word that my horse was drowned, and desired me to return. At the ghât another messenger brought me word saying the animal was well stuck in soft sand. So I sent back coolies, and much to my surprise, found her none the worse, and at

Dhubri by 5 P.M. It seems she had got into the sand at about 7 A.M., and remained in it till 1 P.M. There were several gaps in the road between Jemadarhat and the ferry ghât, but none over 2 feet wide, and the *syce* instead of exercising a little care when having to go off the road, took the shortest cut possible, with the result noted by me. The huge gap I was told of the night before turned out to be a myth.

"On returning to Dhubri, everything was as I had pictured it at 5 P.M. the previous night. The town is in ruins. It has sunk everywhere, and for hundreds of feet in a stretch it is cracked and fissured. The dispensary (main building) stands, but has suffered much. It is built on iron pillars, and its brick walls are only about 12 feet high and 2 feet thick; above, its walls are lath and plaster. Hence the reason it has stood. The cutcherry, the forest house, Local Board bungalow, circuit-house, the club, telegraph office and telegraph signallers' quarters, and the Gauripur zamindars' house stand, also Leslie's and Maher's, because they are built on piles. Of course the plaster and lath are all gone. The treasury, Jewett's house, Jolly's house, the dâk bungalow, the Bijni Hall, two large houses at the immigration depôts, the liquor shop in the bazaar, and the Muhammadan *musjid* and my house still stand, but are dangerous to enter and must all be dismantled. The post office, Hallifax's, Bogribari zamindar's house, the high school, the church, the Sikh temple, the new jail, the newly built magazine, the seven newly built houses in the dispensary ground, and all the outhouses of every single brick-built house are down flat. So far, only one fatal case has been reported, and this a native child about 5 years of age. The natives are all panic-stricken, are living on the roads, in boats, and in steamer flats, and seem most helpless; the better classes encamp out on the roads during the night, although several of their houses are safe. Several of them have, however, suffered considerably; houses, especially those built on new reclaimed land near the Dhubri backwater, have subsided a good deal towards the back.

"Just beyond the front of the old jail and extending for nearly a quarter of a mile below it and in the direction of the old bazaar, the land has subsided quite 5 feet, but this subsidence is not so great as we get further away from the jail; in fact it is as little as 2 feet. Unfortunately for the station this subsidence near the jail is all but communicating with the river, and runs parallel to it behind a row of houses situated in the old bazaar on the river bank. As soon as the river rises, it is certain to flow into this subsidence (which already has water in it), and then there will be one steady flow from the river right on into the recently-excavated tank in connection with the new drainage scheme of the town. Shortly after this takes place we shall, I think, find the narrow strip of land between this tank and the main bank of the river will be *non est*, and that the river will be flowing through what was once the tank and continuing its onward course carrying all before it and skirting uncomfortably near the new bazaar.

"The station drains are *kutcha*, and almost every drain is choked up with sand carried up from the cracks up to or very nearly on a level with the roads. The station tanks have risen considerably and some overflowed. In several of them islands of sand are visible, clearly showing that, though the tanks are full, the actual depth of water is not very much. This I have verified in some instances, and it is further proved by the condition of the public wells in the station. Almost all the pits have been levelled up by the sand from the cracks. The new bazaar, which was very low ground, has benefited considerably by being raised with this overflow of sand. It is at present also more or less flooded. This sandy overflow was restricted to low lands, more especially as *bunded* roads showed no sand or water on them, till after they had subsided to a certain depth. The two *bunded* roads in the station, *viz.*, the Bidyapara and Gauripur roads, and the two or three branch roads from them, as also the 3½ miles of road on the opposite bank of the river over which I had travelled on 13th, have all subsided a good deal in places, and I think it not a bad comparison to make when I say they are not at present very unlike switch-back railway roads on a small scale.

"The station is terribly cracked up and has subsided in places, but this is not to be wondered at, more especially when we recollect that during the rains it is almost an island, and a very narrow one with rivers on three sides of it, and these rivers forming three large expanses of water tearing along. The front of this station is, as you know, very high land, a sort of hill, and on rock. This portion was not cracked up, but as soon as we reach the first road behind the front or river side road, which is low land, we notice terrible cracks in the ground both in numbers and extent, and this road is not more than 300 yards at the back of the river side or front road. It is in this high portion of the station that natives of all classes seek refuge, especially as the evenings begin to close in. I am told the Brahmaputra rose several feet at the time of the earthquake. Next morning when I crossed it, it seemed a very different river: a huge sand-*chur* in front of the station had disappeared; it seemed in full flood, drift wood was plentiful, and I noticed two small boats (empty) being carried along. Bilasipara and Lakhipur zamindars' country residences are down in a heap. Gauripur, Rupsi, and Bogribari are said to be badly damaged. The Joldoba or Gara bridge and the Krishnai bridge, our two chief iron bridges, are reported broken. A hill between Goalpara and Agia is said to have slid forward towards the road. The *sál* wood railing of the bridge near Jemadarhat is quite 8″ × 8″, and it was split right across on one side. On 13th night we had heavy rain. It had been fairly cool till yesterday, and up to the present it is hot again. It has just rained for five minutes at 2 P.M., and is threatening to do so again. But what about these continuous seismic shocks, which are really strong at intervals of every half or one hour? A severe one again at 2-40 P.M., and so on all day and night. We seem to have had such a severe beginning and so much of it since that we are quite accustomed to shocks that at any other time would have been referred to as very serious.

"There seems to be almost one continuous tremor of the earth going on. I attach a tabulated statement regarding the wells in the station, which, I think, will be of great interest. It will reveal how they have filled with sand, and also that those which had not filled entirely with sand filled almost to overflowing with water. In some, both sand and water had overflowed. I am afraid this silting up of sand in wells, tanks, *bheels* or *jheels*, and I presume in rivers, will mean great misery for the villagers and their cattle when the dry season sets in, and especially if we have a long drought."

Though not within the area of the seismic vertical, the northern part of the Maimansingh district lies very close to its limits, and from here we have an account by the late Mr. F. Mercer, Superintendent of Telegraphs, who writes as follows, in a report addressed to the Director General of Telegraphs :—

"On the 12th June, I was at Attrabari in the Mymensing district, with Mr. Parrott, Sub-Assistant Superintendent. We were stopping in a timber and mat building belonging to the zemindar. Shortly after 5 P.M., Calcutta time, the building began to sway and creak, at first thinking it only an ordinary slight earthquake we did not move; but as the motion increased we went out into the garden; we had gone about five paces from the house when the ground rocked violently and we were both thrown down, as we got up I looked at my watch and noted the time 5 hours 6-7 minutes P.M., Calcutta time. The shock appeared to come from the south-west, and on looking in the direction we saw a series of earth waves approaching over the surface of the ground exactly like rollers on the sea coast, as these passed us we had some difficulty in standing, but none of these waves reached the intensity of the first, which had overthrown us. It was raining at the time and I had no compass but by marking a clump of trees which appeared to be directly in the line of the waves with the place where we were standing, and checking it next morning at sunrise; I estimated that the shocks were from almost south-south-west to north-north-east. As the waves above referred to subsided the ground began to crack at our feet, a long crack appearing at right angles to the general direction of the waves; not knowing what further surprises might be in store for us we left the garden and went out on to the main road, as we reached it we saw a series of "geysers" springing up in some waste ground on the far side of the road, pouring out sand and water, the highest of these reached, I should say, about 4 feet; on seeing these I ran back into the house to get my camera, in the hopes of getting a photograph of one, although as it was raining slightly I had not much expectation of getting a good result. I had some difficulty in taking a photograph as just as I focussed the camera on the largest, a new one sprang up at my feet making it necessary to shift rapidly, moreover these geysers varied in intensity considerably, one would spring up two or three feet and then suddenly die down and another rise on a different spot. The water I noted was not hot.

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"On my way to Isvarganj and Ramgopalpur I noticed literally hundreds of miniature craters where these mud and water geysers had sprung up, in one span of 100 yards I counted 52 between the two posts in a strip of ground about 20 feet wide, the largest had a dimension at the bottom of about 4 feet and was above 1 foot high.

"At Isvarganj office I found that a large crack had opened in the ground through the office, this was about five feet wide, and as far as I could judge about 15 feet deep; portion of the office had fallen into it. At Ramgopalpur I found the office, which is in the lower floor of the gate house of the zamindar's house, was merely a heap of bricks and plaster.

"All along the road into Mymensing where numbers of cracks and crevices, some five and six feet wide, rendering the road impassable for wheel traffic, some of these had opened on the site of a telegraph post, and the whole socket and subplate could be seen, the post leaning up against the side of the crevice having slipped down as far as the subplate would permit it to go."

From the same district I have also a copy of a letter addressed by Babu Hiranmoy Mukerji, of Muktagachha, to the Chief Secretary to the Government of Bengal, which I reproduce as a clear and simple account of the earthquake, besides expressing the views of an important section of our fellow subjects on the cause and cure of such catastrophes of nature.

"I have the honour to submit the following report on the effects of earthquake in the District of Mymensingh, so far as I have been able to ascertain, for the information of Government; and to suggest certain measures for palliation of the mischief done by the earthquake, for such notice as the Government will be pleased to take of them.

"2. The shocks were felt at 5-6 in the afternoon of the 12th June 1897, and their duration was about five minutes. The shocks were preceded by a very grave sound like that of a distant thunder, and were so violent in nature that the earth swayed like a cradle with all the contents upon it. The waving of the house-tops above and the rending of the earth below were something very awful to look at. And so long as the shocks continued, nobody could stand on his legs, but had to stoop down and cling to the earth as fast as he could with both the hands and feet, expecting nothing but death at every moment. After the first quake was over there was a temporary rest. Again, from the evening, the shocks were felt at quick intervals during the whole of the night and the whole of the next day. And even though the force was much abated, yet it was sufficient to create a good deal of uneasiness amongst men for the safety of their lives. From the second day the shocks continued with gradually less and less force, lasting for a minute or less, rocking the houses and things, and either making the smaller cracks in the buildings wider and wider, or causing those collapse in which wider cracks were made by the first shock. The shocks continued up to 20th July 1897, though of course their number and force lessened every day.

"3. As the effects of the earthquake are generally the same everywhere in the district, I think it is unnecessary to describe what took place in every village and town. It would be sufficient, I think, to give a general summary of the whole.

"4. Firstly, as to the surface of the land. The ground was rent into two by the violence of the shock. In many places, especially in those on the eastern side of the river Brahmaputra, large gaps were made from 4 to 10 feet wide, running to a considerable length, and resembling a canal, from which oozed out sands and water with or without a considerable force. Within a short time, the canals so made were full of water and were not fordable in many places. In some places the gaps were from 1 to 3 feet wide, and their depth was from 10 to 12 feet or more. Water appeared in these gaps a foot or less below the surface. In one and the same place there were several gaps or fissures running crosswise, causing the ground heave up in one place and sink in another. These gaps sometimes passed through houses and buildings[1] causing the former to sink down with posts and fencing, and leaving the thatches only above the ground, and the latter entirely collapse. In some places, however, the houses and the buildings were only partially buried. The roads in some places sank down to the depth of several feet and in others heaved up. They were for some time almost impassable, and up to this day very many nearly remain the same. In some of the corn-fields, these gaps took the form of little rivulets, which ran sometimes to a considerable length, while in others, sands were deposited to such a height that the jute and the early rice crops, which stood over them, were buried together with the hopes of the cultivators, which were fastened upon them. In one place, a large tree sank so deep that only its branches remained above the surface of the ground.

"5. The shock of the earthquake was very severe in that part of the country which lay on the eastern bank of the river Brahmaputra. It may be noticed here that that part of the country has got an infamy marked upon it because of the Pandavas not having set their foot upon it. There as well as in few places on the northern bank of that river, some shallow rivers, named in the margin were dried up and sands were deposited on their beds, making them appear like roads newly made. Many tanks similarly dried up and sands filled up the hollow. This will again cause the scarcity of drinking water in those places. These gaps, fissures and the deposit of sands in some of the corn-fields have been so great that it would be impossible for long time to come to bring these fields under cultivation again, or perhaps never at all. In some places an entire village has sunk, and water come upon the surface to the depth of the knee or the loins. The people of such villages had to pass one or two days on crafts made of plantain barks. The water there subsided gradually.

Kharia.
Barakhala.
Baraharisha.
Rangsha.
Mahamarykhal.
Kachamatea.
Shomesvar, etc., etc.

"6. But there is no good unmixed with evil or no evil unmixed with good. Although the earthquake has destroyed and damaged corn-fields either by depositing sands over them or causing them to sink down with yawning gaps made through them, yet it has rendered some compensation by causing some very old bheels to be dried up, which in the ordinary course would have never come under cultivation within the quarter of a century. These bheels are being ploughed up and cultivated this very year, and are about to prove an apple of discord to the neighbouring zemindars.

[1] That is thatched bamboo huts and brick built buildings—R. D. O.

"7. In some places, both on the northern as well as on the eastern banks of the river Brahmaputra, coal, burnt sands and other substances came out of the earth along with sands and water. The samples which I have collected are sent herewith in a separate box.

"8. Several persons reported to me that they have seen smoke come out of the ground in a certain locality on the eastern bank of the river Brahmaputra opposite Begoonbary, which is on the northern bank, and that the place from which the smoke came out appeared to be very hot.

Fulpur, Gaira Hatpagla, Barapagla, Bhugly, Char Niamat, Malidanga, Shirtha, Dhamna, etc., etc.

"9. The names of some of the places, where the changes described above took place are noted in the margin.

Houses and Buildings.

"10. Houses were buried, but were seldom levelled to the ground. The buildings in most places were demolished, causing immense loss to the owners. In the town of Mymensingh all the best two-storied buildings were destroyed and also many of one story. There were not, however, so much fissures in the town as in other places. The town next in importance to Mymensingh is Muktagacha. It is in complete ruin. Nearly all the buildings have been demolished, and the few that have not been levelled to the ground have been so badly cracked, both in the foundation and the walls, that they are no longer fit for habitation and are likely to come down any day. The fate of Muktagacha was also shared by the villages called Ramgopalpur, Gouripur, Kalipur, Durgapur, Atarabari and some others which are the seats of the zemindars of this district. These have literally been rendered houseless and have been dwelling in wretched huts temporarily made for the purpose. Many there are who have been literally ruined owing to all their valuables having been smashed, damaged, or destroyed by the fall of the buildings. There are also some who will never be able to build any more. The losses of the zemindars have been very great.

"11. Although the earthquake has not been happily attended with much loss of life owing to its having taken place during the day, which is certainly a manifestation of Divine favour to mankind, yet it has caused much suffering amongst all classes. The upper classes I may say have suffered the most, and the lower classes the least.

"12. This partial wreck of nature was for some time very awful to look at and distressing to ponder upon. Such an earthquake with such dire results is not within the recollection of the oldest man living. There was an earthquake in this district in 1292 B.S.,[1] some old buildings fell down and some were cracked, but there was no change on the surface of the ground. There was also another earthquake in this district so far back as 1254 B. S.[2] Its effect was chiefly felt in the village named Poyari, where there were several fissures of small dimensions.

"13. According to Hindu sastras, such unnatural visitations will frequently

[1] A. D. 1885. [2] A. D. 1846.

appear in this latter end of the Kaliyuga or Iron age. What have already appeared are mere preludes. The real ones are yet in store.

"14. The earthquake is commonly calculated by the Hindus according to a formula quoted below :—

> "If you get famine, drought and plague in one and the same year, you get the earthquake that year.

This calculation has indeed been verified.

"15. Apart from the physical causes which make the geological changes in the earth, the Hindus believe in a supernatural agency, which excites the physical causes that make the change. That supernatural agency is, again, put to action by the vice or virtue of mankind. Changes causing woe and calamity are the result of the former, while those causing happiness are the result of the latter. This is what the venerable Garga says about the causes which produce unnatural changes in the earth, the middle and the upper sky :—

> "Unnatural visitations of nature are caused by too much covetousness, untruthfulness in conduct and action, atheism, impiety and impurity in thought and action. Where there is constant repetition of the above, the gods turn their back to mankind and cause unnatural changes in the earth, in the middle sky, or the region of clouds and lightning, and in the upper sky, or the region of the sun or the solar system, for their destruction.

"We Hindus fully believe in this that the sin of mankind has been causing all these woeful changes, and that unless there is an advance made towards beatitude there will be no end of these.

"16. As remedial measures for the mischief done by the earthquake, I beg to suggest that the local bodies, *viz.*, the District Boards and the Municipalities, may be directed to co-operate with the people in opening up the rivulets or canals which have been silted up, in re-digging the tanks that have been dried up and filled in with sands, in removing the deposits of sands from the corn-fields, in filling up the gaps and hollows which have been made in them, and in repairing the roads which have been rendered impassable. It will be a matter of consideration for the District and Local Boards whether the new canals opened up by the earthquake should be closed or continued to any natural stream which may be close by. I should prefer the latter course, as they will, if continued, water a large tract of the country and supply drinking water to men and cattle. As to the measures to be adopted to guard against the recurrence of such unnatural changes in future, I should only repeat what I have said in some of my previous reports to Government, *viz.*, firstly, that Government should see that every man in every community should follow the dictum of the religion which has been accepted by that community and act accordingly.

"17. I am humbly of opinion that the present system of religious toleration is not suited to India. Any man in any community should not be allowed to violate with impunity the ordinances of the religion which has been accepted by that community. If any man wishes to renounce his old faith and to embrace a new one, he may do so. But then he must act according to the rules of the religion which he has newly embraced. It would, I think, be an abuse of toleration if any man in any community were allowed to exercise his free will in acting or not according to the religious tenets of the community to which he belongs. This state of things brings on anomally in society and impurity in action.

"18. And secondly, *Jagna* should be made according to the rule of the Vedas. And in order to enable one to celebrate the *Jagna* it is necessary that the State should make some assignment in land to the learned and pious Brahmans in selected localities, who will perform the *Jagna* as often as the assets of the land so assigned will allow them to do. As Hindus, we firmly believe that the calamities which have been threatening India will be completely warded off by this means.

"19. I earnestly solicit that our good and kind Government will be pleased to give such consideration to my suggestions as it may think proper."

The town of Kuch Bihar was within the area where the earthquake reached its greatest destructive power and probably not far removed from the region of the seismic vertical. From this place we have the account, written by Mr. D. R. Lyall, C.S.I., Superintendent of the State, to the Chief Secretary to the Government of Bengal, on 28th June 1897:—

"3. In a matter like this, personal experience is generally more valuable than generalities, so I record my personal experience of the earthquake itself. I had gone to the Palace and had looked on at the crowd and seen that all was going on smoothly and then left at about a quarter to five, going out by the northern gate, the main or eastern gate being closed for that day for carriages. I drove round by the outside of the Palace and turned eastward in front of the main entrance to go to my house, when, after going about 200 yards, I became aware of a great noise in the corrugated iron sheds at the side of the road and almost at the same time saw a large two-storied house about 50 yards ahead of me subside and crumble away. I pulled up and now became for the first time aware of the shaking of the earth. I had not felt it while driving, and I see from the papers others have had the same experience. As I pulled up a large fissure opened in the road just in front of my horse, a second under my buggy and a third close behind me, and others were visible at further distances. The road between where I was and the Palace main gate had been nearly clear of people but at once the crowd poured out, shouting that the Palace was falling, and I accordingly turned back and found the Palace more or less in ruins, but the Maharajah and his family and household were all safe with one exception. This man was struck badly by the falling bricks and was taken to the Military Hospital where he died. Several more sepoys and servants were slightly injured, but there was only this one fatal case in the Palace. Up to this time I had heard no sound of the earthquake, but as I took leave of the Maharajah to go and see how my own house and family had fared, there was a rumbling noise from the earth, and sand and water rose up from many of the fissures. In one place I saw it certainly rising two feet.

This was after the shocks had ceased, but in other places notably all round my house, the sand and water appear to have come out with the first shock. It certainly did not do so in the Palace compound. I then drove to my house, nearly two miles off and found the road full of fissures and cracks and every pucka house I passed more or less injured. The worst collapse was the "Chottakuti," the fall of which I have already described. This house being on the line of road taken by the "Tazzias," a number of people were in it looking at the *tamasha*, and five persons were killed by its fall. The whole loss of life was eight persons, one patient in the hospital being killed by the fall of the roof and the firewatchman on the Jubilee tower having fallen with it. This man lived for two days in spite of the height from which he fell. These two with the five in the "Chottakuti," and the one in the Palace, were the only fatal cases, and wonderfully few persons were injured. This is due to the offices all being closed and to the population being to so large an extent out in the open air. I arrived at my own house to find it absolutely in ruins and all round it water and sand which had been vomited from the ground. The fissures here were much larger than near the Palace."

Outside the area of the seismic vertical the accounts of the earthquake all agree in representing the motion as largely an undulatory one, and in many cases the presence of visible earth-waves is recorded. Beginning with the Assam Valley I may quote the account of Mr. A. E. Shuttleworth, District Superintendent of Police, who was in camp in the Mangaldai Subdivision at the time. He writes, under date 16th August, in an official report to the Deputy Commissioner of Darrang as follows:—

"On the 12th June 1897 my wife and I were sitting on the verandah of the Chatgari resthouse waiting for a slight shower of rain to stop. At 5-13 P.M. we were suddenly startled by a very vivid flash of lightning followed by a tremendous crack of thunder. At the same time the bungalow began to tremble slightly. This I at first put down to the thunder, but as the trembling motion began to increase I cried out that it was an earthquake. The motion began getting more and more violent, and as the timbers all began to crack and the verandah floor to split under our feet I hurried my wife outside into the rain, which was coming down in torrents. It was as much as I could do to hold my wife up. We then saw the earth all round heaving in a most frightful manner. The earth resembled waves coming from opposite directions and meeting in a great heap and then falling back; each time the waves seemed to fall back the ground opened slightly, and each time they met, water and sand were thrown up to a height of about 18 inches or so. This shock lasted for about three minutes I should think. There was no rumble with it. The shock was strong enough to knock over a couple of elephants I had in camp with me. My horse too in the stable was knocked off his legs and my dogs could not stand up in the verandah of the bungalow. On re-entering the bungalow we found the verandah floor was one mass of cracks, the roof began to leak badly all over, and the whole bungalow had settled down, so that we could not shut any of the doors that were opened nor open the doors that were shut."

Captain P. R. T. Gurdon, Deputy Commissioner of Kamrup, who was in camp at Nalbari—a place which may have been within the area of the seismic vertical, and was certainly close to it,—reports that earth-waves were distinctly visible from the rest house compound, which is situated close to a large *pathar* or series of rice-fields. The waves could be seen following one another at intervals, the *ahu* rice falling and rising as the waves progressed. On subsequent enquiry Captain Gurdon stated that he could not recollect the length of these waves, but that their rate of travel, though decidedly faster than a man could walk, was not so fast as he could run. We may take it that the rate must have been between two and four feet per second.

From Kohima, in the Angami Naga Hills, an account by a correspondent to the *Englishman* Newspaper, may be reprinted:—

"Notwithstanding a delay which was inevitable, an account of the earthquake in this part of Upper Assam may prove not uninteresting. First, as to Kohima, which is a little known Civil and Military station 4,080 feet above sea-level, standing in the midst of the wild Naga range on the Eastern Frontier of Upper Assam, distant 92 miles north from Manipur and 123 miles south from Nigriting (or Shikarighat) steamer ghat, on the Brahmaputra. It is in the same latitude with, and some 200 miles east of, Shillong.

"On the 12th instant at about 5-20 P.M., local time, we felt the first shock of the earthquake, whose violence made us somehow feel anxious in particular for Shillong and Calcutta, where we knew the numerous masonry buildings would have but little chance if the earth-waves were even half as severe as we had experienced. I was sitting in my garden, facing east, just outside my bungalow examining a flower-bed, when I suddenly began to feel dizzy from an apparent, at first gentle, fore and aft movement. Not having been well, I naturally conceived I was going off into a faint and instinctively pressed my forehead and eyes with my hands; but the peculiarity of the motion and vibration of the ground, both of which became more violent, immediately acquainted me with the fact that it must be an earthquake, and this was at once confirmed by hearing the creaking of the wood and iron work of my bungalow behind and observing the consternation and alarm of my sister who then rushed out of the verandah, and of all the servants who also very speedily vacated the house. On rising and looking around I discovered the whole house bodily rocking—I should say at least six inches each way from the perpendicular at the highest point (25 feet)—distinctly east and west (not to be too particular), the exact situation width-wise of the house being south-east and north-west, and my sister staggering about trying to maintain her equilibrium, almost believing that the world was coming to an end; while the cook in horrified alarm rushed forth from his kitchen repeating aloud the Kulma and calling out that there was something wrong with the bungalow roof. I doubt if he felt re-assured when I told him it was not the roof but the world that was shaking. The other servants could not keep their feet but fell flat to the ground, while our puppy kept running about, watching the house and barking furiously.

"I suddenly recollected that certain valuable ornaments on the drawing-room mantelpiece would be inevitably destroyed, and tried to make a rush to save them but was taken aback to discover I could not at first move, and staggered violently east and west as if on board a boat in a heavy swell. Eventually as the height of the wave diminished I forced my way into the house, dodging the orchids hanging in the verandah which were plunging violently to and fro (east and west) in a most extraordinary manner about two feet from the perpendicular each way. Fortunately not a single ornament had as yet suffered, and I had time to remove them all to the ground. The two mantelpieces of the house faced back to back, north-west and south-east, that is, in the direction opposite to the wave, as did most of the shelves and brackets, and consequently, with the exception of one small vase laid prostrate, not a single article was thrown down during the whole period of the wave. I afterwards discovered slight cracks extending upwards in both chimneys, and the clock on one of them, whose pendulums swung north-east and south-west, stopped short at 5-20 P.M., local time. There were no rumblings or explosion sounds. The appreciable part of the quake lasted some five minutes as ascertained afterwards from the Telegraph Master, who, working before his clock, had at once noted the hour, *viz.*, from 5-24 to 5-29 P.M., local time, or 16-24 to 16-30 (*i.e.*, 4-24 to 4-30 P.M.) Madras time, which is 57 minutes behind Kohima time.

"After the shock had passed we had time to re-enter the verandah (which I had again vacated) and sit down and pass some remarks about the visitation, when, some four or five minutes later I guess, we heard several loud explosions like guns in the direction of the fort three-quarter of a mile north-west which I remarked must be either the mountain battery practising or bombs going off in honour of the Mohurrum."

Southwards of Kohima, Major H. O'Donnell, D.S.O., writes from Kunjukphul in Manipur:—[1]

"The earthquake gave no warning of its coming. It began suddenly and severely, and lasted I should say some four minutes. At first the motion was an up and down one, and one I had never before experienced. This by degrees gave way to the ordinary side to side kind of motion, which was at first a long and slow motion, gradually becoming shorter and quicker till it suddenly ceased. The hill immediately behind I could distinctly see moving, and appeared to move, turn and turn about with the knoll we were on. At the first shock we ran all outside, and for most of the time it lasted it was difficult to stand. I saw the others in motion as you see a person on deck in rough weather."

From Manipur itself Captain H. W. G. Cole, Political Agent, writes:—[1]

[1] Assam Government Official Report, Appendix XI.

"The first tremor was brought to my notice by a servant, but after he had pointed it out it was some seconds before I noticed any motion. The motion then became rapidly more severe, and I went out on the lawn. By the time that I reached it the motion was sufficiently severe to render standing very difficult, if not impossible. The ground seemed to undulate from south to north. I momentarily expected the cracking of the straining timbers to be followed by a crash of their breaking, but just as severe damage seemed inevitable the undulating motions decreased in severity, and were succeeded by what seemed to me a tilting motion from north to south."

Turning now to the south, the earthquake was observed at Silchar by Revd. O. O. Williams, D.D., who had just arrived from Karimganj, and was at the time in the mission bungalow. He writes :—

"The first thing I noticed was a wave-like motion passing under my feet, something like the swing of a suspension bridge. Two or three waves of this kind were felt, there was a perceptible interval between the crest of one wave and that of the next, and I just felt the rising and falling of the ground, an earthquake being far away from my thoughts. Direction from north to south. The second thing I noticed was that the canvas ceiling was thrown into undulations, the waves travelling from north to south, the house being situated exactly facing the four points of the compass. The progress of the waves from one end of the room to the other could be followed by the eye, and my impression is that the length of the ceiling was thrown into about five or six waves.

"Although more than surprised at this phenomenon my thoughts were with the rats, which I believed were then running about distractedly on the moving ceiling. I confess I was wondering how the rats could cause such waves, and was coming to the conclusion that some much bigger animal was required, when, in the third place, the walls claimed my attention. A peculiar shaking and sound of knocking began, when the shaking and knocking suddenly increased in violence and I saw the north end of the room, where I had located the knocking sound, give one great bulge, the convexity being to the south. 'Earthquake' now flashed into my mind * *, I backed promptly into the verandah and got * * a few yards from the house when the wave motion made it very difficult to stand. My impression at this moment was very far from the simple one at the beginning. It was the feeling of a boat tossed in a choppy sea, *i.e.*, a crossing of great waves. These waves were certainly not from north to south, it is quite possible that the most pronounced were from the north-west."

Dr. Williams describes his movements and impressions during the earthquake and continues :—

"I have mentioned the above details that you may form a conception how long it lasted. It seemed five or six minutes; but half an hour or so after the shock when the place was cleared out a little and we were able to sit down and talk over things, I took out my watch, went over my observations and thoughts leisurely, allowing sufficient time for everything, and had finished the recital in 2½ minutes. I do not believe that from beginning to end the earthquake could have exceeded three minutes by any possibility.

"I have only to add that during the great earthquake I had only the sensation of undulating, not of shock."

No noise was heard by Dr. Williams himself, but others in Silchar noticed a sound, like that of a traction engine, just before the shock, and one person, who was seated in a chair at the time, noticed the birds rising suddenly from the trees before he himself felt anything. This was probably due to their greater sensibility to the small preliminary tremors not felt by human beings.

In the accounts from Chittagong, besides clear evidence of an undulatory movement of the ground, we find a feature repeated in the accounts from many other places. The shock was divided into two distinct phases, and the direction of the movement was different in the two. Mr. J. W. Thurlow, Sub-Assistant Superintendent of Telegraphs, writes:—

"When the first shock was felt I was seated facing east, and suspected the shock came from my left. On hurrying out I faced the north and felt a tendency to fall forward. The motion was slight but very regular from north to south for one-and-a-half minutes, when suddenly a peculiar quiver was felt which made me think the direction had changed. Acting on this supposition I faced the west, when I found I could scarcely keep my equilibrium, having a tendency to fall forward. The shocks now came from west to east, and were far greater in intensity than those from north to south. They were regular, but few were more severe again. The severity of the shocks did not end gradually but abruptly."

In Calcutta, much the same was noticed in several accounts, from among which I may select the following, communicated to the daily papers by the Revd. Father Lafont, S.J.:—

"The first intimation that I got of the earthquake was a kind of twisting sensation and a rumbling noise. A few seconds soon convinced me that it was an earthquake, and I ran out on the terrace overlooking the portico of our College: time about 5 P.M. Everything around was in motion, but my attention was chiefly attracted to the energetic oscillations of a heavy stone cross, capping the front of the College. It was clearly moving, and the whole portico as well, almost due north and south; a little statue in my room, placed on a bracket attached on the north wall, fell and rested slanting against the wall. These two facts point evidently to a first and strong oscillation north and south coming apparently from the south.

"Finding the terrace on which we stood unsafe I went down a spiral staircase, and had to prop myself in doing so for fear of losing my balance. Once downstairs in the open I looked again at the cross, but it was then still, the oscillation had been twisted to the east: I found in my laboratory afterwards two clear indications of that twist in two or three heavy objects which had pivoted from south to east. In my opinion the strongest and most lasting vibration was that from east to west, as evidenced by a tall book-case placed against the east wall in my room, being found to have fallen direct towards the west, when I returned to my room. Besides, all the cracks in the College buildings, in St. Thomas' Church, and the Loretto Convent show unmistakable signs of being the result of an east-westerly vibration.

"I have a conclusive proof that the last vibration was in that direction, in a maxim barometer suspended on gimbals, found to be oscillating due east and west, as was also a heavy pendulum in one of my glass cases. Several heavy objects had also been thrown down in the same direction. The time this unexampled earthquake lasted is variously estimated from 4 to 6 or over 7 minutes. It may be interesting to know that a slight but distinct shock was felt yesterday night at about 9-30 and another one at about 8-30 A.M. this morning. The barometric curve of yesterday is almost a straight line, showing an almost stationary state of the atmosphere."

M. Paul de Bure, Assistant Agent of the Messageries Maritimes, writes that he was wakened by a succession of very rapid vibrations which were vertical as it seemed to him; then came some slight oscillations from north to south, and it was only then that a noise as of a heavily laden cart was heard. These oscillations increased till pieces of plaster and masonry began falling down, and he went outside the house. From here he saw that the house was oscillating in a south-east to north-west direction, and the oscillations were unequal as it always seemed as if the house would fall to the west rather than to the east. A lightning conductor rod was set in motion and swung some 20° on either side of the perpendicular, in a direction parallel to Park Street.

From an account of the earthquake received from Dr. Pyari Lal Mukhopadhyaya, I extract the following passage, which, it will be seen, agrees with the Revd. Father Lafont's account in discriminating two distinct phases of the shock:—

"The first shocks or vibratory motions were indiscriminate or all sided. No particular direction could be marked. They were rapid, say some seven or eight per second. Then followed the undulatory motions as the rolling of a mighty ship. They were regular, keeping even time like the movement of a pendulum, telling the second as exactly. The motions first were from north to south as we ordinarily call it; but the exact direction was from north-east to south-west of the compass. I could make it out by a hanging lantern and a cage of a canary bird. Both of them began to swing from north-east to south-west. The rope to which the lantern was hung measures 8 feet 5 inches. When the shocks were severe it swung about 3½ feet on either side, that is described an arc of about 7 feet. As these shocks seemed about to subside, some rude and fearful jerks were felt, the lantern and the cage moving from north-west to south-east, so the direction of those jerks must have been from due west to east, or the lantern and the cage could not have moved in the direction (north-west to south-east) that they did."

As an instance of how difficult it is to tell the direction of movement of the wave particle from mere sensations or the movements impressed on objects of such composite character as houses, I may quote from Mr. Hayden's note:—

"The cracks may be divided into two sets, those running north and south and those running east and west; the former would be due to the fact that the structures vibrated east and west, and the latter to vibrations at right angles to that direction; and during the earthquake, the existence of these vibrations was clearly seen. A good example is found in No. 13 Theatre Road, which house I was carefully watching throughout almost the whole duration of the earthquake. When I reached the compound, a few seconds after the first tremor, I found that the house was violently vibrating east-west, and soon a crack opened through the house from north to south, and the western third of the house could be seen vibrating outwards the large crack opening as much as 4 inches and then closing again. This was observed from the southern side of the house. Suddenly, however, the motion appeared to change, the crack in the south wall ceased to open, and on passing round to the western end of the house, the building appeared now to be swinging north to south, and vertical cracks began to open over windows and along lines of weakness in the west wall, but they did not gape to nearly the same extent as the large crack in the south wall."

It will be seen that this account places the relative order of the north-south and the east-west vibrations exactly the reverse of the other accounts. The fact is that buildings constructed like those of Calcutta can only swing in two directions, and the local variations in the nature of the earthquake motion, which are now sufficiently well established, combined with small variations in the orientation of different houses, would be sufficient to account for either of these taking precedence of the other in different localities.

The nature of the motion at Calcutta appears to have been exclusively undulatory with a period of between one and two seconds. Though destructive to buildings and distinctly felt by persons walking or standing on the ground, it was quite unnoticed by those who were driving at the time, their first intimation of anything unusual being the sight of cracking buildings and of people rushing from their houses, unmindful of their attire in their anxiety to reach a place of safety. The undulation of the ground, though apparently unnoticed by horses in motion, was very distinctly noticed by bicyclists, who were unable to preserve their balance and found themselves compelled to dismount from their machines.

At Saugor Island, the experience was similar to that at Calcutta. According to Mr. R. Gilbert, Telegraph Master, an unusual disturbance of the sea preceded the first vibration, the direction of which was from south-south-west to north-north-east, for about 1 minute and 30 seconds; this was followed by a stillness for about 5 seconds, after which a reaction set in from south-east to north-west, lasting with extreme severity for 4 minutes, and diminishing in force gradually till it stopped 55 seconds later.

The swaying of the lighthouse from zenith to north-west was noticed to be greater than in the opposite direction.

From the neighbourhood of Panchkura, in the Midnapur District, I have received an important account by Mr. S. M. I. Williams Assistant Engineer on the Midnapur-Calcutta Railway, which is interesting as giving some idea of the extent of the undulation of the ground, and of the way in which these surface waves had lengthened out from the comparatively short and conspicuous waves of the region within and near the seismic vertical :—

"I was taking levels on the railway bank about a mile south of the village of Panchkura, and was about to take a reading when I noticed the bubble oscillating, and I at first thought some one had touched the legs. In 5 or 10 seconds I could feel the bank shaking to and fro in a direction which gave me the impression of being from south-south-east to north-north-west. Unfortunately I had no watch with me. I tried to get the exact direction of the waves by turning the level round on its axis, but the legs were not in the right position. Stacks of bricks near me, about 3 feet high, were shaking, but did not fall. The shock appeared to last 3 or 4 minutes, but, for at least 5 minutes after all shaking had apparently ceased, my level indicated that the vibrations were still continuing, and at this point I put away the level. Towards the close of the worst part of the shock, I turned the telescope to the staff being held about 150 feet due east of it, and although the bubble was oscillating most erratically, the level and the staff were perfectly motionless relatively to each other. When I got back, it was 4-44 P.M. by Madras time, and I estimated it was about 15 or 20 minutes after the earthquake. I also set up the level to test roughly at what angle it had been tilted, and found that the maximum angle during the great shock was 0° 48′ and during the lesser oscillation afterwards 0° 1′; the former angle is probably inaccurate."

From Midnapur, Mr. Davies, Telegraph Master, reports that the shock commenced with a rumbling, and the cot on which he was lying rattled to the speed of it, an up and down roll such as could be made with a signalling key, equalling a ten or twelve word per minute pace. This roll lasted about 2 minutes, and as it passed eastwards the doors rattled to the *kick* of it and the motion changed to an undulating south-north one. He tried to rush from the house but had to hold on to a pillar and felt distinctly sea-sickish; the ground was distinctly billowy, and it seemed that "these were waves of motion going forward north but receding south on the forward movement, such as a water wave at the time of tide does." The total duration was 4½ minutes.

From Balasor the Telegraph Master reports that at the first signs of the shock, after noting the time, he went to the battery cells and found the liquid in them undulating from east to west; this motion lasted for about 90 seconds, when the movement changed o north to south for about the same time.

At the same place, Conductor J. W. Turner reports that he timed the earthquake as lasting four minutes. The motion was a long rolling one, such as would be felt if on the deck of a ship in a fairly heavy sea. The circuit bungalow was cracked, and a piece of the parapet which runs east and west, was observed to swing southwards along a crack to the extent of about 9 inches. The southerly movement is said to have taken 9 or 10 seconds, and the closing again more rapidly, perhaps 5 or 6 seconds. This was repeated some seven or eight times.

This slow opening and closing of the crack corresponds with the information I have received elsewhere, but it must not be regarded as the period of the earthquake wave; it more probably represents the natural period of swing of the moving portion of the building.

These two last-mentioned places, it will be seen, experienced an undulation whose direction was about east-west in the first place and subsequently in a north-south direction, whereas at Calcutta and Saugor Island the reverse is said to have been the case.

Passing southwards down the coast, the undulatory nature of the movement was noticed everywhere. Almost every account notices the gentle nature of the movement, which was generally likened to the easy movement of a ship in a gentle sea, and this movement everywhere produced a sensation of nausea in all who are liable to that affliction in the circumstances to which the earthquake motion was likened.

At Bezwada, Mr. C. Napier, who describes the earthquake as giving rise to a smooth, slight rocking sensation, with slight giddiness and the faintest sensation of nausea, noticed that certain files of papers hanging from the edge of a table oscillated slowly from north to south for about two minutes. The rate of oscillation is said to have been slow, the period being about once in two seconds, certainly not so quick as once a second.

Returning to the north, we find the same undulatory movement recorded throughout the Gangetic alluvial plain and the northern part of the peninsular rock area. From Giridih, Dr. J. A. Dyer writes :

"On turning to look at the house I found extraordinary movements taking place in the verandah roof supported by pillars, which movements I could not detect at the east and west ends, where there are rooms with outside walls. They (movements) appeared to be of a wavy kind, from north to south or south to north and moved a few tiles from out their places up near the top of the rows and shot them downwards, by what looked like small repeated shoves, to the distance of 5 tiles length in two cases, and 6 tiles in one case.

"I could see most distinctly the heaving motion, and compared it in my mind to what might have been produced by an elephant under such a roof, if he had rubbed his back against it from north to south. I ought to state that my bungalow stands east and west, and has a pucca roof over four centre rooms running east and west and a sloping thatched roof with country tiles over the thatch, all round the four sides, which tiled roof is supported partly on side dressing and bathroom walls, and front and back on strong double pillars, with beams on them, to support the rafters. It was only over the pillars and beams that the movements could be detected by me. I carefully looked to the parts supported by the walls of the rooms on the north side (I was on that side only during the earthqake), but was unable to observe movements there. We stood so long in the sunshine, that I dreaded a sunstroke, and ran for shelter and shade to a small house from which I observed the continued movements, and I also observed the roof of a godown, near at hand, vibrating *upwards* and *downwards* only."

At Lucknow, the earthquake is said to have commenced with a series of rapid waves like a choppy sea, which gave way to longer ones resembling a heavy swell. The former are said to have lasted two minutes, the longer waves for one minute. The tall column of the Martinière swayed backwards and forwards on either side quite three feet.

From Allahabad, I am indebted to Mr. R. Warneford for some interesting particulars. The earthquake here was of sufficient violence to displace crockery, etc., standing on tables and caused some cracks to form in one or two buildings, apparently old and not of sound construction. At Mr. Warneford's house he noticed that hanging lamps and saddles suspended from the ceiling were set oscillating in an east-south-east to west-north-west direction ; water in tubs was oscillating backwards and forwards in the same direction, rising about 1 inch on each side of the tub, about 2 feet 6 inches in diameter. Quarter of a mile away Mr. Aslett, also an Engineer in the employ of the East India Railway Company, noticed a series of easily distinguishable waves crossing his compound from south south-west to north north-east. The crests were about 30 to 50 feet apart.

Further west, the reports from more than one place mention that no shock was felt, but that an agitation of the water in wells and tanks was observed.

From Sehor in Bhopal, I have an account by Mr. H. de St. Dalmas, of the Friends Mission, who writes :—

"We were not conscious of the shock by any personal sensation, and the only thing observable was the violent shaking of a door in the north wall of the bungalow at the north-east corner, noticed by myself, and a similar vibration of a heavy almirah in the adjoining room, noticed by my wife. We simultaneously called to one another to notice the phenomenon, which we could attribute to nothing else but an earthquake. The vibration continued probably for about two minutes. I may remark that the door, which was closed, and the almirah were both in the same line and in the north-east part of the house, the door facing north."

Further west, the shock was felt by the Thakur of Piploda (12 miles west of Jaora Railway Station) in the upper story of his house. He was sitting at the time, and his body oscillated from side to side, while chandeliers hanging from the ceiling swung in the same direction.

At Khandwa, the shock does not seem to have been actually felt by any one, but a hanging lamp was observed to oscillate.

Something similar appears to have been noticed in Bangalore by the Dewan of Mysore, who has communicated his account through Dr. J. Evans; from this it appears that at the time the Dewan was engaged in a private interview on matters of State, and that he noticed the door moving backwards and forwards as far as the latch would permit, just as if some person were at the door. He went to the door and opened it, but found no one near. The exact time was unfortunately not noticed, but it was about that of the earthquake, and it is reasonable to attribute the unusual and otherwise unaccountable movement of the door to this.

At Bombay, also well outside the area within which the earthquake could be felt, Mr. Moos, Director of the Government Observatory, Bombay, was fortunately engaged on the diurnal readings of the magnetic instruments, and observed the declination needle to swing slowly to and fro. No special estimate was made at the time of the extent or rate, but Mr. Moos considers that the lateral movement cannot have been far from $\frac{1}{10}$ of an inch. As the length of the suspension is about 12 inches, this gives an angular oscillation of about 30′ of arc, an estimate which is doubtless a maximum value.

On the north we have the account of Colonel Wylie, C.S.I., Resident in Nepal, who writes:—

"The shock was felt distinctly at Katmandu at about 4·35 P.M. It lasted some five minutes, and was of a double nature, *i.e.*, the first portion of the shock was apparently from north to south. There was then a pause of a few seconds, and the next motion seemed to be from east to west. It was sufficiently violent to cause a feeling of nausea and faintness, making men sit down on the ground, and to induce nearly every one to quit their houses. In the Residency grounds are many tall pine trees, and these oscillated violently as if they were reeds; I have never seen anything of the kind before. At the same time, I could distinctly hear the roar of terror rising from the city, which is about a mile off."

The Nepalese Representative at Lhassa reported to his durbar that a severe shock of earthquake was felt there at 5-25 P.M. on the 12th June, that it came from the south and lasted about 8 minutes. In this report no mention is made of any damage to buildings, but Mr. H. G. Hobson, Commissioner of Customs at Yatung, specially mentions that no damage was done at Lhassa.

Yatung itself seems to have felt the shock pretty severely, as may be judged from Mr. Hobson's report.

"Little damage was done at Yatung, where the few houses are of wood, with end walls of rough stone cemented together with mud. Two of these end walls fell outward, *i.e.*, to the N. and E., others were cracked.

"Indoors, articles such as bottles, lamps, etc., standing on shelves, fell over to the N.-E. A pendulum clock, on a bracket facing about N.-N.-E. and S.-S.-W. did not stop.

"A flag pole was noticed to oscillate violently in an almost N.-E. to S.-W. direction.

"There were minor shocks during the night of the 12th and on several days following, but they caused no damage.

"Damage sustained in the neighbourhood:—

"1. At Langrang, situated halfway between this and the top of the Jalep pass, the Dak bungalow, a stone structure with roof of wood shingles, collapsed entirely, most of the débris falling to the eastward.

"2. Below Yatung, the barrier wall built of stone and roofed over the parapet with wood shingles, was thrown down in part and otherwise shattered, the eastern end coming to most grief.

"3. Over a mile below, the Ka Govi monastery, situated on a spur overlooking the vale of the Mo Chhu, was wrecked. The main buildings fell, the high compound walls, of concrete were cracked from top to bottom, whilst those at the back fell to the N. and E.

"A small fort just below had its parapets thrown down, the wreckage falling both inwards and outwards, say to the N.-E. and S.-W.

"4. In the Chumbi valley all official residences, barracks and private dwellings were badly damaged. Compound and other walls fell mostly to the E. and S.-E. From Ki Bim Ka to Gopa Jong in the upper Tomo district, some 70 houses were destroyed, a child being killed and four adults seriously injured by falling walls.

"From To Mi to Do Chaka in the lower Tomo region, two houses were wrecked and others badly cracked.

"The earthquake would appear to have pretty well expended itself in this direction at the base of the high range of mountains to the north and east, at the foot of which the Mo Chhu runs eastward towards Bhutan."

"Little damage is reported from Phuri to the N. of this, and none from Shigatze or Lhasa. In recent letters from the latter places it is mentioned that an earthquake had been felt, but no alarm had been caused thereby."

In Burma the motion was of the same character, *i. e.*, in the main undulatory. The accounts are proportionately less numerous and less full than from Upper India, but two may be selected for quotation. The first of these is that of Mr. A. E. English, Assistant Commissioner, who was at the time in camp on the banks of the Theingale, some 7 miles south-west of Kyauko village and about 19 miles east of Tagaung. Between 5 and 6 P.M., he

"Noticed the water in the tank, which was an old river course, containing about 300 yards of shallow water, lapping up against the bank below my tent. My hunters said it must be elephants bathing, but on looking there were none at the other end. Some one then pointed to the trees shaking, and we knew it must be an earthquake, * * *. The shocks were not felt, and, except for the lapping of the water, would not have been noticed."

A somewhat similar account was received from Thayetmyo, where Mr. E. Gabbett, Executive Engineer, writes that—

"I, Lieutenant Marsden, XIII Madras Infantry, and Lieutenant Sharpe, 1st East Lancashire Regiment, were fishing in a small tank, 40 yards square (very approximately), on that evening. About 5-30 o'clock (this is only a guess, as no one looked at their watches) the water in the tank started going backwards and forwards just as if the water in a basin had been tilted backwards and forwards; the maximum rise of the water on the east end of the tank was 18 inches. This movement lasted about 3 minutes. The movement appeared to be from west to east as near as we could judge. People standing on the bank could feel nothing. No cracks, that I am aware of, occurred in any buildings or bridges."

Some other accounts from Burma make specific mention of the same undulatory motion. Mr. C. F. Gilbert, Executive Engineer, Bhamo, in the course of his account of the earthquake as felt at Nahakaung, the junction of the Katha branch of the Mu Valley line, writes:—"I have experienced considerably more severe earthquakes in the Himalayas, but the sensation of sea-sickness which accompanied this one, and which seems to have been noticed by everyone almost, is quite a new feature." At Bhamo Mr. P. D. C. Pereira, Inspector of Police, reports that the shock was not the usual short jerks, but resembled more a gently rocking motion. It caused a sensation of nausea in several people.

These two accounts are valuable as being comparative and showing the difference between the nature of the disturbance produced by a very severe earthquake at a distance from its centre, and the possibly more severe, disturbance of a slighter earthquake at a short distance from its centre.

Such are the accounts of the nature of the shock. Besides those printed, many more have been received, but they do not add anything of importance. From them it may be gathered that there was everywhere a marked undulatory movement of the surface of the ground, the waves being shorter in the central area and lengthening out as they progressed. In the central area, and wherever they were small enough to be seen as wave-like undulations of the surface, it is certain that they can have only been locally produced waves, the result of the earthquake, but not spreading far, or travelling at anything like the speed of the real earthquake wave, this being of too great a length and travelling too rapidly to be seen. At greater distances, where the shock was only slightly felt or not felt at all, and only rendered itself noticeable by disturbances of level of pools of water, it is probable that what passed was a real wave of translation, and was in fact the earthquake wave.

In the central area the horizontal to and fro movement was large, and abrupt and very sensible, but as the wave travelled, this became a simple undulatory movement, very different, according to the accounts, from the more common short and quick to and fro movement experienced in the case of less severe earthquakes which do not spread far from their origin.

Though somewhat apart from the scope of this chapter, the effect of the earthquake on the mud volcanoes of Kyauk Pyu may be noticed. It is contained in a letter from the Deputy Commissioner, Kyauk Pyu, to the Commissioner of Arakan, No. $\frac{286}{1-97}$, dated Kyauk Pyu, the 25th August 1897 :

"The mud volcano in this island is well known to all people, and is occasionally active.

"On this occasion loud reports were heard coming from this volcano followed by a flow of mud, which continued for an hour and a half.

"About 11 o'clock that night loud reports were again heard, and a new volcano opened out 2,500 feet to the south of the old volcano. There was a very large flow of mud from this new crater, so large in fact that it spread out over the land near, destroying acre 1·05 of paddy land belonging to a cultivator named Na-Ban-San. The flow continued until about midday on the 13th June. The reports made by the opening of the new crater were followed by a very brilliant meteor which appeared to travel from the south to the north.

"On the 23rd June about 7 P.M., a slight shock of earthquake was felt and another meteor was seen, and three sounds as of the distant booming of a gun were heard."

"This is ascertained by Maung Po from personal enquiry. The latter part is vouched for by him as he himself saw and heard all."

The only other reports which mention any effect on hot springs are those of the Collectors of Chittagong and Patna. The former reported that the burning springs of Sitakund were unusually lively after the earthquake, while the latter reported that the hot springs at Rajgir (Rajagriha) were said to have discharged discoloured water for three days.

CHAPTER III.—THE ISOSEISMIC LINES AND AREA OVER WHICH THE SHOCK WAS FELT.

The determination of the isoseismic lines, that is to say, lines of equal violence of shock, is the necessary preliminary to determining the varying rate of diminution of seismic energy in different directions. Strictly speaking there should be little difficulty in determining these lines, as the violence of the shock may be regarded as a function of the amplitude and period of the wave, or more simply, of the maximum rate of acceleration of the wave particle. All these elements are capable of determination from the records of a complete seismograph, and, in the absence of these instruments, a tolerably complete substitute may be found, at any rate when an earthquake is severe, in the overturning of simple objects, such as pillars, in countries where they are sufficiently numerous.

In the present case, however, objects suitable for giving seismometric results of any degree of accuracy are rare, and, owing to the extent of the country over which the earthquake was more or less destructive, they have not all been examined by competent observers. It has consequently been necessary to fall back on the general accounts of the earthquake and its effects, and to draw the isoseismic lines on the basis of the effects of the earthquake on masonry buildings and on human sensations.

In the account of the Charleston Earthquake, Captain Dutton made use of the Rossi-Forel scale of intensities and drew isoseismic lines, or isoseists, representing ten different degrees of intensity. In a closely populated and civilised country, where most of the buildings are of brick or stone, this was possible, but the area over which this earthquake was felt is largely a wild, thinly populated country, and even in the thickly populated parts brick and stone buildings are rare and widely scattered. As a result it has been found impossible to attempt to define more than seven degrees of intensity lying within their isoseists, which may be defined as follows :—

1. The first isoseist includes all places where the destruction of brick and stone buildings was practically universal.

2. The second, those places where damage to masonry or brick buildings was universal, often serious, amounting in some cases to destruction.

3. The third, those places where the earthquake was violent enough to damage all or nearly all brick buildings.

4. The fourth, those places where the earthquake was universally felt, severe enough to disturb furniture and loose objects, but not severe enough to cause damage, except in a few instances, to brick buildings.

5. The fifth, those places where the earthquake was smart enough to be generally noticed, but not severe enough to cause any damage.

6. The sixth, all those places where the earthquake was only noticed by a small proportion of people who happened to be sensitive, and being seated or lying down were favourably situated for observing it.

This scale does not pretend to scientific accuracy, nor are the differences between the successive isoseists by any means uniform; all that can be said in its favour is that it is the best which the materials available allow of being used. As compared with the Rossi-Forel scale it may be said that, roughly speaking, the isoseist number

No. 1	includes	degree	10	of the	Rossi-Forel scale
„ 2	„	„	9	„	„
„ 3	„	„	8	„	„
„ 4	„	„	6 and 7	„	„
„ 5	„	„	4 and 5	„	„
„ 6	„	„	2 to 3	„	„

To those who were in the area affected by the earthquake a better idea of the scale may be given by the quotation of specific instances of each degree. The first isoseist includes all such places as Shillong and Goalpara, where destruction was universal; the isoseist runs near Rangpur and Kuch Bihar. No. 2 would include Murshidabad, Malda, Darjiling; No. 3, Bhagalpur, Krishnagar and Calcutta. Beyond this, No. 4 would include western

Bihar and the eastern half of the North-West Provinces. About Allahabad comes the isoseist No. 4 and about Agra No. 5.

It will probably surprise many who were in Calcutta at the time to see it stand so low in the scale as I have indicated above, and shown on the map No. 1, and when they recollect the alarm caused at the time and the ruined aspect of the city shortly after the earthquake the surprise is not unnatural. There are, however, special causes in the mode of construction of the Calcutta houses which account for the great destruction resulting from the earthquake.

Figure 3 represents the transverse section of a typical Calcutta house. There is a central portion built with thick walls, with flat cemented roof and cemented or marble floors to each story; on the south is a broad verandah, where the roof and floors are carried by

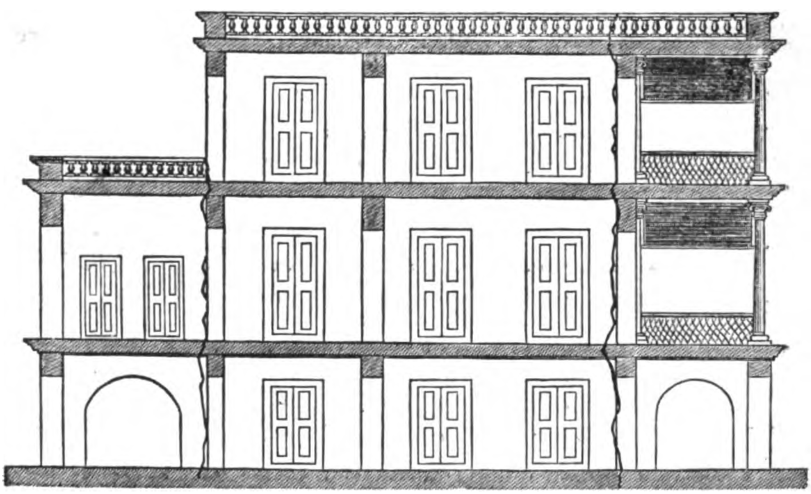

Fig. 3. Typical Section of a Calcutta House.

tall brick pillars, the upper half of the openings being filled by wooden venetian blinds; on the north is a large porch, often with a room built over it, as shown in the figure, but sometimes without this. The two storied houses are built in the same manner, with the omission of the top story.

From this description it will be seen that the house is divided by two vertical planes into three very distinct portions of very different weights and proportions. Consequently when the house is set rocking each portion will try to swing as an inverted pendulum, with its own proper period of oscillation. As this will be different in each case, and as the difference is greatest in the case of the main body of the building and the south verandah, the different portions, unless strongly tied together, will alternately separate and press upon each other.

This separation of the verandah from the main body of the building was observed by more than one person, and the rate at which the separation and return took place, estimated at from 7 to 20 seconds by different observers, shows that it was not directly due to the bending of the house on the top of the earth wave, whose period was much quicker, but to a swing communicated to the building, and the elastic oscillation of its different parts. Tall factory chimneys are known to sway several feet in a high wind, and bricks and mortar have sufficient elasticity to allow of a separation of several inches between two parts of a tall house swinging in opposite directions.

After the earthquake it was found that by far the greater amount of the serious damage done was of the character described, and few were the houses, even those otherwise little injured, where two cracks did not open as shown in fig. 3. Moreover, it was found that where the main beams supporting the roof and floors ran north and south, in the same direction as those of the verandah, and hence acted in some degree as ties, the damage was much less than when the beams in the main building ran east and west and those in the verandah north and south.

Another cause of the damage in Calcutta was the heavy and weak balustrades and cornices found on most of the older houses. These will be noticed in the views reproduced on Plates XXIII and XXIV, and are represented in section on figures 4 and 5, for which I am indebted to the courtesy of Messrs. Macintosh, Burn and Co. Figure 4 represents in section the roof, cornice and balustrade of an ordinary private house; fig. 5, that of the Calcutta Town Hall, which may be regarded as an extreme case of this type of construction. The balustrade, whose general appearance can be seen on Plates XXIII and

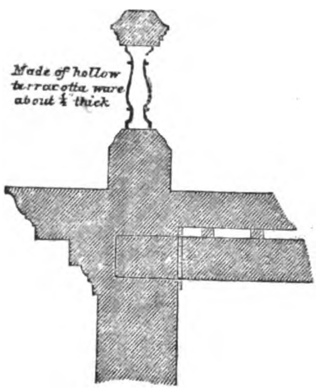

Fig. 4. Section of roof, cornice, and parapet of a private house, Calcutta.

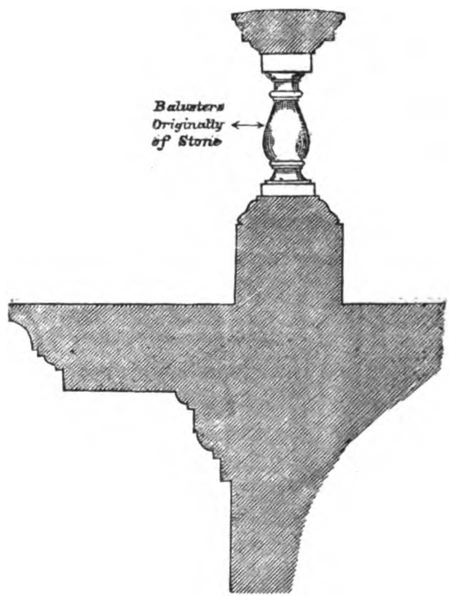

Fig. 5. Section of roof; cornice, and parapet of Calcutta Town Hall.

Scale ¼ inch = 1 foot.

XXIV has a heavy upper rail, made of brick and mortar, heavily plastered over, and supported on a row of thin earthenware hollow supports, sometimes filled with mortar, but more often left empty. These earthenware supports are generally plastered over to match the rest of the building, but the plastering adds little to their strength, and when the earthquake came they were in very many cases unable to support the strain thrown on them by the inertia of the heavy upper rail, broke across their narrowest part, and allowed the rail to be precipitated to the ground, carrying with it any projections that stood in its way (Pl. XXIII, fig. 1).

Little less dangerous were the heavy cornices which adorn not only the outside of these houses, but are often repeated in the interior. They project two feet or more (in the case of the Town Hall over five feet) and, being constructed of ordinary brick and mortar covered with stucco, have little transverse strength at their junction with the main wall. In the interior of the house they do not project so far, but are often a foot or more wide and made principally of plaster. These heavy cornices proved especially liable to damage; long lengths of them were broken off, and in their fall caused wreckage and damage.

Yet another reason for the great apparent damage done was the almost universal practice of coating the brickwork with a thick coat of stucco. This is done for climatic reasons, a house so treated being much cooler than one in which bricks are left bare, but the plaster is easily detached when the whole house is caused to rock, as was the case in the earthquake, and an appearance of great damage was produced where, but for the stucco coating, the house would have been almost uninjured. Plate XXIII, fig. 2, is a view which may be taken as typical of a large number of houses after the earthquake, where it will be seen that, apart from the detachment of plaster and the damage done by its fall, the house is practically uninjured.

After making allowance for these special considerations, and for the fact that brick-built houses are far more numerous than anywhere else in Bengal, and that, consequently, the number seriously injured would naturally be greater, it will be found that the destructiveness of the earthquake was, proportionately, much less than throughout the north-eastern portion of Bengal; a conclusion which is borne out by the comparatively small amount of damage done in the native quarters of the town, where a different mode of construction is adopted and brick buildings are, as a rule, smaller and more homogeneous than those in the European quarters. Another source of strength is to be found in the buildings being, as a rule, not detached but built in rows, and where this was the case it was seldom that any but the end houses suffered, except in the case of those which were old and badly built.

In accounts of great earthquakes, at any rate those written in modern times, it is usual to attempt a detailed delineation of a greater or less number of isoseismal lines, and much information can doubtless be derived from the evidence their irregularities gives of the irregular distribution of the energy of the earthquake. In no case do the isoseists have that regular circular or elliptical form which would be found if the wave was propagated through a homogeneous medium, but in the case of the present earthquake it has been found impossible to draw these irregularities with any degree of accuracy, and the isoseists actually drawn on map No. 1 are purely diagramatic and represent their probable course if we could suppose local conditions everywhere uniform, and the diminution of the violence of the shock comparable to that which can be recognised in a westerly direction along the plains of Upper India.

It will be noticed that these curves come closer together on the east and south-east than on the west and south-west, and I believe that this closing in is, at least partly, real, and not due to imperfect information. On the north nothing is known of the course of the isoseists, and it is not impossible that the closing in of the inner isoseismic lines on this side is incorrect. I have drawn them in accordance with what little is known and with what might reasonably be expected, but no value can be attached to this portion of the curves.

So sketchy a delineation of the isoseismic lines may be regarded as unsatisfactory, and it certainly compares unfavourably with the elaborate delineation of the actual courses of a much larger number of lines given by Captain Dutton in his account of the Charleston Earthquake of 1886. The difference is largely inevitable but partly deliberate. At a very early stage of the investigation of

this earthquake it was seen that quite one-thir
which it was sensible lay in regions from wh ich
attempt to obtain any information, while more t
maining area was sparsely inhabited by ign orant
with but few and widely separated centres from
account could be hoped for. In these circumsta
been impossible to obtain such detailed informati
have allowed of the delineation of the actual cou
lines. Moreover, any attempt to have obtained thi
undoubtedly have occupied much time, besides
doomed to failure, so the attempt was delibe
order that attention might be given to those poi
which this earthquake seemed likely to add to ou

This being so, I shall not enter on a deta
accounts from various places (sufficient will be fo
of this report,) and will merely notice certa
the distribution of the energy of the shock which
the accounts.

Two partial exceptions may also be made to t
bility of drawing the isoseismic lines. The first i
area over which serious damage to brick-built ho
This corresponds to the isoseist between degrees
on p. 43 or between 7 and 8 of the Rossi-Forel
is the outer limit of the sensible shock, and may b
between degrees 1 and 2 of the Rossi-Forel scale.
in these two lines are indicated on Map No. I l
lighter tint, respectively.

The irregularities in the course of the inner li
ment; they are closely connected with the geologi
country, and are largely, if not entirely, due to tl
that earthquakes are more destructive in alluvial g
at an equal distance from the centre.

At the outer limit there are some peculiarities detailed notice and the most prominent of these is the detached area about Baroda and Ahmadabad. The Collector of Ahmadabad reports that he did not experience the shock himself, and that though it was reported to have been felt, he does not think that one person in a thousand noticed anything. Even this small proportion is, however, probably larger than that which noticed the shock over a large area to the east, and the number of separate accounts which mention the shock as having been felt in the Ahmadabad district and Baroda territory, though accompanied by a larger number which report that nothing was felt, leave no doubt that the shock was just sensible on the alluvial tract bordering the western edge of the peninsular rock area.

Further east we find the same thing. In the alluvial area of the Narbada Valley the shock seems to have been pretty generally felt, though only by a portion of the inhabitants, and at the western end it seems to have been noticeably more feeble than at the eastern. North of the Narbada alluvium the shock was much less noticeable. The accounts received from Sehore in Bhopal and from Piploda have been given on page 37. At Nimach the shock was not felt by anyone in cantonments, but the Subah, whose house is situated on high ground overlooking the city, some 2 miles from cantonments, reports that the shock was felt by him and caused the door-chains to clank and the tiles to rattle on the roof. The Station Master at Raoti, 17 miles west of Ratlam, reports that the shock was felt there, but all other places, to the west of those just mentioned, report that it was not felt; the only exception being Mount Abu where the shock appears to have been felt by one or two persons.

One more instance of the local appearance of the earthquake as a sensible shock must be noticed in this western region. I have a complete series of reports from the the Station Masters on the line from Jabalpur to Bombay. From Jabalpur to Seoni they all, with a few exceptions, report the shock as having been felt; from Seoni, which is still on the Narbada alluvium, to Bombay, every Station Master reports that the shock was not felt, with the single exception of Burhanpur where it is reported to have been felt. It is possible that this exception may be due to a greater sensitiveness or keenness of observation on the part of the Station Master, but it is noteworthy that Burhanpur is on the northern edge of the Tapti alluvium, but close to the boundary between it and the great spread of Deccan trap.

Before leaving the western area it may be of interest to note that in Lalitpur in Bhandelkhand, far beyond the region where any serious injury to masonry buildings is reported, the Birdha inspection-house on the Cawnpur-Jhansi road is reported to have suffered serious damage. The building was of stone, with the roof supported on stone slates carried by stone beams. A few cracks were opened in the roof of the main building, parallel to the stone beams supporting it, and the walls and roof of an outhouse fell down. From the account submitted to me it does not appear whether there was any local cause to explain this damage which, though slight, was much greater than any other in the North-West Provinces or Oudh, or whether it was entirely due to age or defective construction of the buildings.

Turning to the eastern limit of the known area, the shock is said to have been severe on the northern frontier of Burma, and to have thrown down trees in the Hukong Valley and at Sampawn but at Myitkhina it is said to have been so slight as not to have been generally noticed at the time. In the North Shan Hills it was felt more or less over the whole charge, except at the Tawmo outpost east of the Salwin.

In Southern Burma the shock appears to have been very noticeable all down the Irawadi Valley, as all stations report that it was felt, even as far south as Diamond Island, but it was not felt at the Alguada reef lighthouse. To the east of the Pegu Yoma the shock appears to have been very much less felt, and the difference cannot be attributed to a greater distance from the centre. At Toungoo it is reported to have been very slight, and a few only of the Sta.ion Masters on the Rangoon-Mandalay Railway felt it. It was felt in

Western Karenni, and seems to have been felt in parts of Myelat, though there is an uncertainty about the date, but was not felt elsewhere in the Southern Shan Hills

These records give an approximation to the eastern limit of the area over which the shock was felt, but east of Bhamo we have no records. An enquiry instituted through Her Britannic Majesty's Envoy Extraordinary and Minister Plenipotentiary at the Court of China failed to elicit any information as to the earthquake having been felt in China; but as the region where it could have been felt is one of the most remote from the capital, largely inhabited by primitive tribes, and as the earthquake must have been too feeble to attract general attention, no great value can be attached to the negative result of the enquiry.

On the north the only information available is that contained in the reports of Colonel Wylie and Mr. Hobson quoted in the last chapter.

Summarising the results reviewed above we find that the area over which the shock is known to have been felt amounted to not less than 4,200,000 square miles (statute), or 3,120,000 square kilomèters and this does not include the detached area near Ahmedabad or any part of the Bay of Bengal, nor does it include the large area in Thibet or Western China, over which the shock was certainly sensible, though we have received no reports. If we round off the area by including these tracts we get a total area over which the shock was sensible as about 1,750,000 square miles, (4,550,000 sq. km.) while the area over which it is known to have done serious damage to masonry buildings is not less than 145,000 square miles, (377,000 sq. km.,) or, if we include the area from which no reports are procurable, about 160,000 square miles (416,000 sq. km.).

These estimates, it must clearly be understood, large as the figures may seem, are not sensational ones. That is to say, the extremest possible dimensions have not been taken in order to attain a large result, but so far as possible the actual areas calculated, and if the figures are in error at all it is in defect and not in excess.

CHAPTER IV.—THE RATE OF PROPAGATION, AND TIME OF THE COMMENCEMENT OF THE SHOCK.

Of all the data required in seismological investigations none are so important and none so difficult to obtain as the exact times at which the various phases of an eathquake were felt. This is partly due to habitual inaccuracy in timekeeping, accuracy to a second or even to a minute of time being seldom required in ordinary life, but also to the nature of the eathquake wave or series of waves. They do not commence abruptly and cease absolutely at determinable moments, but the sensible shock is preceded by minute tremors and followed by longer and slower undulations, both of which are insensible, but in different degrees to different people. The time, for which the preliminary and terminal stages of the disturbance last, increases with the distance from the centre, and it would be possible for two careful observers, side by side, to record materially different observations of the time of commencement and cessation of the shock, as the movements felt by one might be quite insensible to the other.

In the case of this earthquake I have received a large number of time records from various sources, which may be classified as follows:—

(1) The automatic records at Calcutta and Bombay.

(2) Reports from the Telegraph Department.

(3) Reports from Station Masters.

(4) Accounts of private individuals.

The second of these categories comprises the reports which all telegraph offices in India and Burma were ordered to submit. It might be supposed that the time records from these would show a high degree of accuracy, seeing that a time signal is transmitted daily to every office. The result has not, however, fulfilled this anticipation. It is not in human nature to take more trouble than is necessary to attain the purpose desired, and in small offices where telegrams are seldom received or despatched[1] no great trouble is taken to keep accurate time. In many of these small offices it is evident that no note was made at the time when the earthquake was felt, and the conjunction of these two causes of error has vitiated nearly all the returns. In a few cases the time reported is obviously in error to the extent of several hours.

From the larger and busier offices, where a careful record of time is essential to the proper conduct of the business, the returns are of greater accuracy and value. In these the signallers have to keep a log-book in which the times of receipt and despatch of messages and the alteration of the electric circuits are recorded; and where the work is sufficient to keep the office continuously employed, it is obvious that a considerable degree of accuracy in timekeeping is necessary. But a high degree of accuracy, according to the standard of ordinary life, may be a high degree of inaccuracy where even fractions of a second should be taken into consideration, and it is obvious from the returns that, even where accuracy is most to be expected, the time is often in error by several minutes.

On the railway the same considerations affect the accuracy of the returns, but here the constant traverse of trains, each of which has to keep its running sheet in agreement with the times kept by the Station Masters, introduces a certain check on the time kept at roadside stations. Yet it is evident from the returns that the times recorded at large and busy stations, where many trains stop, are, on the whole, more accurate than at the roadside stations where only a few trains stop. It is also noticeable that on the main lines a more accurate record of time is kept than on the branch lines, or on lines which do not carry much through traffic. On the East Indian Railway, the busiest, and by common consent best managed, line in India, it has been possible to adopt a method of treatment of the records which gives a more accurate result than could be obtained by using the

[1] I have myself had occasion to despatch a telegram from an office where I was informed that mine was the first message received or despatched for two months; but this is an extreme case.

recorded times from individual stations. The records obtained from the main line stations between Calcutta and Delhi were plotted and a curve drawn (see Plate XXXIX) in which the abscissæ represent the distance of the stations, the ordinates the times; the curve so obtained is irregular, but by smoothing it a curve was obtained which gives the probable time of commencement of the shock at each station with greater accuracy than the actually recorded times.

The same method was attempted in the case of the Eastern Bengal State Railway line from Calcutta to Darjiling, but in this case the individual variations in time between neighbouring stations, and the very large proportion which gave what was evidently merely the nearest five minute interval renders the method inapplicable. In this case, as in that of all the other lines from which returns have been obtained, it has been necessary to adopt the less satisfactory method of selecting those of the returns which appear on the face of them to be most trustworthy.

The fourth category, voluntary reports from private individuals, varies most largely in value. In a certain number of cases every care seems to have been taken to ensure accuracy, and it is expressly stated that the watch or clock, by which the time was taken, had been or was subsequently compared with the timepiece of the nearest station or telegraph office, or with the daily gun. All these standards are, however, liable to errors which may—for the present purpose—wholly vitiate the result.

A fruitful source of error, and one that it is often impossible to eliminate, is the different times that are kept and used. I do not refer to isolated localities where there is neither railway station nor telegraph office, and where the local time is determined by the gastric sensations of the individual in charge of the station time-gong, or the indications of a sundial, more often than not constructed for a different latitude to that in which it is set up, and probably adjusted to the meridian with no more accurate instrument than a cheap pocket compass; but to those places where the presence of telegraphic communication should enable accurate time to be kept.

The official standard time, used by the telegraph department and by all railways in India, is that of the Madras Observatory, 5 hours, 20 minutes, 59·2 seconds[1], east of Greenwich. But the Indian telegraph system ranges over nearly two and a quarter hours of longitude,[2] and, as the hour-zone system has not yet been adopted, the use of Madras time would be inconvenient in many cases. A system has consequently sprung up of using local time, this being obtained by a correction of an integral number of minutes, the number to be added or subtracted being printed in the official telegraph guide.

This, in itself, would introduce no element of confusion if the system was uniformly adopted, but it is not. Throughout the Madras Presidency, Madras time is used, except at Vizagapatam, where local time is used. Elsewhere local time is that in general use, but where the difference is not great, railway time—as that of the Madras meridian is usually called—is used in some places, local time in others. Yet another source of confusion is to be found in the practice of using a local time which is not that of the locality, but that of the nearest large city; for instance, at many places in Bengal, the time conventionally used is that of Calcutta, not that of the meridian of the place or standard time.

As a consequence of this divergence of time-systems in use it is necessary to be certain, even after an observation has been accepted as on the face of it good, which system has been used. As a rule, there is no difficulty, for the difference between them is great, the only possibility of confusion is at places near the meridian of Madras, and in Bengal, when the local time may not be that of the locality, but of Calcutta.

In the reports on great earthquakes it has been usual to print at length the time records obtained. In the present case to do so would take up a large amount of space and serve no useful purpose.

[1] According to the most recent determination; the old value was 5 hours 20 minutes 59·4 seconds.

[2] According to the Indian Telegraph guide the most westerly open station is Chaman, 55 minutes slow, and the most easterly Keng Tung, 75 minutes fast, of Madras.

It is only necessary to refer to the reports on the Charleston[1] Earthquake, or those of Agram[2] (1880) and Laibach[3] (1895), to see how largely even what may be regarded as careful records can vary, and those of the great earthquake of 1897 exhibit an even greater divergence. I shall consequently confine myself to noticing those records which appear to be most accurate.

In making such a selection great care should be, and has been, taken to exclude, as far as possible, any bias to select those records which give a result most concordant with the anticipated rate of transmission. Were the inherent probability of the recorded times solely taken into consideration, or even largely so, it would be possible to obtain ample evidence for almost any assumed rate of propagation. The proper course is to look only to the inherent probability of the record being correct, as judged from the circumstances of the reporter's occupation, or the details of the precautions taken to ensure accuracy. In some cases records which on the face of them carry a presumption of accuracy, are so discordant with the others of the same class, that they must be rejected on this ground alone, but no good can result from accepting a large number of records whose only claim to credit is a consistency with other records, this consistency being perhaps due to accident or a combination of errors which happen to compensate each other.

Turning now to the detailed consideration of the records, we may begin with those from Calcutta and Bombay, where they attain a greater degree of accuracy and trustworthiness than at any other places.

At Calcutta a tide-gauge is permanently established. The time is checked every day at 4 P. M. and 6 P. M. and the times of the disturbances recorded on the afternoon of 12th June can consequently

[1] Captain E. Dutto. The Charleston Earthquake of 31st August 1886, Ninth Ann. Rep. U. S. Geol. Survey (1889).

[2] F. Wähner, Das Erdbeben von Agram am 9th November 1880. Sitz. ber. d. Math. naturw. Cl. k. Akad. Wiss., Wien. LXXXVIII, pt. I, 1884.

[3] F. E. Suess, Das Erdbeben von Laibach am 14th April 1895. Jahrb. k. k. Geol. Reichsanstalt. XLVI (1897).

be depended on within the limits of the accuracy of measurement of the diagram. The results of the measurement, as communicated by Major S. G. Burrard, R.E., in charge of Tidal and Levelling operations are as follows:—

The first effect of the earthquake was to cause the level of the water to fall 1 inch, between 4-53 P.M. and 4-55 P.M., June 12th.

At 4-55 P.M. the water rose suddenly ½ inch, after that the change in the water-level was normal till 5 P.M., when it rose and fell 3 inches in rapid succession many times for a period of 3 minutes. After that a just perceptible alternate rise and fall of at most 1 inch continued till 5-21, when the change in the water-level again became normal; at 5-54 this slight agitation recommenced and lasted till 5-56.

The first small disturbance between 4-53 and 4-55 P.M. was doubtless seismic, and is the only indication we have of any premonitory tremor. It was not, however, a sensible disturbance, at any rate there is no record of its having been felt by any one, and it may be neglected for purposes of comparison. The main disturbance commenced somewhat suddenly immediately after 5h. 0m. P. M.

Another instrumental record was obtained at the Alipur Observatory in the disturbance of the barograph trace, a reproduction of which is given in fig. 6. This would have been a valuable record

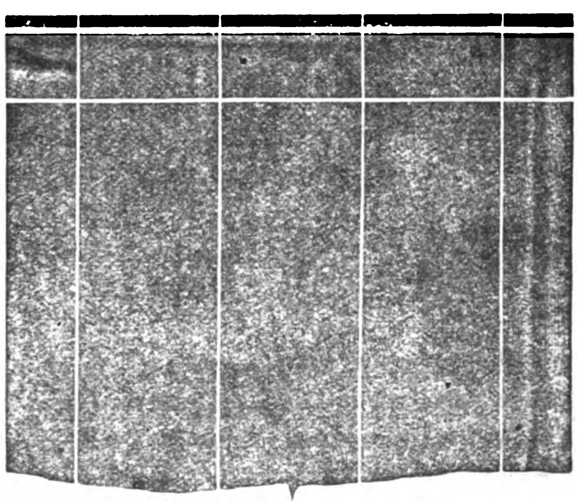

Fig. 6. Portion of trace of the barograph at Alipur on 12th June 1897. showing the effect of the earthquake.

if the time could be depended on, but I am informed by Mr. C. Little, Meteorological Reporter to the Government of Bengal, that no special care is taken to keep the time strictly accurate, as an error of one or two minutes is not material, and the time recorded on this diagram is not to be depended on for a greater accuracy than this. The time of the maximum disturbance is about 5h. 3m., which shows that error of the clock must have been well within the limits mentioned.[1]

The only detailed time observation, other than instrumental, which has been communicated to me, is that of Babu Pyari Lal Mukhopadyaya, of 71-1 Bencatola Street, who writes:—

"I am a medical practitioner residing in the native quarter of the town. Having prepared myself for my usual evening round at about two minutes short of five in the evening of the 12th instant, my Garrhy ready at the door, I had a short chat with a gentleman waiting for me. Just as I was stepping in, I felt somewhat giddy and questioned myself as to what ailed me. I thought something wrong in the head and waited a moment. When lo! everything began to swing, and I found my mistake out. The shocks then were slight but rapid, resembling a sort of general tremor, and the directions could not be apparently marked. I immediately took out my watch, which was correct to the minute. It was 5h. 1m. 23s. The watch had been compared with the gunfire the very same afternoon. In order to make assurance doubly sure, I compared it with the gun-fire the next afternoon, and found it as accurate as I expected. Some 15 or 20 seconds must have passed before I could collect myself, and, making allowance for the distance from which I heard the booming of the gun, say some 12 seconds it takes the sound to travel that distance, the exact time of the earthquake must have been at about 5h. 0m. 51s."

[1] The record is a photographic one, a ray of light falling through a narrow slit on a slowly travelling band of sensitised paper. The mercury column stands in front of this slit; and, as it rises and falls, protects a varying amount of the paper from the action of the light. The downward point of the curve during the earthquake is consequently due, not to an actual fall of the barometer, but to a disturbance of the mercury column by which its upper surface was caused to oscillate and admit light to a level below the mean height of the barometer. That such movement of the mercury column did take place is shown by the report of the Meteorological Observer at Chandbali, to the Meteorological Reporter to the Government of Bengal, in which he says "as soon as possible I looked at the barometer, but the mercury was agitated to such an extent (pumping) that the nearest mean reading I could get was 29·650. At 4 P.M. it showed 29·674, Ther. 83°, nearly motionless; and at 5-30 P.M. 29·700, Ther. 83°, pumping slightly."

From the construction of the instrument, no tilting of it as a whole could affect the record, as the change in height of the barometer, due to such inclination as could have been given to it, would be inappreciable.

From Budge-Budge, to the south of the town of Calcutta, Mr. Thomas Harris, Deputy Wharf Supervisor, Customs Department, writes:—

"On Saturday, 12th instant, I left my office a few minutes to 5 o'clock and proceeded to the petroleum depôt to supervise the landing of kerosine oil cases from the S. S. *Nedjed*, at No. 3, Port Commissioner's pontoon, and exactly at 5 o'clock by my watch (this time is daily compared with the telegraph office clock), which keeps excellent time, I felt the ground beneath me quake, followed by a rumbling sound."

At the Government Central Telegraph Office the time of the commencement of the shock was noted by Mr. Sub-Assistant Superintendent Stow as ½ minute after 5.

I have also received information, both verbal and written, from many individuals, all of whom claimed to have noticed the time of the commencement of the shock and determined it by watches which had been checked by the daily time-gun at one o'clock. The times given vary from 1 to 3 minutes past five, a very few being beyond that limit.[1]

The times recorded agree very closely; that of the tide gauge, which gives the commencement at 5h., of Babu Pyari Lal Mukhopadyaya who makes it 51 seconds after 5, of Mr. Harris who makes it immediately after 5 o'clock, and of Mr. Stow, who made it ½ minute after 5. All are in very fair agreement with other careful observations, and the true time may be assumed as about 5h. 1m. P.M. by local time.

At Howrah Railway station, the terminus of the East Indian Railway, the time, according to the Station Master, was 16h. 28m., Madras time. The Fairlie Place, Chitpore and Armenian Ghat offices of the same company give 16h. 27m. Other stations gave returns which are evidently only approximate.

[1] Many clocks were stopped, two of these being the astronomical clocks at the Alipur Observatory. One, whose pendulum swung east-west, stopped at 5h. 3m. 5·31s P.M. local time; the other, whose pendulum swings north and south, at 5h. 4m. 11·71s. It is well known that no dependence can be placed on the time of stoppage of clocks, as it never coincides with any definite phase of the shock; moreover, a pendulum may go staggering on for some minutes after it has received the impulse which ultimately leads to the stoppage of the clock.

The Station Master of Sealdah, the terminus of the Eastern Bengal Railway, gives the time of commencement as 16h. 27m.

A mean of these returns would give the time as about 16h. 27·5m. and the time as obtained by plotting the returns from the stations on the East Indian Railway and smoothing the curve as described above, gives about 16h. 27m. 40s. as the time of commencement at Calcutta.

Calcutta local time is conventionally, in accordance with the official Telegraph Guide, 33 minutes in advance of Madras or Railway time, but the local time actually used is that of the daily time signal controlled by the Alipur Observatory, which is 32m. 20s. in advance of Madras, and this is consequently the correction to be used. In the case of Mr. Harris' record from Budge-Budge, as the time was obtained from the Telegraph office, the correction of 33 minutes would have to be applied. Reducing the observations to Madras or standard time, we have—

Tide-gauge	16h.	27m.	40s.
P. L. Mukhopadyaya	16h.	28m.	37s.
Telegraph Central Office	16h.	28m.	10s.
T. Harris	16h.	27m.	0s.
Railway stations, mean	16h.	27m.	30s.
Do. Smoothed curve	16h.	27m.	40s.

All these times are liable to an error of 30s. and cannot be regarded as accurate within that limit; an arithmetical mean gives 16h. 27m. 49s., which is probably as close an approximation as circumstances permit. With observations so few, and with so large a probable error in each case, more refined mathematical treatment seems out of place and would only lead to an appearance of accuracy which has no foundation in fact. The time deduced may be taken as accurate within a quater of a minute, and the local time of commencement of the shock was between 5h. and 5h. 0m. 30s. P.M. of local time.

At Bombay, which was beyond the limits over which the shock could be felt, we have the records of the magnetic instruments detailed in chapter XI, and also the barograph trace which exhibits a disturbance precisely similar to that of the Alipur barograph. Mr. Moos, the Director of the Observatory, tells me that the clock of this is regulated with the same accuracy as those of the magnetic instruments, and that the time derived from it may be regarded as accurate within one minute at the outside.

Abstracting the results, we have the following times of commencement and cessation of movement as derived from the records of the different instruments:—

	Commencement.	Close.
Declination	. 16h. 5m.	16h. 34m.
Horizontal force	. 16h. 2.5m.	16h. 36m.
Vertical force	. 16h. 6.5m.	16h. 14m.
Barograph	. 16h. 5.5m.	16h. 12·5m.

It will be seen that the disturbance of the horizontal force instrument commences 2½ minutes before that of the declination, while the vertical force shows no disturbance till 1½ minutes later. The disturbance of the barograph must necessarily be purely mechanical, and the early commencement of the disturbance of the horizontal force instrument is probably the same, but it is doubtful which of these we should compare with the commencement of the sensible earthquake at other places. The movements which affected the horizontal force instrument are very likely due to the small unfelt tremors which run in advance of the main earthquake wave and gain on it as they travel from the origin. This being so, it is the barograph and the vertical force instrument that more closely recorded the advent of the phase of the disturbance which corresponds to the commencement of the felt earthquake at places further east.

How far the difference in the recorded times, 16h. 5·5m. and 16h. 6·5m. is due to a difference in the sensitiveness of the two instruments, and how far to errors of the timepiece, or of reading the traces, it is not possible to say. Probably the best result would be obtained by taking a mean of the two, or 16h. 6m. local time. As the difference in longitude between the Madras and Bombay Observatories is 29m. 43·5s., this makes the Madras time 16h. 35m. 43·5s., or say 16h. 35·75m. If the time of commencement is taken from the horizontal force instrument this would be 16h. 32·25m. or 3·5m. earlier.

At Rangoon the tide-gauge shows a disturbance of the curve commencing at about 5h. 36m. P.M. local time, and lasting till 6 P.M. As there is no Observatory at Rangoon the time is presumably taken from the Telegraph office and subject to the correction of 64 minutes given in the Telegraph Guide. This would make the Madras time of commencement 16h. 32m. This record is, however, not of the value that could be wished for, and the time of commencement of the disturbance of the curve cannot be determined within two or three minutes. It begins gradually, instead of abruptly, as in Calcutta, and the inking in of the pencil trace having been done somewhat clumsily has added an uncertainty to that which would, in any case, have attached to the determination of the exact commencement of a disturbance which began gradually.

The other time observations, or such of them as have been selected as being, *primâ facie*, probably more accurate than the rest, may now be recorded. When a place is mentioned as a railway station and no further authority is given, the time is on the authority of the Station Master; in all other cases the authority for the time recorded is given.

Siliguri.—Eastern Bengal State Railway, terminus, and junction with Darjeeling and Himalayan railway: *commenced* 16-26, *ended* 16-30.

Goalundo.—Eastern Bengal State Railway, terminus: *commenced* 16-27, *ended* 16-32.

Sonada (Darjiling). Mr. M. Livermore, manager of the Turzum Tea estate, Nagri spur, writes—"I have an excellent timekeeper which I frequently compare with the local telegraph office. The earthquake commenced at 4-58 P.M." This corresponds to 16h. 26m. Madras time.

Darjiling.—Darjeeling and Himalayan railway, a terminal station: *commenced* 16-26, *ended* 16-29.

Hugli.—East Indian Railway, a junction: *commenced* 16-27, *ended* 16-32.

Naihati.—Eastern Bengal State Railway, a junction: *commenced* 16-28, *ended* 16-31.

Chittagong.—From this place I have received two reports through the Telegraph Department which approximately fix the time at which the earthquake reached that place. In the first of these the Telegraph Master writes:—

"An entry by Sign. F. S. DeSouza in the Log Book of the Ca 34 instrument reads as follows: '16-27 severe shock of earthquake.' Sign. DeSouza says he made this entry at the moment the shock occurred and then ran out."

The second is the account of Mr. J. W. Thurlow. Sub-Assistant Superintendent of Telegraphs:—

We all experienced a shock. This being immediately followed by a second. I drew my watch and noted the time, *viz.*, 5h. 13m. 4s, * * these shocks did not end gradually but abruptly, at 5h. 16m. 25s. * * I hurried into the office * * and at the same time compared my watch with the office clock, allowing 46 mts. as difference between Madras and local time. I found I was 1 mte. slow, so that the actual time of occurrence of the earthquake at Chittagong was 5h. 14m. I allowed the 4 seconds for not at once taking out my watch on the first shock, but I really do not think I was later than 4 seconds.

Chittagong local time is 46 minutes in advance of Madras, according to the Telegraph Guide; 5h. 14m. P. M. corresponds, therefore, to 16h. 28m. Madras time. A mean of these two observations gives 16h. 27½m. as the probable time.

Khana.—East Indian Railway, a junction: *commenced* 16-26, *ended* 16-33.

On the westerly line we have—

Saraghat.—Eastern Bengal State Railway, terminus of metre-gauge: *commenced* 16-28, *ended* 16-28½.

Damukdea.—Eastern Bengal State Railway terminus of broad-gauge: *commenced* 16-27, *ended* 16-32.

Luckeeserai.—East Indian Railway, a junction: *commenced* 16-29, *ended* 16-34.

Giridih.—A terminal station: *commenced* 16-28, *ended* 16-32.

Gaya.—East Indian Railway, a terminus: *commenced* 16-29, *ended* 16-33.

Chapra (Saran).—The telegraph master reports the shock as *commenced* 16-29½ and lasting 4 minutes.

Buxar.—East Indian Railway: *commenced* 16-30, *ended* 16-34.

Benares.—Oudh and Rohilkund Railway: *commenced* 16-30, *ended* 16-31¾. The Government Telegraph Master reports: *commenced* 16-29½, lasted 3½ minutes.

Mirzapur.—East Indian Railway: *commenced* 16-31, *ended* 16-35.

Faizabad.—Oudh and Rohilkund Railway, a junction: *commenced* 16-30, *ended* 16-32.

Naini.—East Indian Railway, a junction: *commenced* 16-30, *ended* 16-34½.

Allahabad.—East Indian Railway, an important station: *commenced* 16-30, *ended* 16-34. This time is said to be correct within one minute

The Telegraph Master reports:—*Commenced* 16-30, lasted 3 minutes. From the Kuttra telegraph office in Allahabad the return was *commenced* 16-33, lasted 2m. 33s.

Mr. R. Warneford writes that the mean of the times of 4 watches, which were observed at once, gave the commencement as 31½ minutes past 4 P.M., the greatest difference being 2 minutes.

Cawnpur.—East Indian Railway, an important junction: *commenced* 16-30, *ended* 16-32. The Government Telegraph Master gives: *commenced* 16-30.

Mr. C. Curtis, Traffic Superintendent, Cawnpore and Achnera Railway, writes:—

"I was the only one writing at the time and first noticed the earthquake owing to the table shaking and asked the others not to shake it. They replied they were not doing so, and I saw that they were sitting away from the table (not touching it). I then looked under the table thinking it might be a dog, scratching himself, but seeing nothing there, and the table still shaking, I said "It is an earthquake," the station master immediately looked up at the clock in the telegraph office right in front of him, and said '16-30.'"

Utripura.—27 miles from Cawnpur; the Station Master reports it as 'felt just at 16-31, when No. 7 up whistled, who is arriving here at 16-32.'

Lucknow.—Oudh and Rohilkund Railway, an important junction; *commenced* 16-30, *ended* 16-35. The Superintendent of Telegraphs reports that he noted the time of commencement of the shock as nearly as possible 16h. 30m., the same time being noted in the Lucknow telegraph office and in the Dilkusha office. The town-clock in the People's Park stopped at 16-30.

Bareilly.—Oudh and Rohilkund Railway, a junction station: *commenced* 16-30, *ended* 16-33. This is evidently a mere approximation. Mr. A. L. Bickers told me that he observed it, *commenced* 16-32, *ended* 16-35. The Telegraph department return gives the time of commencement as 16-33.

Hoshangabad.—Mr. G. G. White, Executive Engineer, gives the time of commencement, which was noted on the spot, as 4-35 P. M., railway time.

Gwalior.—The Telegraph Master reports *commenced* 16-32, *ended* 16-34; the times were noted in the log-book.

Ghaziabad.—East Indian Railway, a junction station: *commenced* 16-32 *ended* 16-35. This time is said by the Station Master to be 'correct to a second, the times were tested by the office clock immediately the two shocks were felt.'

Delhi.—East Indian Railway, an important station: *commenced* 16-30, *ended* 16-33; the Telegraph Master reports *commenced* 16-30.

These are evidently approximations, being the nearest half-hour.

Kotah.—Captain W. Stratton, Political Agent, reports that the shock was felt at 4-29 P.M., railway time, which is telegraphed daily to Kotah, and was carefully taken. It is evident, however, that this time is some minutes too soon.

Jaipur (Rajputana).—Mr. J. R. Irwin, Resident, writes: "By my watch, which I believe was at least approximately right by Railway time, the earthquake was felt about 4-34 P. M." The Meteorological Observer noted the time as 16-38 by his clock, which is compared weekly with the Railway station clock.

Anand.—Bombay, Baroda and Central India Railway: *commenced* 16-35, *ended* 16-36.

Dabhoda.—Ahmedabad and Parantij Railway: *commenced* 16-34, *ended* 16-34 12s.

Dehegam.—Ahmedabad and Parantij Railway : *commenced* 16-34½, *ended* 16-34½.

Bilimora.—Bombay, Baroda and Central India Railway: *commenced* 16-35, *ended* 16-35½.

These four stations are the only ones in Western India from which the returns have any pretension to accuracy. They are interesting for comparison with the Bombay records.

To the south there are two isolated stations whose records could not be advantageously combined with the above.

Kharagpur—53 miles from, on Sini-Midnapur Railway. Mr. C. R. Duggan, Engineer in charge of this district, writes:—

"The vibrations were distinctly felt for the first time at 16-29, Madras time, the time being taken by my watch, which could not be more than a minute wrong, as it is frequently checked by the Railway clock in the Telegraph office. The movements ceased at 16 hours 31 minutes 15 seconds."

Bezwada.—East Coast Railway : *commenced* 16-29, *ended* 1631.

The time records received from Burma are extremely imperfect. The returns from the Station Masters not only exhibit the same irregularity that is observable in those from the branch and smaller lines in India, but there is besides a constant error, running through the whole of them, which can only be explained by supposing that there was an error, apart from that referred to below, in the time used by the Railway administration and supposed by them to represent Madras time.

From the returns by Telegraph Masters I select the following as apparently good:—

Kindat		16h. 31m.,	Madras time.
Kalewa		16h. 30m. 5s.,	,,
Akyab		16h. 30m.	,,
Ru		16h. 26m.	,,
Thayet-myo	5-32 P.M. =	16h. 31m.	,,
Allan-myo	5-33 ,, =	16h. 32m.	,,
Henzada	5-34 ,, =	16h. 34m.	,,
Le-myet-hna		16h. 32m.	,,
Yandoon		16h. 28m.	,,

All the other returns received are evidently approximations and in many cases palpably inaccurate.

Though these times are given here as appantly good records, it has not been possible to make any use of them, as it was found that they were too discordant. There is, besides, a constant error of some two or three minutes of time in the majority of them, which is easily explicable. The daily time signal originates from Madras, but before it reaches the Burma stations it requires to be repeated so often by relays that a considerable retardation occurs. I have been informed that when, some years ago, the longitude of Mandalay was determined telegraphically, it was found that the ordinary daily time signal was between two and three minutes late in arriving there. This error, if applied to the time records from Burma, would bring most of them into very fair accordance with those from Northern India, but as the error exists, and as its amount is unknown, it has not been possible to harmonise these time records, and no further use will be made of them.

Turning now to the discussion of these records, we have those from Calcutta and Bombay forming a class by themselves as regards accuracy and authoritativeness. The others, comprising those alone which seem on the face of them good observations, fall into three geographical groups. The first of these comprises a series of stations running north and south, between Calcutta and Darjiling, and those lying within a hundred miles or so on either hand of this line. The second forms a long series stretching approximately westward across Northern India, and the third another long series, stretching approximately south-south-east to south-east through Burma.

In making use of these time observations to deduce the rate at which the earthquake travelled, it is necessary to know the centre from which it started, and hence it might be considered more appropriate to defer this chapter till after the discussion of the position and extent of the seismic vertical in Chapter X. But the time observations themselves have to be taken into consideration in this discussion, and for this reason their description, and the investigation of the rate of travel of the earthquake, are undertaken here, although this course involves a certain assumption of what is only established in subsequent chapters.

In calculating the distances of the stations at which we have time records from the epicentre, it is necessary to assume this as a point; but, as will be seen later on, this was a large area, and it is consequently necessary to determine what point to accept as that of departure of the earthquake wave. Two courses are open, either to take a central point in the focal area or, as all our stations lie to the west, one near its western limit. In either case, certain errors are possible.

Supposing the earthquake to have been due, as suggested in Chapter X, to the formation of a great thrust-plane, the movement probably commenced near the centre and spread outwards. Now the rate at which the fissure spread may have been the same as, greater, or less than, that at which the earthquake waves travelled. In the latter case, if we assume a starting point at the western limit of the focal area, it is evident that all the calculated distances will be less than the true distances which the earthquake wave had travelled, for the wave would have reached the assumed centre before the disturbance starting from that point was originated. If, on the other hand, the formation of the fissure started at more points than one, or, if it spread at a greater rate than that of travel of the earthquake wave, then all distances calculated from the centre of the focal area would be greater than the true distance travelled by the earthquake wave. The probability is that the rate of spread of the fissure, and of the travel of the earthquake wave, were practically the same; and in this case we may reckon from a point near the western end of the focal area when deducing the rate of travel of the disturbance. An assumed centre in Lat. 25° 45′ N., Long. 90° 15′ E., has accordingly been used in all the following calculations; this being more or less of a compromise[1].

Taking this as the starting point, we find the distances, measured along the surface[2], to Bombay and Calcutta are 1208·3 and 255·5 statute miles, respectively, while the time interval was 8 minutes. From this we find the average rate of travel of the earthquake wave, as between these distances, was probably 119.1 miles per minute, or 3 kilometres per second. The time interval cannot be depended on for absolute accuracy; it might possibly be as much as one minute in error, but, seeing the nature of the records by which it was obtained, it is probably not more than half a minute out in excess or defect. Assuming this as a probable error, we get the values of the rate of propagation as —

	Per Minute.	Per Second.		
	Miles.	Miles.	Feet.	Kilometres.
Maximum	126·5	2·10	11,135	3·2
Minimum	111·7	1·86	9,725	2·8
Probable mean	119·1	1·98	10,450	3·0

Making all allowances for possible inaccuracies, there remains the fact that the mean rate of travel of the earthquake wave at the surface of the earth was about 120 miles a minute, or 3 kilometres a second, as between Calcutta and Bombay.

The remaining observations are not sufficiently accurate, or sufficiently concordant to permit of their being advantageously treated by direct calculation, and a more satisfactory result is to be obtained by the graphic treatment adopted in the hodograph on Plate XXXIX. Here the two lines at right angles to each other represent, respectively, a scale of distances and time,

[1] It may be pointed out that, as the stations from which we have time observations are in an approximately east and west line, an easterly or westerly shifting of the assumed focus would make little or no alteration in the difference of distance of any two stations from it. The only exception to this is in the case of stations like Calcutta, which lie far south of the general E. W. line; and even here, when compared with distant stations, such as Bombay, the difference is not such as to appreciably vitiate the results obtained.

[2] These distances, and all others in this memoir, are calculated to a mean radius of 3,956 miles and a spherical globe. The errors so introduced are trivial in comparison with the inevitable errors of the time observations.

all the time observations referred to above, except those from Burma, are plotted, the series of stations lying nearly west of the origin being distinguished by having their names printed below, while those which lie to the south or north-west, off the general westerly line, have their names printed above.

Taking the westerly group we have, in order of their distance, from the origin :—

Name of place.	Distance.	Time.	
Sara Ghat	138	16h.	28m.
Damukdea	140	16h.	27m.
Luckeeserai	260	16h.	29m.
Giridih	270	16h.	28m.
Gaya	336	16h.	29m.
Chapra	349	16h.	29½m.
Buxar	391	16h.	30m.
Benares	448	16h.	29½m., 30m.
Mirzapur	476	16h.	31m.
Faizabad	496	16h.	30m.
Naini	518	16h.	30m.
Allahabad	522	16h.	30m., 33m., 31½m.
Cawnpur	613	16h.	30m.
Utripura	630	16h.	31m.
Lucknow	632	16h.	30m.
Bareilly	688	16h.	32m., 33m.
Hoshangabad	725	16h.	35m.
Gwalior	755	16h.	32m.
Ghaziabad	812	16h.	32m.
Delhi	820	16h.	30m.
Jaipur	905	16h.	34m.
Anand	1,107	16h.	35m.
Dabhoda	1,109	16h.	34m.
Dehegam	1,111	16h.	34½m.
Bilimora	1,117	16h.	35m.

The second group is less numerous and comprises—

Parbatipur	7	16h.	25m.
Siliguri	112	16h.	26m.
Goalundo	131	16h.	27m.
Sonada	160	16h.	26m.
Darjiling	167	16h.	26m.
Hugli	221	16h.	27m.
Naihati	223	16h.	28m.
Khana	237	16h.	26m.
Chittagong	237	16h.	27m., 28m.
Gidni	340	16h.	29m.

The third group of observations, those from Burma, have not been utilised for reasons given on page 68.

Turning to Plate XXXIX, we see that the observations show a fairly regular relation between the time of commencement and distance from the epicentre. These records fall so well together that it is possible to draw a line through them, which represents the rate of progression of the earthquake, and from which we can deduce the rate of travel at any point with greater accuracy than is possible by direct calculation from the times recorded.

Two such lines are in fact drawn on the plate. Of these the one drawn firm is that which most closely passes through the centre of the constellation of time observations, and represents the probable true curve of the times of arrival of the shock at different places; the other, drawn as a dotted line, is that which, for reasons that will appear in the sequel, is theoretically more probably correct, though not so closely in accordance with the recorded observations. In either case the meaning of the line is that, taking any point on the line, a place at the distance from the origin indicated by the scale of miles at the bottom would have felt the earthquake commence at the time indicated by the scale of minutes at the right hand end of the diagram. Taking first the gently curved firm line, and tabulating the results obtained from this we find that, taking 16h. 26m. as the time at which the earthquake wave first reached the surface and started on its outward course, the distance travelled in—

1 minute was	170 miles.
2 minutes ,,	280 ,,
3 ,, ,,	350 ,,
4 ,, ,,	460 ,,
5 ,, ,,	580 ,,
6 ,, ,,	700 ,,
7 ,, ,,	840 ,,
8 ,, ,,	990 ,,
9 ,, ,,	1,150 ,,

Or, in other words, the distance travelled in the—

1st minute was	170 miles.
2nd ,, ,,	110 ,,
3rd ,, ,,	80 ,,
4th ,, ,,	110 ,,

5th minute was	. . . .	120 miles.
6th ,, ,,	. . . .	120 ,,
7th ,, ,,	. . . .	140 ,,
8th ,, ,,	. . . .	150 ,,
9th ,, ,,	. . . .	160 ,,

From these tables it will be seen that the slowest rate of travel seems to have been in the third minute and the third hundred miles. On either side of this limit, as we approach the centre or recede from it, there is seen to be a steady and regular increase in the rate of travel. This is evident from the diagram if it is borne in mind that, from the manner in which it was constructed, the rate of travel is indicated by the slope of the line drawn, the more nearly horizontal this is the greater the velocity indicated, and the more inclined the slower the rate of travel. If the diagram is examined, it will be seen that the line can be divided into two parts, one near the origin which is concave upwards—indicating that the rate of travel is diminishing—and the other away from the origin, which is convex upwards, indicating a progressive increase in the rate of travel. The point of junction of these two parts of the hodograph is that where the rate of travel was least and lies at about 280 miles from the origin.

The form of the hodograph drawn on Plate XXXIX resembles that of Schmidt's hodograph[1], based on the assumption of a higher rate of transmission of the earthquake wave in the deeper seated than in the more superficial portions of the earth's crust, and also the form of the same author's modification of Seebach's hyperbola,[2] when the curvature of the earth's surface is taken into consideration, and this might, at first sight, seem to favour its acceptance as the true one. On closer examination, however, it is found that the acceleration at a distance from the epicentre is too small to be accounted for by either of the hypotheses taken separately, and still more so by the combined effects of the two causes, *i.e.*, of the known curvature of the

[1] Jahresheft Ver. f. vaterl. Naturkunde in Wurttemberg, 1888, p. 254.
[2] *Ibid*, 1890, p. 227.

surface of the earth, and of the assumed increase of velocity of propagation with the increase of depth of the wave-path.

Rejecting Schmidt's hypotheses as, in this case, requiring a greater variation in the curvature of the hodograph than is indicated by the recorded observations, we must fall back on Professor Milne's suggestion that the shock which was felt was not the direct result of waves propagated from the centre through the earth, but of waves of an undulatory nature, originated at the surface in the epicentral tract, and propagated outwards along the surface, at a uniform rate of travel.

If this is so, the apparent variations in the rate of travel do not exist, and the hodograph would be a straight line which may be drawn through the Bombay and Calcutta times, continued to 50 miles from the assumed centre, and thence carried horizontally to the origin. This, which is shown by the broken line on Plate XXXIX, would agree with the recorded observations almost, if not quite, as well as the cuved line, and would give a uniform rate of propagation of about 119 miles per minute outside the epicentral tract.

So far as the time observations go, there is nothing to enable us to decide between the two, for, though the curved line more closely represents the mean of the observations plotted, yet the straight line does not anywhere depart from it by more than about half a minute of time, while, if we exclude the very discordant records such as those from Allahabad and Bareilly, and give less weight to those which give times of 30 or 35 minutes past 4 o'clock, and are consequently merely approximate in their intention, it will be seen that the straight line represents the mean as closely as does the curved line, when all the observations are taken into consideration and given approximately equal values. When, however, the records of the unfelt earthquake at distant observatories come to be considered in Chapter XV, we will see that the second explanation, that represented by the dotted line in Plate XXXIX, is the more probable one of the two, and we may take it that the earthquake wave travelled along the surface, at a tolerable uniform rate of about 120 miles an hour.

A point of some importance to determine is the exact time of origin of the shock or rather that at which it first reached the surface. In doing this, we may take the records of places within the central area, such as Shillong, and deduce the time directly; or obtain it by calculating back from the observations at places outside that area. Of these two methods the latter gives the best results, at any rate in this case, but before discussing the result so obtained, the few observations that were made in the central area may be noticed.

At Shillong the exact time of the commencement of the shock is given by Mr. J. C. Arbuthnott, C.I.E., Deputy Commissioner, as 5-11 or 5-12 P.M.; the Assistant Superintendent of Telegraphs, Shillong division, in his official report says—"As soon as the shaking was over, I looked at my watch, and allowing for the error of my watch by that day's time, found the time was 5-16 P.M. I estimated the duration of the whole earthquake to be about 1½ minutes." This would place the commencement at from 5-14 to 5-14½ P.M. Babu Nishi Kumar Ghose, Agent of the Oriental Life Office, writes that his time-piece, which was regulated with the gun at 1 P.M., was stopped by the earthquake at 5-13 P.M. Other clocks dug out of the ruins are said to have shown times varying from 10 to 15 minutes past 5. Taking 5-13 P.M. local time as a probable mean, and deducting 47m., the correction given in the Telegraph Guide, we obtain 16h. 27m. as the probable Madras time of origin, with a possible variation between 16h. 25m. and 16h. 29m.

This estimate can be checked by the returns from other places situated within the central area, or close to its borders. The Telegraph Master of Goalpara reports the commencement as 5h. 9m. P.M., or 16h. 27m., Madras. From other telegraph offices there are either no returns or the times given are evidently mere approximations. At Kuch Bihar, which, as will be seen in chapter X, was close to the central area, if not within it, I have a report from Babu Kedarnath Mozumdar, Superintendent of Works, Kuch Bihar State, who was looking at the clock in the Lansdowne Hall at the time and noticed that it was 2 minutes past 5 (16h. 25m., Madras time). The Station Master of Siliguri gives the time as 16h. 26m.; of Parbatipur as 16h. 25m.; and the same time is given by a number of neighbouring stations on the line, being probably the nearest even 5 minutes. All these tend to confirm the Shillong time, and we may take it provisionally that the time of origin was not later than about 16h. 26m. or 16h. 27m., Madras time.

This time can, however, also be obtained, with a greater degree of accuracy, from the hodograph. It will be seen that none of the time records from the central area, just referred to, have been incorporated on Plate XXXIX, the reason being, partly their divergence and the absence of any indications that any one of them could be regarded as of greater accuracy than the others, and partly the fact that any error in the position of the assumed centre would introduce a proportionally very large error in the deduced distance, an error which becomes practically negligible in the case of the more distant stations. This being so, the curve of the hodograph, for its first 150 miles, has been filled in by inference, and drawn so as to harmonise with the rest of the curve and with the results which have been obtained from other earthquakes. Consequently the point at which it cuts the central line is subject to all the risks inherent to the method of extrapolation. The time obtained, 16h. 26m., Madras time, may be out more or less, but I do not think that the error can be more than one-half minute of time either way, while the error is probably not more than 15s., and more probably of defect than excess. The time at which the earthquake first made itself sensible at the surface may be said to have been between 16h. 25m. 45s. and 16h. 26m. 30s., Madras time, or between 11h. 4m. 45s. and 11h. 5m. 30s., Greenwich mean time (civil), of the 12th June 1898, a result which shows as close an accordance with the time directly obtained as could be expected.

Before leaving this subject it may be well to devote a few words to the consideration of the degree of accuracy of the results obtained. This I regard as much greater than might reasonably have been expected, or than I myself expected, from the data available. It is true that the hodograph is a one-sided one, as no observations of any value were obtained except to the westwards, and to this extent its value is discounted, as the more distant observations could not be checked by corresponding ones lying in a different direction from the centre. On the other hand, the observations in that one direction show a surprisingly close agreement among themselves, an agreement which is in no way the result of the selection of observations on account of their concordance. All the observations, which are given in this chapter, were selected in the first instance on the grounds stated above (pages 63 to 67), because, from internal evidence of care or other reasons, they appeared intrinsically more trustworthy than those which did not, on the face of them, appear to possess that value which would alone make it worth while considering them. The selection was made before the distances were calculated, and was moreover originally made at a time when it was still believed that the earthquake originated in a very different situation to what afterwards turned out to be the case, a difference which would have introduced a very appreciable modification in the relative distances of all the places lying within 300 or even more miles of the centre finally accepted.

No subsequent additions were made to the selected list, though there are a large number of observations which show a close agreement with the times deduced from the hodograph, nor were any subsequently rejected, except those mentioned in this chapter. But briefly, it may be said every care was taken to prevent the results being affected by any bias, conscious or unconscious, and they may, I consider, be accepted as accurate at any rate, within an error of less than five per cent.

CHAPTER V.—THE RATE AND RANGE OF MOTION OF THE WAVE PARTICLE.

In determining, or more correctly speaking giving a numerical value to, the violence of an earthquake, there are two quantities that have been used; one the greatest velocity or rate of movement of the wave particle and the other the greatest acceleration or change in the rate of movement. In the absence of self-recording seismographs these may be approximately determined by the size and dimensions of objects overthrown and by the distance to which objects have been projected by the earthquake.

In the case of this earthquake the data are not so abundant as could be wished for, owing to the paucity of objects suitable for seismometry, and as the details of the results of the calculations are given in Appendix C, together with a short discussion of the validity of the formulæ in use, they will not be repeated here. It will be shown there that the results obtained from the formulæ which give the values of the two elements, velocity and acceleration of wave particle, are not in accordance with each other, and the explanation of this want of accordance discussed. Here it will suffice to say that, even if we cannot compare the values obtained by two different formulæ at two different places, or even at one and the same place, we may still compare the results obtained by the same formula from similar data and so see whether there is any difference noticeable in the deduced violence of the shock.

Taking the maximum rate of acceleration first, we have the following probable average values :—

Dhubri .	. 2,700	mm.	or	9	ft.	per sec.	per sec.
Goalpara .	. 4,200	,,	,,	14	,,	,,	,,
Gauhati .	. 3,600	,,	,,	12	,,	,,	,,
Shillong .	. 3,600	,,	,,	12	,,	,,	,,
Cherrapunji	. 3,000	,,	,,	10	,,	,,	,,
Sylhet .	. 3,600	,,	,,	12	,,	,,	,,
Silchar .	. 1,200	,,	,,	4	,,	,,	,,

In each case higher and lower accelerations have been obtained, some of which have been rejected for reasons given in Appendix C. Others represent real but local variations in the rate of acceleration, which is known to vary within wide limits even in closely adjacent spots. The values given are what appear to be fair average ones for the whole station.

Comparing these results it will be seen that the violence of the shock was practically the same at Shillong, Gauhati and Sylhet,[1] somewhat more at Goalpara and less at Dhubri, while at Silchar, it was decidedly less. It is to be regretted that no numerical value can be given for the violence of the shock at Rangpur or Kuch Bihar.

At Cherrapunji the shock would appear from the figures to have been slightly less violent than at Shillong, but it was quite as destructive, the lesser acceleration being apparently made up for by the greater range of movement.

In the foregoing passage reference has only been made to the acceleration in a horizontal direction, as deduced from the formula in common use. This has been employed as it is the only one available, though it seems certain that no great value can be attached to the results where, as in the present case, there was a large vertical component in the motion. At Shillong, Gauhati, and throughout the epicentral tract, stones have been projected upwards, as described in Chapter IX, and this fact shows that the acceleration in an upward direction must have been greater than that of gravity, that is to say more than 32 feet per second per second. How much greater it is impossible to say but in places it may have been four or five times as great.

Put into simple language this means that the measured violence

[1] It must be noticed that the violence, or power of destruction, is not the same as the destructiveness, or destruction actually caused, and this is especially true where, as is generally the case, the terms are used solely with regard to the effects produced on buildings. Here many other considerations come into consideratior besides the violence of the shock.

of the shock was equal to that of a sudden arrest after a fall of about 8 feet. That the effect produced on human beings and animals was not the same as that of such a fall is not difficult to explain; it is due both to the smallness of the range of motion, and to the fact that its direction was oblique and not directly upwards, thus allowing the muscles and joints to yield and so diminish the violence of the shock.

Fishes were differently situated; attacked on all sides and over the whole surface of their body by a blow of greater violence than this, they were killed in myriads, as by the explosion of a dynamite cartridge. In the Garo Hills, even where the rivers had been unaffected by landslips, the fine fishing pools of the Sumesari river were found devoid of fish; I was informed too by the Garos that the number of fish caught in their traps was phenomenally small in 1897, and that for days after the earthquake the Sameswari river was choked with thousands of dead fish floating down from the upper reaches. In the Borpeta subdivision of the Kamrup district the fish were killed in the same manner, and I was informed by Captain Gurdon that on his way in from Nalbari to Gauhati he saw two floating carcases of Gangetic dolphins which had been killed by the shock.

At Dilma, in the Garo Hills, I got some evidence to show that the shock was locally of sufficient violence to disable men. I was informed that two Garos were drowned in one of the lakelets, formed by the Chedrang fault, through which a village path used to run. The lakelet is due to the damming up of a small drainage valley by the fault, which has here a throw of about 25 feet; the stream is a very small one and the valley open, so that it is improbable that the water would accumulate sufficiently to drown men in full possession of their faculties and able to escape, but if we suppose that the violence of the earthquake was sufficient to stun them it is easy to understand how they might be drowned by the collecting waters before they recovered consciousness.

The way in which forest trees have been snapped across in the neighbourhood of these faults, as described in Chapter IX, shows that the violence of the shock must have been very great, probably four or five times as great as at Shillong or Gauhati. If we assume that it was only twice as great, or the acceleration at least 64 feet per sec., it would be equivalent to the shock of sudden arrest after a fall of 64 feet; if three times, then the corresponding fall would be 144 feet, and so on, and as the men must have been close to the line of fault, where the focus came up to the surface, it is difficult to put a limit to the possible violence of the shock.

This, however, is conjecture, incapable of support by numerical estimates or calculation. All that can be regarded as certain is that violent and destructive as the shock was at such places as Shillong, Gauhati, Goalpara, it was still more violent at other places within the epicentral tract, where fortunately there were no towns or populous settlements to feel the full power of the earthquake to destroy.

For the maximum velocity of movement, I propose to take only the values obtained from bodies projected by the shock. These give for—

Goalpara . .	3,300	mm.	or	11	ft. per sec.
Gauhati . .	2,400	„	„	8	„ „ „
Rembrai . .	4,200	„	„	14	„ „ „
Silchar . . .	450	„	„	1·5	„ „ „

These figures do not come near those of some other earthquakes. For instance, if Von Humboldt's statements are accepted, the maximum velocity of movement of the wave particle must have been 80 feet per sec. in the Riobamba earthquake of 4th February 1797,[1] as against 14 feet per sec., the highest recorded here.

Seeing that the maximum velocity, maximum acceleration

[1] R. Mallet, Neapolitan Earthquake of 1857, Vol II, p 340.

amplitude, and period of an elastic wave, are so related to each other that, given any two, the others can be determined, it might be thought that from the data available we could deduce both amplitude and period of the earthquake wave; and from the data so obtained to form some idea of the violence which accompanied the high velocity obtained at Rembrai. When this is attempted, however, it is found that the results are absurd, and the only possible conclusion that can be come to is that the high velocities of movement required to account for the way in which stones were shot through the air, to a distance of as much as 8¼ feet, were not those of the earthquake wave, but due to bodily displacements of the ground; movements which left the hills permanently higher than they had been before the earthquake.[1]

As this means that the motion of the ground due to the earthquake waves was complicated by movements of a much larger scale of a very different character, it is evident that we cannot employ the high velocities obtained at Rembrai to form any sort of estimate of the acceleration, or violence, of the earthquake at that place. We are thus deprived of the only means of attaining even an approximate estimate of the extreme violence attained by the earthquake, and must remain content with such vague guesses as have been attempted.

The only direct measure of the amplitude of the wave, or of the greatest backward and forward movement of the wave particle, was at Cherrapunji. Two oblong masonry tombs, standing close together and oriented with their longer axes north and south, have been partially destroyed on the inner sides, the space between them being filled with debris. On the outer sides, they are almost intact, but the tombs have been driven bodily down into the ground, and on either side, to east and west, there is a depression with a vertical side parallel to the outer surface of the tomb and a smooth flat bottom

[1] See Appendix C.

over which the base of the tomb has slid. The pair of tombs and the depressions are shown in section in fig. 7.

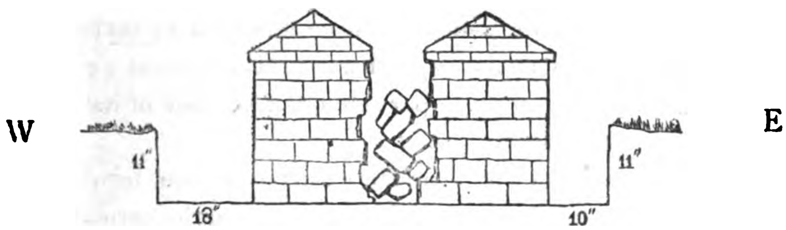

Fig. 7. Section of tombs in the cemetery at Cherrapunji.

The edge of the western depression has the grass growing undisturbed up to the edge of it, and along the edge small fragments of lime and plaster show that this was originally in contact with the edge of the tomb, which has now moved away to a distance of 18 inches. On the east the edge of the depression is raised and the grass and earth forced upwards by the thrust of the tomb against it; the breadth of this depression is 10 inches.

These depressions are evidently due to the backward and forward movement of the tombs in the ground, or rather the backward and forward movement of the ground against the tombs, which remained comparatively stationary in consequence of their inertia. If we assume that the two tombs behaved as a single mass, but that after the shock they were left in a position slightly different from their original one, the range of motion of the earth would be the mean of the widths of the two depressions, that is 14 inches. But the earth on the east has obviously been forced up, while that on the west has not; the movement on the east side has consequently received a check which that on the other has not, and we may take the wider depression, 18 inches, as representing the range of movement. A third supposition is that the two tombs have not exactly retained their original relative position, but have been pressed closer together: if this was due to an easterly movement of the western tomb, then 18 inches would represent the range of movement added to the displacement of the tomb, while 10 inches would represent the range of movement, less any easterly shifting of the eastern tomb which may have taken place.

Whatever the interpretation may be in detail, it is clear that the extreme range of motion cannot have been less than 10 inches, may have been as much as 18 inches, and was probably about 14 inches; the amplitude, or range of wave particle on either side of its original position, being half these amounts.

Large as the amplitude appears there can be no room for doubting its correctness, but this probably does not represent the normal amplitude. The cemetery at Cherrapunji is situated near the edge of a high sandstone scarp, and the presence of this free surface would lead to a locally greater amplitude than what prevailed in these hills generally. In a somewhat similar position, on the Bálpakrám plateau in the Garo Hills district, I found vacancies separating the soil from the larger rocks, against which it lay, that indicated quite as large a range of motion.

At Tura I obtained some direct evidence indicating the range of motion. The house occupied by Mr. Dring, of the American Baptist Mission, is a wooden frame house resting on wooden posts, which are not continued into the frame of the house. After the earthquake, Mr. Dring noticed that some of the posts had rocked in the ground with the movement of the house, but others had stood firm and the framework of the house had slid over their top. The extent of this movement, as shown by the marks on the under side of the frame, was 5 inches away from the post, or a total range of 10 inches. Another wooden house, also belonging to the Mission but built with posts sunk into the ground, had a wooden flight of steps leading down to the ground; after the earthquake it was noticed that their lower end had been thrust out about 5 inches from its original and final position. Assuming, as is fair to do, that there had been an equal displacement in the opposite direction, where its traces could not be seen, we may conclude that the house moved 10 inches relatively to the ground. In either case the relative movement was probably less than the actual, for the houses would, to some extent, be dragged along by their attachment, and it may be taken that the amplitude of the wave at Tura was not less than 6 inches, or the total backward and forward travel of the wave particle 12 inches.

I was also informed by Mr. Dring that after the great shock was over, he went across to a neighbouring house, which had been wrecked, and on the road he saw a fissure, the opposite sides of which were moving up and down to the extent of a couple of inches. Besides these measurements of the range of motion I noticed throughout the Khasi hills, that vacant spaces by the side of large boulders were common and frequently four or five inches across, even when I saw them, about six months after the shock; originally they must have been larger, and it may, I think, be taken that throughout the whole tract lying west of Shillong and Gauhati, as far as the hills extend, and probably over a large area of the plains besides, the amplitude of the wave motion was nowhere less than 3 inches, while in many places it was over 6 inches, the extreme range of motion of the wave particle being twice these amounts.

CHAPTER VI.—EARTH FISSURES, SAND VENTS, AND ALLIED PHENOMENA.

Fissures in the ground, and the formation of vents from which sand, water and mud have been poured out, are phenomena which have been known to accompany almost every really great earthquake, and even moderate ones, where favourable conditions have existed, but in no case, of which there is historic record, have they been so widespread or so numerous as in the great earthquake of 1897.

The theory of their formation was first clearly understood in the case of the Cachar earthquake of 1869,[1] and the explanation has been

[1] R. Mallet and T. Oldham: Notice of Some Secondary Effects of the Earthquake of 10th January, 1869, in Cachar: Quart. Jour. Geol. Soc., XXVIII, 255-270 (1872). See also Mem. Geol. Surv. Ind., XIX, 46-60. (1882).

so generally accepted and repeated in subsequent memoirs and textbooks that it might seem unnecessary to reproduce it here. This will, however, be done briefly, in order that the additions to our knowledge, consequent on the effects of the last earthquake, may be more clearly understood, and the repetition will besides enable me to bring out more clearly the fact that the fissures, which are formed by, or at any rate are observed after, a great earthquake, belong to two distinct types, a distinction which does not seem to have been generally recognised and sufficiently emphasised before now.

One class of fissures comprises those superficial ones caused by the disturbance of the surface soil, or occasionally of solid rock. These fissures probably start at the surface and penetrate down to the depth, whatever it may be, that they reach. They are a result, more or less indirect, of the wave motion, which has been set up elsewhere and travelled to the place where the fissures are formed. The other class is of deep seated origin, and when a fissure of this class, which I propose to distinguish by the name of *fracture*, appears at the surface, it may be taken to have been propagated upwards from below. So far from being a result of the wave motion, fissures of this class must be regarded as a cause, and as surface manifestations of the deeper seated fracture by whose formation the wave motion was originated. In their immediate vicinity there will usually be found indications of an abnormal violence of shock, which falls off rapidly on either side, while in the case of fissures of the first class no such local excess of violence will be noticed. Only those fissures which fall into the first class will be noticed here, a discussion of those belonging to the second will be found in Chapter IX.[1]

[1] As an instance of what I believe to be a confusion of these two types of fissures, I may quote Dr. J. F. Julius Schmidt's account of the Vostizzia earthquake of 26th December, 1861. (Studien über Erdbeben, 2nd ed., Leipzig, 1879, p. 68.) In the description and map (plate IV), a great fissure is shown running along the foot of the hills for about three miles, and is said to have been marked by a change of level of the opposite sides to the extent of 6 feet or more. Besides this number of smaller and more irregular fissures, accompanied by sand vents are described as occurring in the alluvium near the sea shore. Dr. Schmidt attributes all to the same cause a displacement of the alluvial deposits, but after a careful study of his description, I find it difficult to resist the conclusion that the great fissure represents part of the focus of the earthquake, and is in fact a fault, while the others are secondary effects of the earthquake similar to those treated in this chapter.

The mode in which the fissures, with which we are at present concerned, are formed is fully dealt with in Vol. XXVIII of the Quarterly Journal of the Geological Society of London, and at page 52 of Volume XIX of these Memoirs. It will consequently be unnecessary to go over the same ground in detail, but an explanation of the process involved may be given in as few words as seem compatible

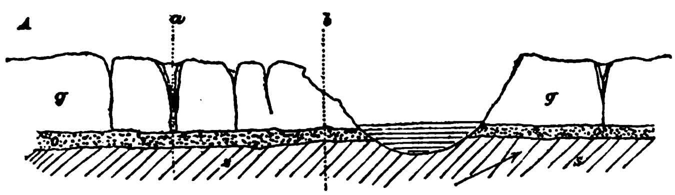

Fig. 8. Diagram to illustrate the formation of earth fissures.

with clearness. In fig. 8 let *g g* represent an upper stratum of the alluvium, cut by a river channel, and *o o* a sandy or muddy bed of less cohesion, along which the upper stratum *g* can slide over the lower *s s*. When *g g* is thrown into movement by the earthquake wave there will occur a time when all the particles between the lines *a* and *b* will be moving towards the river, and all to the left will be moving in the opposite direction. In these circumstances the momentum of the mass *a b*, which is partially free to move over the layer *o o*, sets up a strain which tends to part the surface layer at *a*, the plane of separation between the portions of the surface layer which are moving in opposite directions, that is to say, in opposite semiphases of the wave; if this strain is sufficiently great, a fissure will be formed and the piece *a b* will move forward towards the river channel, and this movement may well give rise to fresh fissures by the strains set up in the moving mass.

I have spoken of the fissures as entirely due to the horizontal movement of the wave particle, and this horizontal movement would of itself be sufficient to account for, and is probably the main factor in their formation, but for the ejection of sand and water a certain amount of vertical movement is necessary. In fig. 9 suppose the wave to be

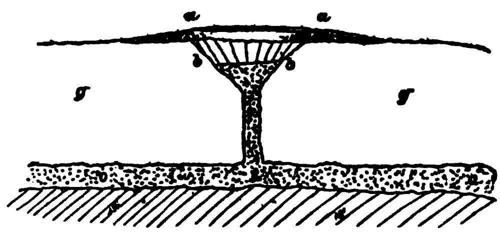

Fig. 9. Diagram to illustrate the formation of sand vents.

emerging in the direction of the parallel lines in *s s*. The upper surface of this layer will move upwards against the stratum *o o*, of loose sand or mud and water, and the wave motion will be transmitted through it to the upper layer *g g*. But the inertia of this will cause *o o* to be strongly compressed, and if there is an opening through to the surface, whether pre-existent or a fissure formed by the earthquake, this pressure may be sufficient to force sand and water to the surface. By the repetition of the pressure a succession of spurts may be forced up; but a large body of semiliquid matter, once set in motion, does not come to rest at once, and so, by the momentum of the moving water, its flow would be made more or less continuous, and the spurting, which has been described as taking place, is to be attributed to a closing in of the sides of the fissure, and consequent forcing out of the water between its walls, rather than to the direct action of the earthquake wave on the underlying stratum.

After the passage of the earthquake the pressure on the soft water bearing stratum will be relieved, and the water which had been forced out may be sucked back with sufficient force to wash down the upper edges of the fissure and form a crateriform hollow with deeply scored sides.

Turning now to a consideration of the special facts revealed by this earthquake, which lead to a modification or addition to the explanation given above, there is one which stands out prominently, that the existence of a free surface, such as that formed by the river channel in fig. 8, is not essential to the formation of fissures in a compressible material, such as forms on alluvial plain. Throughout the region where fissuring was common the fissures are certainly more numerous and conspicuous near the edges of river channels, or of the artificial reservoirs known in India as tanks, but they are not confined to such positions and may be met with in positions where they cannot be accounted for by the movement of a portion of the alluvium bodily towards an excavation, whether natural or artificial.

The possibility of the formation of such fissures is a direct consequence of the soft and unconsolidated nature of the soil, but the mechanism is not so clear. It seems improbable that the inertia of the stretches of alluvium thrown into movement in opposite directions could cause this compression and subsequent separation along the lines of fissure; the late Mr. R. Mallet showed that they could not be the direct result of a wave of elastic compression[1]; and the most probable explanation is that their formation was in some way connected with the visible undulations of the ground, induced by the earthquake, which travelled as independent quasielastic or purely gravitational waves. Such waves traversing the alluvium would throw each part into alternate compression and extension as the surface was bent into a concave or convex curve, and in a compressible material, decidedly lacking in elasticity, this might easily lead to the formation of fissures.

A very noteworthy point about these fissures, formed away from and independent of, the river courses, is the manner in which they usually run parallel to, and along either side of, any road or embankment. It is a well known mechanical principle that where there is a sudden change in section, in other words a sudden change in strength, the point of junction is a point of weakness, and the strength at that point is less than it would have been if one part had not been stronger than the other. For instance, in a screw bolt, as ordinarily made, the portion on which the screw thread

[1] Brit. Ass. Rep., 1850, p. 53.

is cut is weaker than the shank; if the screw thread ends abruptly the bolt will always give way at the junction of the two parts, this being a point which is weaker than any other in the bolt, and, paradoxical as it may seem, that bolt may actually be made stronger by weakening the stronger part till the strength of the bolt is equal at every point of its length.

This principle is of universal application, and from it we see how the heaping up of an embankment on the surface of the alluvium produces a line of weakness along its base on either side. Besides this cause of weakness, we have the fact that the material for the embankment is usually derived from a row of borrow-pits on either side of the bank. These two causes acting together give rise to a special aptitude for fracture, and we find nearly everywhere throughout northern Bengal and lower Assam that the roads and railway lines were bounded on either side by a set of fissures running parallel to the road in all such places where fractures have not, for other reasons, been formed across the road.

There was a very noticeable tendency for fissures, of the nature now being considered, to range themselves parallel to each other, and at first the direction was not unnaturally presumed to be at right angles to the direction of propagation of the earthquake wave. This assumption was, however, found to be untenable and no such general rule applicable. Whether any connection might have held good between the direction of the fissures and that of the visible surface waves cannot be decided, as the observations are too scanty. It is certain that these undulations did not necessarily travel in the same direction as the earthquake wave,[1] and it is possible that where the movement was sufficient to cause fissures to be formed, they followed the direction of the crests and hollows of the surface waves. Even if we suppose, what is probable enough, that the direction of propagation of these waves is largely governed by local peculiarities of the constitution of the surface layer of the alluvium,

[1] See Chap. II, pp. 20, 26, 36, 40.

these same peculiarities would encourage the formation of fissures in the same direction as the crest of the waves, or at right angles to it, rather than in any other direction.

In his official report on the earthquake in Kuch Bihar, Mr. D. R. Lyall, C. S. I., Superintendent of State, remarks that where the soil is sandy the usual form of fissure was a simple opening of the soil, but in the racecourse at Kuch Bihar, where the soil is more clayey, there was generally a double fissure, the soil between which sank from a foot to eighteen inches, and, as a rule, no sand issued. Near Maimansingh Mr. Grimes noticed the same feature, where fissures ran on either side of the road, and throughout the area affected by fissuring, it is common to find two parallel fissures bounding a strip of sunken land.

Where the fissures penetrate down to a bed of sand or slime, part of which has been forced out through the fissures, it is easy enough to account for this subsidence, but it may also take place where no material has been forced out from below. Suppose two parallel, or nearly parallel fissures starting from the surface and gradually approaching each other underground so as to cut off a wedge shaped piece of alluvium as shown in fig. 10, then, as the wave reaches such a position that we have opposite semi-phases of the wave on either side of this pair of fissures and the movement of the wave particles away from the fissures, as indicated by the lower pair of arrows in fig. 10, there will be an opening of the

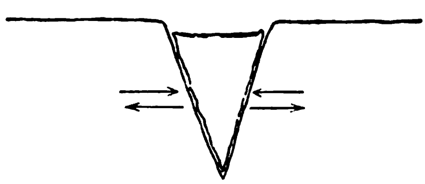

Fig. 10. Diagram to illustrate the formation of fissures in alluvium.

fissures and the wedge will drop down. As the wave passes on the action is reversed, the motion of wave particles in both semi-phases will be inwards and the wedge will be compresssed, as indicated by the upper pair of arrows. The waves pass on, the first condition is resumed, the wedge drops a little further, to be compressed once more, and the process is repeated and the subsidence of the wedge continues till the alluvium has attained its maximum possible compression or the earthquake motion ceases, whichever occurs first.

Another form of fissure, which is much akin to that just treated, in as much as it is due to compression of the alluvium and not to bodily movement at a free surface, is the fissure which so constantly runs along the junction of hill and plain and is accompanied by a settlement of the alluvium.

All along the foot of the Khasi and Garo hills, wherever the alluvium of the plains extends up to foot of the hills, and is not separated by the fan of a local stream, the alluvium has separated from the hill, and a sudden drop of from 1 to 5 feet is found. This scarped face of separation is very marked where the road from Tura issues on to the plain of the Brahmaputra, and has been referred to in official reports as a proof of subsidence. The vertical face of separation is about 5 feet high and at first sight has much the appearance of a true fault, but on closer examination is found to follow the windings and irregularities of the foot of the hills in a manner which makes this explanation impossible.

The separation along the foot of the hills is not confined to the alluvial plain of the Brahmaputra but is also noticeable in the case of the small patches of peaty alluvial soil found in the valleys on the plateau of the Khasi hills. These alluvial bottoms are carefully terraced for rice cultivation, up to their very edge, and as the Khasias had commenced to irrigate them when I marched through the hills in March, I was able to see at a glance, by the varying depth of water lying on the land, what changes of level had taken place.

In many places I noticed that the original curve of the horizontal alluvial surface into the hill slope was abruptly cut off by a perpendicular drop, as at *bc*, fig. 11. From *b* outwards from the hill was

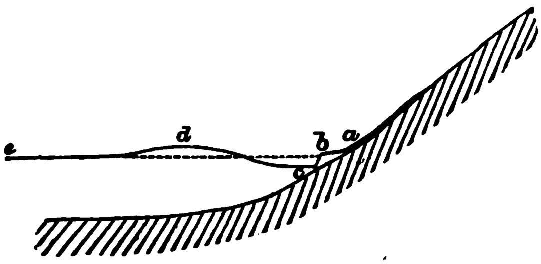

Fig. 11. Diagram to illustrate the displacement of alluvium along the foot of a hill.

a depressed area of from 10 to 20 feet broad in which the water had accumulated and completely flooded the fields; immediately outside this was a strip, *d*, which had evidently been raised above its original level, for the water could no longer be led onto it, and beyond this came the alluvium, preserving its original level and apparently undisturbed, except where it has been cut by fissures.

These features clearly reveal what has taken place. The thrust of the hill and plain against one another has caused the alluvium to be thrust forward and raised into the low ridge or roll at *d*, while on the return a space was left which could not be filled up by the alluvial soil without its surface being lowered. As in the case of the depression of a wedge of alluvium referred to above, the action was doubtless not completed by a single movement, but was the cumulative result of a succession of waves of compression.

On the borders of the alluvial plain of the Brahmaputra cultivation does not extend right up to the edge of the hills, and we lose the datum level afforded by the ricefields, but the same action took place there also, and produced the same result. In no case was the subsidence other than local and confined to a very narrow strip of land immediately bordering the plane of separation; in some places, as on the road from Tura, the amount of subsidence is increased by the large quantities of sand extravasated, and the impression of a general subsidence was favoured by the exceptionally high floods which rose right up to the foot of the hills, over land they never covered before. As will be seen in Chapter IX these may be accounted for without invoking any change of level, and, though it is not impossible that there may have been some permanent change of level it certainly did not take the form of a differential change just at the foot of the hills, nor is it reasonable to invoke an explanation of, which could not be applied to the precisely similar appearances observed elsewhere.

In the foregoing passages the opening of fissures, where they cannot be explained directly by a movement of the superficial portion of the alluvium towards an excavation, whether natural or artificial, has been attributed to a direct compression of the alluvium consequent on the momentum imparted to it in each semiphase of the wave, or to the effect of hard rock in contact with the softer alluvium. This has been done as the explanation seemed the most natural and simplest, but it must be pointed out that this same compressibility of the soft alluvium may permit of a general movement of the alluvium on a larger scale than that indicated; and several instances of this have been reported.

When the interrupted telegraphic communications were being restored, the repairing parties found that in many places the telegraph poles, which had originally been set up in a straight line, were displaced to the extent of ten or fifteen feet, and it was not always possible to trace any connection between this displacement and the neighbourhood of river or stream channels. The most conspicuous and best established instance which has been reported is on the Assam-Bengal Railway. Mr. Grimes' account of this will be found in Appendix A and it is also referred to in the Inspection report of Mr. J. E. Dallas, Offg. Senior Government Inspector of Railways, Assam, in the following words:—

"The worst case of the lateral shifting of banks occurs at mile 163¾. The centre line in this case was shifted to a maximum of 6 feet 9 inches; the length affected is several hundred feet.[1] I am not here describing the shifting 'of the permanent way on the bank, or of the bank on the ground. On examining the relative position of embankment, berm, borrow pits and trees, it is evident that the lateral shifting is due to the displacement of the ground and not of the bank only: there is no fissure at the foot of the bank, no wrenching of one part from the other. At the points where the displacement begins and ends the bank was much disturbed, practically wrecked, but there was no clean shearing anywhere."

From Mr. Grimes' account, it seems that this cannot be accounted for by a movement of the alluvium towards a river course, for the movement is parallel to the only river course in the neighbourhood; it is more probably attributable to the local presence of some yielding bed underground, along whose upper surface the superficial layers were able to move, the movement being taken up at the margins of the displaced tract by a gradual compression, extension, or distortion of the alluvium in a manner that would not have been recognisable but for the accident of the railway line crossing this disturbed tract.

Another effect of this shifting of the alluvium, due to its power of yielding to compression, was to be seen throughout large areas of Northern Bengal, Lower Assam and Maimansingh. Here the rice-fields, which are most carefully levelled to allow them to be flooded to a shallow and uniform depth, were found, after the earthquake, to be thrown into gentle undulations with a difference of level of occasionally as much as two or three feet between crest and hollow, and this apart from any changes of level directly due to the opening of fissures or sand vents.[2]

The displacement of the piers of bridges might be attributed to a similar cause. I do not refer at present to the displacement of the abutments of the bridges, or the shortening of their span, which is everywhere noticeable in the fissured tracts, but to the lateral

[1] In reply to an enquiry, the Chief Engineer of the line stated this to have been 2,400 feet.

[2] The disturbance, which even comparatively deep-seated beds in the alluvium were subjected to, is evidenced by the fact, recorded in Mr. D. R. Lyall's official report to the President of the State Council, Kuch Bihar, that eleven bends were found in a single length of pipe in a Norton's tube well when it was taken out after the earthquake.

displacement of the piers whose foundations are sunk in the beds of the rivers and could not consequently move laterally in the manner indicated in fig. 8. Instances of such shifting are mentioned in Mr. Hayden's report (Appendix A), and the effects in one instance are represented in Plate VII, where it will be seen that the piers have been shifted in an up and down stream direction, and also along the length of the bridge in such manner as to deprive the ends of the girders of their proper support. Another instance is shown in Plate XXVI, fig. 2, where the narrowing of the space between the abutments is made very conspicuous by the bending of the hand rails and the projection of the girder over the abutments, beyond its original bearings.

Though this movement of the piers might be attributed to a general movement of the alluvium, such as that recorded on the Assam-Bengal Railway, it is more reasonably attributable to the disturbing effect of the forward thrust of the banks, which has disturbed the equilibrium of the alluvium under the river bed and caused its displacement, even to the depth of the foundations of the bridge piers.

The pushing forward of the abutments of bridges was universal throughout the fissured tracts and is referred to in Mr. Hayden's report and that of Mr. La Touche, and the narrowing of the river channels seems to have been still more conspicuous in places where there were no massively built bridges to assist in supporting the banks. In all cases it is due to the throwing off of the unsupported river banks and accompanied by the formation of fissures. As it was important to determine whether this narrowing of the river channels was in any way connected with a general compression of the country, enquiries were specially instituted with this object, but the replies received from the engineers in charge of the railway lines were unanimous in saying that the narrowing of the river channels had always been accompanied by breaks in the line on either side of an equivalent amount.

A very striking result of the displacement of the alluvium, whether by throwing off at the free surfaces of river channels or tanks or otherwise, was the bending of rails. This has been reported and illustrated before, especially in the case of the Charleston earthquake of 1886, and the great Japanese earthquake of 1891, but never has it been exhibited on so large a scale, or over so large an area as in the earthquake of 1897. The splendid series of photographs taken by Messrs. Kapp & Co., of the effects of the earthquake on the Assam Bengal and Eastern Bengal Railways, show many instances of this, but none so striking as that on the Tezpore-Balipara tramway reproduced on Plate VI from a photograph for which I am indebted to Mr. Kemlo.

This bending of the rails is uncontestible proof of compression, as it means that the two ends of the rail are closer together than they were before the earthquake, and here again there was an opportunity of determining whether there had been any general compression of the country or not. If the compression of the rails was only a local manifestation of a general compression it would be unaccompanied by a corresponding expansion, whereas if the compression were only local and due to displacements of the alluvium by the action of the earthquake wave there should be, for each case of compression, a corresponding stretching of the line elsewhere in the neighbourhood.

With the object of ascertaining whether this was the case or not special enquiries were instituted, of the managers of the Eastern Bengal Railway and of the Tezpore-Balipara tramway, as to whether each case of compression was accompanied by a corresponding extension of the line near by, or whether any general shortening was noticed. Unfortunately repairs had already been carried out and detailed measurements could no longer be made, but the replies distinctly point to each case of compression being accompanied by breaks in the line indicating an expansion which was, at any rate approximately, equal in amount.

Mr. J. W. de Tivoli, agent and manager of the Tezpore-Balipara tramway, writes :—

"No measurements were taken at the time, excepting of the biggest gap between the ends of rails where the line was torn apart. This distance was 5 feet 6 inches between the end of one rail and the other rail which had been fished to it. This break occurred 73 yards (measured by pacing) from the bend in the rails nearest the camera in the photograph (Plate VI) showing the two bends. There were eight other breaks between Sessa and Rangapara (4½ miles), the break being in all cases from 200 to 600 feet from the places where the line was bent out. In every case of a gap there was a corresponding bend or bulge within a few hundred feet as above stated. All the damage done to the line occurred where the subsoil was sand, saturated with water. Where the subsoil was compact red clay there was no damage whatsoever."

From the authorities of the Eastern Bengal State Railway the information received was of the same general tenour. Mr. J. A. Anderson, Engineer in Chief, wrote :—

"From two sketches I took on the ground, with measurements, I can state that in one case two rails closed up 1′ 8″ in 48′, and in another 3 rails closed up 1′ 4″ in a distance of 72′; in each case, besides a large amount of pulling out of joints, there were sheared fishbolts and gaps of 5″ to 8″ at each side of the compressed portion.

There were several lesser contortions in each case and I would guess the total shortening of rails, including closing up of joints to be about 2′ 6″ in 240′ this shortening being equated by the pulling out of some 30 to 40 joints on each side and the gaps above mentioned of 5″ to 8″.

In ordinary line the joints could close up a little less than ¼″ each, and could open out a little more than ¼″."

Mr. G. Moyle, Superintendent of Works, wrote :—

"Platelayers had to cut out such a large number of bent rails and close up so many joints that I am almost certain they kept no record that I can supply, with as near an approach to accuracy as possible, the general effect of the earthquake on the permanent way.

Cranking of rails and tearing of fished joints was frequent at miles 132-133 (Nilphamari), miles 157½ to 165 (Haldibari); still more freqnent between Rangpur and Kaunia, miles 126-145; very frequent throughout the trans-Teesta 2′ 6″ gauge lines, on account of light rails and small gauge. There were only two cases of 50lb rails cranking—the rails adjacent to Nilphamari up points and just beyond Nilphamari down-signal—and no instance of tearing. I only saw one instance of the line buckling in one place without tearing open at another within a few hundred yards, and that was at Raninagar, where the main line was shortened about 1¾″.

In all other cases cranking at one place was always accompanied by tearing at one or other, or on both, sides of the cranked rails, sometimes about 80 yards away, but usually much further, and in a few cases upwards of a quarter of a mile away. As a rule, rail joints, when torn, only opened about 3" but in some cases they opened out considerably more, and in a few instances as much as 10" or 11". I do not remember any case of the rails being torn asunder without cranking occurring in the vicinity."

From these statements it is obvious that the shortening of the rails does not necessarily indicate any general compression, and that it is rather to be attributed to local displacements of the alluvium, whereby a compression in one place is compensated by an expansion elsewhere, and generally at about 300 yards away.

So far I have considered only the effects of the horizontal component of the wave motion, or at any rate, the effects which might have been produced had there been no vertical component of the wave motion. We now come to the consideration of those effects which can only be explained by supposing that the wave motion had a vertical component, in other words, that the movement of the wave particle was to a certain extent up and down as well as from side to side.

First of these come the sand vents, and the first thing to be noticed is that in some cases they were not formed till after the earthquake shock had passed away. On this point the evidence of Mr. D. R. Lyall's account is decisive in itself[1], and a similar statement, to be found in the reports of Captain Gurdon and of the Magistrate of Bogra, who records that the *bhorkas* or sand craters appeared after the earthquake had ceased[2].

This appearance of sand vents, after the actual movement of the earthquake wave had passed away, is easily explicable, as the result of the momentum imparted to the water bearing stratum, a momenture which could not be immediately absorbed, and was in some cases sufficient to force the sand and water through the overlying beds weakened, as they doubtless were in places, by the earthquake which had passed away.

[1] See p. 26.

[2] See Appendix B

Less obvious of explanation is the fact, which appears well authenticated, that the issue of sand and water went on in some places for several hours after the earthquake was over. In the case of the earthquake of Vostizzia, on 26th December 1861, Dr. J. F. J. Schmidt observed that some of the vents then formed continued active for two hours after the shock had passed, but the activity was in this case, due, to the issue of gas, smelling strongly of sulphuretted hydrogen, the product of decaying organic matter. In the case of the present earthquake, too, some of the reported cases of continued activity of the sand vents were due to the deceptive appearance produced by the rising of gas bubbles through the water which filled the depressions in the craters, but there is still a sufficient residuum of credible accounts which point to a real outflow of water from the vents for some hours after the earthquake, in some cases said to be for 24 hours.

In Captain Gurdon's account he distinctly says that, the 'sand geysers were subsequent to the great shock and continued for quite half an hour.' In the Assam Government's official report on the earthquake, it is said that at Gauhati the bubbling lasted for 24 hours; other accounts from different parts of Bengal, which it is needless to quote in detail[1], mention the discharge as continuing for 12 or 24 hours, periods which evidently do not represent accurate periods of time, but may be interpreted as some or several hours.

Captain Gurdon's more moderate statement is, however, sufficient to show that there are cases in which the issue of sand and water may continue for a longer period of time than is explicable by the momentum imparted to the sand and water, or the overlying impervious layer, by the earthquake wave. This may most probably be explained as follows. When a layer of clay or clayey silt begins to form over loose sand, it at first exercises but little pressure, but as the thickness increases by successive additions of silt, the pressure on the underlying water logged sand increases. The specific gravity of this compact silt is greater than that of the quicksand

[1] See pp. 16, 20, 25, and Appendix B.

below and, were there a free outlet, it would sink into or on to the sandy layer till this had been compressed as far as the superincumbent weight could compress it. In the normal condition of affairs, however, the continuity of the surface layer allows of no free outlet of sand or water. The earthquake not only opened such outlets but, by the disturbance of the sand below, doubtless loosened it and made it more mobile, and as the specific gravity of the surface layers was greater than that of the water mixed with sand which issued from the fissures, the blocks, into which the former was broken up, settled gradually down on to and into the underlying quicksand, forcing up the superfluous water, which carried with it a certain amount of sand.

It is probably to this settlement of the surface layers that, in many parts, there was a conspicuous absence of the deep crateriform hollows due to the washing down of material by the indraft of the water returning after the passage of the shock. The absence of the scoring of the sides of the craters, so well shown in the photographs taken after the Cachar earthquake of 1869 was due, doubtless, to their obliteration by the heavy rains which fell immediately after the shock, but the crateriform hollows, shown so conspicuously in Plates X and XI, are in many places wanting, and all that could be seen were low rings of sand with a shallow hollow in the centre.

The force with which the sand and water issued from the vents was evidently considerable. In many accounts it is vaguely stated that the fountain rose to as much as 10 or 15 cubits, but these may be rejected, unless the phrase is meant to apply merely to stray splashes, which may easily have risen to that height. In the Charleston earthquake of 1886, it was found that the branches and leaves of trees standing over some of the vents bore splashes of mud up to a height of 13 feet above the ground,[1] and, considering the much greater scale of this earthquake, it is easy to suppose that stray splashes may have risen to even greater heights. The main body

[1] U. S. Geol. Surv., 9th Annual Report, p. 289 (1889).

of the water and sand, however, did not rise to anything like this height, though there is ample evidence that in many cases it rose in a solid column to a height of 2 to 4 feet or more.

Mr. R. R. Morgan, Superintendent of Pilots on the Brahmaputra river informed me that he was, at the time of the earthquake, proceeding up the river and was an hour's run from Dhubri. The first sensation felt made him think the steamer had run aground, and on going on deck he saw two spouts rising one on the north, and the other on the south, whose height he estimated at 12 feet.

Other credible accounts do not place the height at so high a figure, though this need not impugn the statement of Mr. Morgan, as it is probable that locally and for a short time the water was forced to a greater height than the average.

A few of these accounts may be noticed. At Nalbari, in the northern part of the Kamrup district, Captain Gurdon observed the water rising to a height of from 3 feet to 4 feet; Rai Bahadur Madhub Chandra Bardolai, Subdivisional Officer of Barpeta, reports that the sand and water rose to heights varying from 2 to 12 ft.; in a report by Devendra Bijoy Sur, Munsif of Isvarganj in Maimansingh, he states that he saw several vents being formed and estimated the height to which the water rose at 10 feet; at Rangpur the vents were seen in action by Mr. J. Elison, who observed them to rise in a solid column of sand and water to a height of about 1 feet 6 inches to 2 feet. In chapter II, there will be found accounts of eyewitnesses who estimate that the sand and water rose to heights varying between 2 and 4 feet.[1]

From these accounts we see that, omitting stray splashes or exceptional spurts, the bulk of the sand and water was forced not only to the surface but in a solid stream to heights of 2 to 4 feet above it. The force with which the water issued from these vents is also exemplified by the solid substances brought up with the sand. From almost every district where sand vents were formed to any great

[1] pp. 15, 20, 25, 26; see also Appendix B.

extent, it is reported that trunks of trees were thrown out, and from places near the foot of the Garo Hills the presence of lumps of coal and fossil resin is recorded. The specific gravities of these substances is, however, low, and they might be raised, even in pieces of considerable size, by no more rapid a current than was necessary to raise the sand.

This explanation will not, however, apply to two recorded cases of heavy substances being ejected. In the north of the Tezpur district, near the Bhoreli river, waterworn pebbles of hard rock were thrown out with the sand, and at Haldibari, in Northern Bengal, lumps of "lava" weighing as much as half a pound were thrown out with the sand. On examination this proved to be what is known in India as *jhama*, the overburnt bricks from the lining of the fire-chambers in brick clumps; it had undergone a marked decomposition and the fragments had acquired a whitish coating; they were evidently the remains of an old brick kiln, which had long been buried and were washed up with the sand and water as it issued from the ground.

In the inspection notes of Lieutenant Colonel H. St. P. Maxwell, C.S.I., Officiating Commissioner of the Assam Valley districts[1], two instances are mentioned which, if accepted as they stand, would lead to a very exaggerated idea of the force with which the sand and water issued, and for that reason must be noticed here. The first of these is at Nowgong, where it is said that the ejection of the sand had such force that covers of wells, imbedded in mortar, were hurled aside. The second is at Goalpara, where it is said that a well was altogether filled with sand and a portion of the wooden cover was hurled 30 feet distant where it lies half buried.

The first mentioned instance I was not able to examine personally, but the statement that the force of the issuing sand and water was sufficient to detach the wooden well covers may be accepted as correct; the other statement, regarding the well at Goalpara,

[1] Printed in the appendix to the official report of the Government of Assam.

is also correct if taken literally, but not in the interpretation which would naturally be put on it that the well cover was hurled through the air to its present position; while the true facts are, in a way, even more remarkable than Colonel Maxwell's description would indicate.

The well in question was a brick well surrounded by four brick pillars 5 feet high by 1 feet 3 inches square, which supported a wooden framework carrying pulleys for convenience in drawing water. Of these three remain standing, though cracked, while the fourth is missing. The well stands just on the line of one of the fissures which opened in the Goalpara bazar, and from which large quantities of sand were poured forth. This issue of sand was naturally especially abundant at the well, and the flood of sand and water picked up the broken pillar and floated it 65 feet to N. 50° E., from its original position to the spot where it now lies. The wooden well-cover I did not see, as it had probably been removed before my visit.

It will be seen from this that we have not to do with an actual projection of the masonry, and probably not of the wooden well-cover either, but still the force of the rush of sand and water must have been great to enable it to pick up a mass of brick-work of about 6 cubic feet in volume and carry it 65 feet from its original position.

Closely connected with the formation of sand vents was the filling up of river channels, tanks, wells, and all other depressions or excavations, over a large area. In part this was due to an actual outpouring of sand, but to a far greater extent to the forcing up of the bottoms of the excavations. That this is the true explanation especially in the case of light, bamboo structures, is clearly shown by many bridges crossing small streams or canals, these have in innumerable instances been forced up in the centre (see Plate XXVI) and the roadway, which was once horizontal or nearly so, rose after the earthquake in a more or less steep slope from either side. This forcing up of the central piers of the bridges shows that the filling up of the channels was due to an actual raising of their beds, and not to the outpouring of sand through vents and fissures.

The mechanism of this effect is easy to understand. If, instead of the continuous stratum represented in figs. 8 and 9, we suppose it partially cut through, as in fig. 12, by the tank T, the well W or

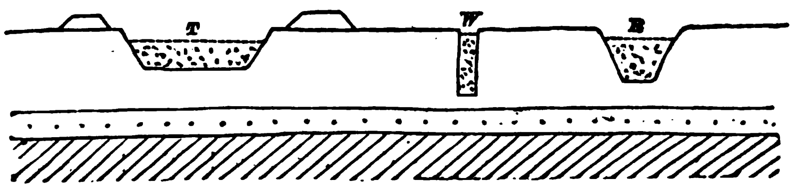

Fig. 12. Diagram to illustrate the filling up of stream channals and excavations.

the stream bed R, it is obvious that these introduce areas of special weakness and that when pressure is brought to bear on the bed of loose sand it is at these spots that the overlying layers of alluvium will most readily yield. Owing, however, to the area over which yielding takes place, it will often happen that pressure is completely relieved without any actual outpouring at the surface, and as the same amount of relief can be given by a lesser actual rise where the area is large than where it is small, the raising of the floors of depressions will, *cæteris paribus*, be inversely proportional to the area. This is in accordance with experience; the greatest raising is usually observed in wells, and these have often been affected when there has been no noticeable change in tanks or watercourses. Next to wells narrow watercourses have been most affected, while in large tanks and natural pools the raising of the bottom has been less than in water channels of equal depth but smaller width in the neighbourhood.

This filling up of river channels took place over a large area, but probably nowhere so conspicuously as in the tract of lowland which lies between the foot of the Garo Hills and the Brahmaputra. This tract is intersected by numerous channels, which carry a limited drainage in the dry weather, but, when the Brahmaputra is in flood, help to carry off the surplus waters that would otherwise submerge the country they drain. Before the earthquake these channels were from 15 to 20 feet deep, and in the dry weather the country was intersected by steep-sided depressions of this depth, at the bottom of which flowed a shallow stream. During the earthquake the bottoms of all these channels were forced up till level with the banks on either side, and during the ensuing dry weather the drainage of this tract, instead of flowing in deeply sunken channels flowed nearly level with the general surface of the land in shallow sandy channels.

This blocking of the drainage channels prevented them from serving their natural purpose when the rivers rose in flood, and large volumes of water which would otherwise have escaped were forced to spread over the surface of the land, thus giving rise to the exceptional floods of 1897. This matter, being dealt with elsewhere[1], will not be further referred to, but a direct result of the upheaval of the river channels may be noticed. As this upheaval was not due to an eruption of material from a great depth, but to a redistribution of comparatively superficial material, the rise of the river beds had to be compensated by a corresponding subsidence elsewhere, in general immediately contiguous to the river banks. It is obvious, that in a material which offers so great internal frictional resistance to deformation as the alluvium, the movement by which the deformation took place would ordinarily be transmitted to the shortest distance compatible with the effect to be produced; hence for this reason alone the subsidence of the banks would probably be greater than that of the alluvium further back.

Added to this there are two facts to be considered: firstly that, as the alluvium near the river banks was most broken up by fissures, the separate blocks would subside more readily than a large continuous sheet, and secondly that, as is the case with all deltaic rivers, the river banks were higher than the land behind them, and the pressure on the subjacent yielding layers greater than elsewhere.

[1] Chap. IX.

All these causes combined would cause the land immediately on either side of the river channels to subside more than elsewhere, and so the relative greater elevation of the river banks would disappear. In fact, the general effect of the earthquake throughout the districts where vents and fissures were formed, may be described as tending to reduce inequalities of level by causing a depression of the high ground and an elevation of the low.

A very remarkable result of the earthquake was the sudden rise of the rivers which accompanied it over a large area. I do not here refer to the extensive floods which were experienced later on and were indirectly the result of the earthquake, but to a sudden and immediate rise, varying from two to ten feet, which was observed immediately after the earthquake and passed off in the course of the next day or two.

At Gauhati the river gauge, which is fixed on a hill of gneiss, showed a height of 167·41 ft. above sea level at 7 A.M. on the morning of the 12th June; at 6 P.M., about three quarters of an hour after the earthquake, the water stood at 175·00, showing a rise of 7·59 ft; the next morning it had sunk to 173·11, at 7 A.M. on 14th to 169·96 and at 7 A.M. on 15th to 167·91, having thus recovered its normal level in two and a half days.

At Goalpara the Brahmaputra river is said to have invaded the station in the form of a wave 10 feet high and remained at 8 feet above its previous level after the earthquake had passed; at Kaunia, the Dharla river is reported to have risen 3 feet immediately after the earthquake. At Maimansingh the Brahmaputra river rose 4 feet and at Jamalpur 5 to 6 feet. In the Bogra district it is reported that the rivers all rose from 1 to 4 feet and that they all fell again within the course of the next three or four days; and so on. Many more reports could be quoted, but sufficient has been done to show that the phenomenon was a general, not an isolated, one.

In part this rise of the rivers may be attributed to the large volumes of water poured out from the sand vents. Surgeon Major Dobson's account[1] shows clearly how this might affect the amount of water in the drainage channels, and other accounts also describe how streams that were nearly dry suddenly filled with the water which issued from the ground. This cause would, in many instances, account for the sudden rise in the smaller drainage channels, but in the larger streams the rise was too sudden and followed too promptly on the earthquake to be explained in this manner. Here we must look to the raising of the stream beds to account for it, and to the gradual scouring out of the barriers so formed for the subsequent fall in level.

The raising of the river beds was probably continuous to a greater or less extent all along the channels, and the water was lifted bodily to a certain extent by the earthquake, but the major part of the rise appears to have been due to a different cause. The forcing up of the river beds was by no means uniform, and in some places was more extensive than in others; in this way barriers were formed across the stream, and on the up stream side the water was ponded up to the height of the maximum rise of the next barrier down stream. Thus a greater rise of water level occurred than would have been the case if the raising of the river beds had been uniform, while the barriers, being composed of loose sand, were more easily scoured away and the material of which they were composed distributed along the stream bed in such manner as to leave the water lower than the level to which it had risen immediately after the earthquake, though a little higher than it was before.

It was only where the blocking of the river channels took this form, and where there was a strong current, with its consequent power of scouring, that the channels reopened. Where the current was slack the beds were not scoured out and remained choked when the floods of August and September subsided; and where the channel was continuously and completely choked, the streams have in many cases deserted their old channels and formed new ones.

[1] See page 15.

In the foregoing passages the bearing of the phenomena, which were observed on the formation of earth fissures and sand vents has been discussed; we must now consider their extent and distribution. Before entering into this, however, it may be well to notice one qualification which must be borne in mind whenever it is said that they were universal or generally distributed over any specified area, namely that they can only occur where the local conditions are favourable.

The whole of the hill area must, of course be excluded, but even in the alluvium there are large tracts of an older alluvium, characterised by a much greater compactness than the newer. This older alluvium is usually of a red colour and forms elevated tracts, rising from the newer, of which the Madhupur jungle, lying between Dacca and Maimansingh, is the best known, though not the only one. To the north of the Ganges and in the Assam Valley there are several tracts of similar alluvium, which have everywhere escaped fissuring or the formation of sand vents, owing to their greater compactness and the absence of beds of loose waterlogged sand. Even in the newer alluvium such beds of sand are not everywhere near enough to the surface to allow of the production of the effects described in this chapter, but with these exceptions it may be said that fissures and sand vents were universal throughout the Goalpara and Kamrup districts, the western part of Darrang and the greater part of Nowgong, Sylhet, and the northern parts of Cachar. In Bengal they were equally prevalent throughout Rangpur, Dinajpur, Rajshahi, Maldah, Purniah, Pabna, Bogra, Maimansingh, and the greater part of Dacca.

Outside the area over which they were widespread, there is a larger area where they were less frequent. Fissures and sand vents are said to have been formed in the Murang district of the Nepal Tarai, north of Purniah. In Bhagalpur a few were found in the Supul sub-division, and near Colgong, on the banks of the Kosi and Ganges, respectively. A fissure 50 feet long by 1 foot broad is said to have opened in the Bihar cutchery compound. In the Santal Parganas they were formed near Deogarh and Godda. Stray fissures are reported to have been formed in the Bardwan, Bankura, Birbhum, and Midnapur districts, but none in Hugli or Howrah.

Fissures and vents are also reported from the Murshidabad, Nadiya, Jessor districts, none were formed in Faridpur or Bakarganj, or in the Chittagong division, with the exception of the extreme northern part of Tipperah.

In Assam fissures are reported from as far east as the Lakhimpur district, but only to the west of the Subansiri river. In the Sibsagar district a few occurred in the western part of the Sibsagar sub-division, but none to the east of Sibsagar. They were formed in the alluvium of the Dhaneswari (Dhansiri) valley, but none in Manipur. In Cachar they are confined to the north-western part of the district, and they were formed all over Sylhet.

From this it will be seen that the area over which fissures were fairly frequent, wherever conditions are such as render their formation practicable, corresponds very closely with that included in the fifth isoseist on map No. I, while the fourth isoseist includes the most distant places at which fissures could be formed even where circumstances were most favourable. In other words, the area over which fissures were formed abundantly, or would have been if local conditions were not adverse, reaches about 400 miles from east to west and about 350 miles from north to south, while the extreme limits from which they are reported to have been formed was nearly 600 miles in an E. N. E.—W. S. W. direction, between Sibsagar and Bihar; and 300 miles from north to south, between the Nepal Tarai and Midnapur.[1]

The greater length in an east-west direction is, however, deceptive, for it is partly, and may be wholly, due to the great range of

[1] Fissures were reported to have been formed in Gwalior and in the Kistna district. On closer enquiry being made, it was found that no connection could be traced between them and the earthquake beyond the fact that they opened somewhere about 12th June. They were probably due to drying or slippage of the soil and would have attracted no notice had it not been for the earthquake.

the Himalayas, which not only limits the area over which the formation of fissures and vents could be possible, but places an absolute barrier against the acquisition of any information as to the effect of the earthquake in that direction.

CHAPTER VII.—THE LANDSLIPS.

Landslips were caused by the earthquake on an enormous scale, and deserve a special notice, both as to their origin and distribution.

The cause of the landslips is not difficult of explanation. In fig. 13 let the shaded portion represent the solid rock of a hill, drawn

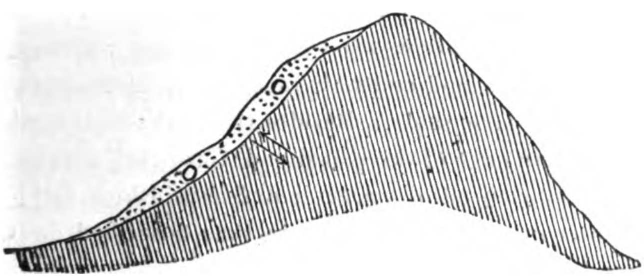

Fig. 13. Diagram to illustrate the formation of landslips.

in section, covered by the soilcap o o which is kept in place on the underlying rock by the friction between them. When the rock of this hill is set into elastic vibration by the earthquake wave, the superficial portion will, at one period or other of the shock, be set in movement outwards, and this movement will be communicated to the soilcap. In the next semiphase of the wave, the movement of the surface of the rock will be inwards, but the inertia of the overlying soilcap will prevent this following at once, and the effect will be a more or less complete reduction of the pressure of the soilcap on the rock. This reduction of pressure means a reduction of the friction, which alone prevents the soilcap from sliding bodily down the hill, and so a landslip is formed, where the reduction of resistance, and the slope of the hill, are sufficient to allow of it. In cases where the adhesion of the subsoil to the underlying rock is great, where its thickness is small, or where the violence of the shock is not great enough, the slippage of the surface layer does not amount to a landslip, and in these cases the hillsides are found to be scarred with fissures. At the other extreme, the momentum imparted to the surface layer may be so great that an actual outward pull is set up, sufficient to overcome the resistance, both of gravity and the adhesion of the subsoil to the rock, and then we have not merely a landslip, but the whole face of the hill shot bodily off. The conditions that allow of this appear to be rare, but they certainly did occur in some of the high scarps of the Khasi and Garo Hills.

So far I have spoken only of the landslips produced by the displacement of the more or less weathered surface layer; they seldom extend deep into the hill, and resemble in all their characters ordinary landslips of the same scale. Besides these, the high sandstone scarps of the southern edge of the Khasi and Garo Hills exhibit landslips due to the throwing off of a greater or less width of solid sandstone, in a manner precisely analogous to that described in Chapter VI but on a larger scale.

In the case of both these forms of landslips, the part of the hill which is left standing is always scarred with deep fissures, extending more or less parallel to the free face of the fall, and due to a partial detachment of the material between them and the edge of the actual slip. These fissures are very conspicuous on the Bálpakrám plateau west of the Mahádeo valley, as shown in Plate XXVII, fig. 1, but they are in all cases a secondary effect of the transmitted earthquake wave, just as the sand vents and earth fissures treated in the last chapter.

Having noticed the mode of formation of the landslips, we have now to consider the limitations on their formation. Foremost among these must be placed the violence of the earthquake, for it is only under very exceptional circumstances that a wave of low velocity, or acceleration, of wave particle could give rise to landslips. Given a sufficiently violent earthquake the other factor that comes into play, is the natural tendency of the hill to slip. This obviously varies with the slope, a gentle slope being much less liable to slip than a steep one and the nearer the slope reaches that critical angle, at which the soilcap would slip away of its own accord, the less the impulse required to set it in motion.

There is, however, another factor which appears to be of almost equal importance with the angle of the slope, and that is its height from base to crest. While travelling in the Assam hills during the cold weather of 1897-98, I had many opportunities of observing how steep slopes and scarps of a low height, had remained uninjured, while gentle slopes, when forming part of a hill rising to several hundred feet had been scarred with landslips.

This is well seen on the road from Shillong to Gauhati; for the first 14 or 15 miles, where the hills are high and cut by deep valleys, landslips are common, but for the rest of the way, where the height of the hills above the valleys is much smaller, landslips are almost unknown though the earthquake was on the average equally severe over the whole of this tract.

The explanation of this connection between the height of the hills and the degree to which they have been scarred by landslips is doubtless the greater swing which was imparted to the higher hills. In part, this is due to the fact that an equal angular motion would result in a greater linear movement at the top of a high hill than of a low one, but mainly it is due to the greater elastic play of the high hill, especially when steep sided; just as the end of a long switch jerked to and fro describes a larger are than that of a short one.

There is yet another factor in the production of landslips, and that is the mineral constitution of the hill. When this is composed of crystalline rock, the surface layer of disintegrated and weathered material is either thin, or it passes down into the unweathered rock in a gradual manner. In the former case, the thin skin may not acquire sufficient momentum to cause it to be detached from the underlying rock; in the latter, the gradual increase in the cohesion of the surface layer adhesion to the underlying rock is, more or, and in its less, proportionate to the increase of strain applied, and the surface layer will be much less liable to come away than if there was a more or less well defined plane of weakness.

In the case of sedimentary rocks, the boundary between the weathered soilcap and the underlying rock is generally more abrupt and the surface layer readily separates from the rock below. Added to this the sandstones, which form so large a proportion of the hills along the southern face of the range, have a much lower cohesive strength than the crystalline and metamorphic rocks of the central and northern portions of the range and, when they form high scarps, portions of the solid rock itself may be thrown off.

I have thought it necessary to devote some space to a general consideration of the causes which are concerned in the formation of earthquake-landslips, as very erroneous conclusions have been drawn from their distribution, and are generally held in Assam, as to the position of the focus of this earthquake. We see that besides the energy of the earthquake wave, the production of landslips is controlled by the petrological composition of the hill and by another factor, into which the angle of slope and the height of the hill enter, in other words, by its size and form. It is not possible to express mathematically the relative importance of these different factors, the nature of their influence can only be pointed out in general terms, but it is evident that any conclusion drawn by attributing the whole of the effects to only one of the operating causes must necessarily lead to error.

After these preliminary remarks we may proceed to a consideration of the distribution of the landslips and of their effects. In doing this, it is necessary to remember that the observations and information, on which the following passages are based, was obtained some time after the great earthquake, and that a part of the effects noticed was due to the action of the heavy rains of the three months following the earthquake, and part to the aftershocks of the great earthquake. Many of these were themselves violent enough to cause landslips, the more so as many hillsides, which had not come down in the great shock, had been badly shattered and weakened, and were more easily broken down than would otherwise have been the case.[1]

The heavy rains which followed the earthquake had probably even a greater effect than the aftershocks in bringing down hill-sides, which had been fissured and weakened by the earthquake, and the total results observed and recorded after the close of the rainy season included those of both these causes, nor was it found possible to separate the direct effects of the earthquake from its indirect effects, or those of the aftershocks. It may, however, be safely said that had the earthquake occurred three months later, at the end instead of the beginning of the rainy season, and at a time when all the hills were waterlogged, the landslips then developed would certainly not have been less extensive than those which were actually observed during the cold weather of 1897-98.

It seems certain too, so far as I could gather from careful enquiry, that by far the greater number of the landslips which actually occurred were the direct result of the great earthquake, and that the subsequent additions to the size and number were only a fraction of what could be seen immediately after the first shock.

Landslips were developed more conspicuously along the southern edge of the Garo and Khasi Hills, and especially in the neighbourhood of the Paniathit river and the hills immediately to the west of it. Viewed from the deck of a steamer sailing up to Sylhet, the southern face of these hills presented a striking scene. The high sandstone hills facing the plains of western Sylhet, usually forest-clad from crest to foot, were stripped bare, and the white sand

[1] On the 23rd of August, the Deputy Commissioner of the Garo Hills records in his tour diary that there were several severe shocks of earthquake, some of which sent rocks rolling down the hillside.

stone shone clear in the sun, in an apparently unbroken stretch of about 20 miles in length from east to west. Beyond this, the landslips, though still large and conspicuous grew gradually fewer, and it was not difficult to suppose that we had here the centre of the disturbance.

The true explanation, however, lies in the physical features of the hills, rather than in any greater violence of the earthquake. It is in about 91° E. Long, that the hills rise highest and most abruptly from the plains, and, being composed largely of soft nummulitic and supra-nummulitic rocks, are more easily broken into landslips. To the west, a strip of low hills separates the high hills from the plains, and to the east the height of the hills decreases in a marked manner beyond Cherrapunji. Eastwards of this I have not been myself, but according to accounts received the landslips, though still fairly numerous, are much less so than those near Cherrapunji.

At Cherrapunji the deep valleys are scored by landslips to a striking degree, so much so, that when looked at from a distance there appears to be more landslip than untouched hillside. It is difficult to detect any relation between the size and frequency of the landslips and the direction of slope, but though they seemed equally abundant on the east and west sides of the valley, they did seem to be somewhat more abundant on the slopes facing southward than on those facing north.

Further north, towards the centre of the hills, no such relation could be detected; the landslips were practically confined to the sides of the deeply cut valleys, whose general direction is about north north-east, south south-west. In the granite area round Laitlynkot (Lailang Kot) granite tors had been thrown down in great numbers and lay at the foot of the slopes. All this region has been extensively washed for iron ore in the old days, and most of the tors, which were overthrown, had been more or less undermined in the process.

Throughout the high plateau of the Khasi Hills, to the westward of Shillong, landslips are scarce, as the hills have mostly gentle slopes and do not rise high above the valleys. When, however, there is a high range, like that of the Mauterichán or Laubersát, which rises in a steep slope of 2,000 to 3,000 feet, or where the high plateau is cut by a deep gorge, landslips are not uncommon; and on the steep sandstone scarps of the southern face they are large and conspicuous, as has already been remarked.

Nowhere that I know of are they so strikingly developed as in the small valley of the Mahádeo, to the south of the Bálpakrám and Pundengru Hills. The valley forms an amphitheatre of about four miles long from east to west, and a mile and a half across. On the north are the hills of Bálpakrám and Pundengru, united by a narrow ridge of sandstone, scarped on each side ; to the west is another narrow ridge of sandstone, uniting the Bálpakrám hill to the plateau which separates the upper Mahádeo valley from the plains ; at the eastern end, one of the spurs of Pundengru runs southwards towards the outlet of the valley to the plains of Sylhet.

Here everything combined to favour the formation of landslips. The hills were composed of soft sandstone, they were steep sided, high, and narrow from side to side, and consequently were doubtless thrown into actual oscillation as a whole ; while the range of motion of the wave particle was not less than eight inches near the edge of the precipices. The result of these local conditions, added to the indubitably high energy of the earthquake wave, has been to produce an indescribable scene of desolation. Everywhere the hillsides facing the valley have been stripped bare from crest to base, and the seams of coal and partings of shale could be seen running in and out of the irregularities of the cliffs with a sharpness and distinctness which recalled the pictures of the cañons of Colorado. At the bottom of the valley was a piled up heap of debris and broken trees, while the old stream course had been obliterated and the stream could be seen flowing over a sandy bed, which must have been raised many feet above the level of the old watercourse.

At one place on the watershed, and on most of the narrow spurs running into the valley, the landslips on either side of the ridge had united to form a sharp edged crest to the ridge; and at one spot on the ridge connecting the Bálpakrám and Pundengru Hills, where a narrow strip of the old forest clad summit had been left, the violence of the oscillation it had undergone was such that the forest had been levelled to the ground.

This was not the only instance of this sort, but wherever throughout the sandstone plateau, there was a high spur with steep sides and a comparatively level forest clad top of a couple of hundred feet or less in width, I noticed that the trees had almost invariably been uprooted. They were not snapped across, like those described in Chapter IX, the conditions which allowed of this form of destruction being altogether local, but had been bodily up-rooted by the swaying of the trees from side to side.

In the country on either side of the boundary of the Garo and Khasi Hills Districts landslips are everywhere conspicuous in the sandstone country and are decidedly larger and more abundant on the southern than on the northern faces of the hills, but no conclusion can be drawn from this, as to the direction of travel of the earthquake wave, since the geological and orographical conditions are such as to necessitate the highest and steepest slopes facing southwards.

Westwards of the Sameswari (Sumesari) river, the Garo Hills, instead of rising in a high scarp from the plains, descend gradually by a series of low hills, and the conditions are less favourable for the formation of landslips. We find them, accordingly, less conspicuously developed, but wherever there is a high slope, such as the southern face of the Tura or of the Arbela ridges, landslips are numerous, while throughout the Garo Hills small ones are found on the steeper slopes.

The eastern limit of landslips appears to be in the North Cachar Hills, as the reports specially called for state that none were formed in Manipur or in the Naga Hills Districts. In the latter district cracks in the hillsides, or incipient landslips, were formed near

Kohima, and it is probable that the same might have been observed in the hills of the western part of Manipur, from which it is impossible to obtain any information. No landslips were observed in the Mikir Hills east of Nowgong, or in the hills south of the Sylhet valley.

The great range of the Himalayas with its deeply cut, steep sided valleys is always a region of landslips. Every year, in a large number of places, the strain becomes too great and a larger or smaller mass of soilcap and partially weathered rock is detached, and crashes into the valley below. In such a region, where there are large areas of hillside in a critical condition, and the restraint on the movement of the soilcap almost in equilibrium with the downward pull of gravity, the effect of a severe earthquake may be expected to be great ; and such was in fact the case. All along the north side of the Brahmaputra Valley, the range of the Himalayas is scarred by landslips, even to beyond Tezpur. In all years some are seen, but after the rains of 1897 they were in most unusual abundance, and many of them evidently of great size. As seen from the deck of one of the Brahmaputra steamers, they are abundant even to the north of Tezpur, but the effect of the earthquake does not appear to be very marked much eastwards of this. Westwards from the meridian of Tezpur, they get more numerous, and, so far as can be judged from the reports, attain their maximum to the north of the Goalpara District, in a part of the range not visible from the Brahmaputra. In Bhutan, landslips are reported to have been numerous and extended far back into the hills. They were observed in north-eastern Sikkim, and on the south face of the hills were formed even as far west as Darjiling, but apparently not in Nepal.

It will be seen from this that the east and west range of the landslips was more extensive in the Himalayas than in the hills south of the Brahmaputra Valley, and as there is no reason to suppose that the earthquake wave would be more readily transmitted along the Himalayas than through the crystalline rocks of the Shillong plateau this greater extent must be ascribed to the greater natural liability of the Himalayan hillsides to slip.

One more point may be noticed, that the region where they are most numerous lies a little west of the 91° meridian, or nearly north or north-north-west, of the region where they are most developed in the Garo and Khasi Hills.

Before finally leaving this subject, it will be necessary to notice some secondary effects of the landslips in modifying the forms of the watercourses. In the sandstone country at the southern edge of the Garo and Khasi Hills, the dislodgement of large bodies of weathered rocks, and to no less an extent the consequent exposure of hillsides previously protected by forest, caused enormous volumes of sand to be cast into the streams. One effect of this was the formation of great sand fans along the southern foot of the hills, where they wrought great havoc in the fields, and more especially in the orange and areca-nut groves, of Shella and other villages near the southern edge of the hills. Every stream of any size has in this way devastated many square miles of country, and the mischief is not yet complete; for not only are there still large quantities of sand not yet removed from the landslips, but the bare faces of the hills will be the source of fresh supplies of sand as they are scoured by the rain, until such time as vegetation once more resumes its sway.

Within the hills the effect has been no less striking. The burden of sand cast on to the streams was far greater than they could carry along their old gradients, and everywhere the beds have been raised, changing the whole character of the river channel in the process. Ordinarily, the beds of these rivers, which are raging torrents when in flood, consist of a succession of deep pools separated by rocky rapids. After the rains of 1897, it was found that the pools had been filled up, and the rapids obliterated by a great deposit of sand, over which the rivers flowed in a broad and shallow stream. In this manner the well known fishing pools of the Sameswari and the

Paniathit have been obliterated, and many smaller streams converted from deep, clear, rocky mountain streams to a shallow spread of muddy water, flowing over a sandy bed.

That this change is entirely an indirect effect of the earthquake, and a direct effect of the landslips it gave rise to, is shown by the fact that it is only within the sandstone area, where landslips are numerous, that the beds of the streams are raised in this manner. When we get further back into the hills, where landslips are few and where the crystalline rocks exposed by them are not so weathered or so easily washed down as the tertiary sandstones, and where, in consequence, the additional burden cast on the streams was comparatively small, we at once enter on an area in which the stream beds retain their original character unchanged.

Cases where streams were ponded up for more than a day or two were rare. One instance I saw at a village called Chochalja about 8 miles to the east of Damra, on the northern foot of the Garo Hills. Here a landslip had come down and shot out about 400 yards into the open valley, crossing the drainage channel and giving rise to a shallow pond, which had been completely filled up with sand by the end of January 1898. A much more remarkable instance was that of the landslips near Sinya, to the east of Rambrai, which dammed up the drainage of a large area for nearly three months and gave rise to a destructive flood.

To the east of Sinya, in the northern Khasi Hills, the Scob river flows in a narrow gorge of about 2,000 feet in depth, whose sides are scored throughout its length by innumerable landslips. Near Sinya village one much larger than the rest came down and, shooting across the valley, formed a barrier, of which the remains are more than 200 feet above the present level of the river bed. Above this barrier, the waters of the Scob accumulated in a great lake till, about the 7th September,—I was not able to ascertain the exact date—the barrier burst and a flood of water rushed down the valley. Three miles lower there is said to have been another landslip as large as that at Sinya, but it was not able to stand against the rush of the waters, while all the way down the eighteen miles to where this river issues from the hills, the old channel was encumbered by innumerable landslips, none able to check the rush of the flood, which, picking up from them a mass of boulders, gravel, sand and trunks of trees, carried it along in one great rush, dealing destruction for many miles within and beyond the limits of the hills.

Where this river leaves the hills at Ukiam and enters the Kamrup District it takes the name of the Kulsi, having been joined by an affluent from the west, known as the Sri Nadi. At Ukiam it is joined by a small tributary from the west known as the Dharan, which drains some low hills by a series of valleys of very low gradient, the lower part filled with alluvium. Still lower down, the Kulsi is joined by an affluent known as the Lokia Ján (Khoolsee Khal of the Revenue Survey maps), a sluggish stream flowing through an alluvial flat, from which groups of low hills rise.

The effect of the flood in this part of the river course was remarkable and, though not seismic, may be noticed here. The direct effect of the flood was to sweep everything before it; trees were uprooted and soil and subsoil washed away from the underlying rocks, but in the side channels the rush of the water was *upstream*. As a result, I found in the Lokia Ján that trees had been bent over, and vegetation flattened down in an upstream direction, while every obstruction had an accumulation of driftwood and weeds on the downstream side, or just the reverse of what would have been the case had the flood been an ordinary one coming down this channel. The distance that the flood rushed up this channel, with sufficient force to leave conspicuous traces of its effect, was fully two miles, and at the junction of the tributary with the Kulsi was a great barrier, some 30 feet high and 300 feet across, composed of a matted mass of tree trunks that had been swept down from the hills and stranded there.

In the Dharan, the same effect could be seen; a short way from the junction stood a tall fig tree, with a runk of about six feet in diameter, but rotten at the core. This had been broken off, probably by the earthquake, and the rush of the flood wave travelling up the valley had picked up the trunk and carried it full quarter of a mile upstream.

The indirect effect of the flood has been to raise the bed of the Kulsi. This can be seen in the main stream, which had formerly a series of deep pools and was a well known fishing river, but now flows over a broad and shallow, sandy bed. In the side streams it is even more conspicuous, for the raising of the bed of the main stream has ponded up the water in them, and led to the submergence of a large area of ground. In the Dharan the streams have been flooded for a distance of five miles and more from the junction, and all the cultivation of Ukiam village submerged. Close to the junction, I found a depth of 20 feet of water in the Dharan, but this is local and due to the scour of an eddy from the Kulsi; further back the depth of water was about 12 feet, showing that the bed of the Kulsi had here been raised not less than 10 feet above its former level. In the Lokia Ján and another small tributary flooding had also taken place, but to a less degree.

In the Sri Nadi, which joins the Kulsi just above the Dharan there had been similar flooding, but the depth of water was only about five feet, and only extended a short distance, to a sandy delta composed of material brought down by the Sri Nadi, which had nearly joined on to the deposits in main stream. The Sri Nadi differs from the other tributaries already referred to, not only in its greater size but in draining the higher hills by a steep sided, narrow gorge, on the sides of which are many landslips. Evidently the stuff washed down from these and from the valley of the main stream and other tributaries joining it below the landslips at Sinya, had already raised the level of the bed by over five feet, before the great flood came down; the remaining rise of five feet, being due to this flood and to debris brought down during the rest of the rainy season.

CHAPTER VIII.—THE AFTERSHOCKS.

The study of the aftershocks of earthquakes is one to which much attention has been paid of late years, and the investigations by Messrs. Omori[1] and C. Davison[2] of the records of the aftershocks of the great Japanese earthquake of 1891 have thrown light on the laws which govern their gradual diminution in number, and the gradual shifting of the main centre of seismic activity.

In India there is no regular system of recording earthquakes, such as has been established in Japan, but one of the first steps taken after the great earthquake of last year was to interest as large a number of observers as possible in keeping a record of the shocks felt by them. Such record is of course much less perfect than one kept by automatic instruments, but in spite of this drawback a large number of valuable observations have been recorded, which will be published in a separate part of these Memoirs so far as seems necessary. At present the time has not come, nor the time been available, for a collation and discussion of these observations, but a brief review of the general course and character of these series of aftershocks may be given.

At Shillong, Tura, and all other places within the epicentral area, as defined in the next chapter, the shocks felt during the day following the great earthquake were to be numbered by hundreds. In fact it is impossible to give a number, for it does not seem to be an exaggeration to say that for days the earth never came to rest, but was in a constant state of gentle tremor, interrupted at frequent intervals by distinctly sensible, and again at longer ones by severe shocks. At the Bordwar tea estate, situated right on one of the focal fractures which extended to the surface, I was informed that for a week after the great shock the surface of a glass of water standing on a table

[1] On the aftershocks of earthquakes Jour. Coll. Sci. Imp. Univ. Japan, VII, 111-200 (1894).

[2] On the distribution in space of the Accessory shocks of the great Japanese earthquake of 1891: Quart. Jour. Geol. Soc. LII, 115 (1897).

was in a constant state of tremor, and at Tura I was informed that a hanging lamp was kept constantly on the swing for three or four days. Some idea of the frequency of the earthquakes in Shillong may be gathered from the fact that a record kept on the night of the 19th June, seven days after the earthquake showed 33 distinct sensible shocks in 4½ hours, or an average of one nearly every 8 minutes.

Besides the innumerable smaller shocks there were many which would have attracted considerable attention in any other years, and not a few that would have been classed as great earthquakes and have become the subject of special investigation. Dwarfed as they were, however, by the great one which preceded them they attracted comparatively little attention, and it is impossible to get much more information about them than a somewhat imperfect record of the area over which they were felt.

One of these, occurred at about 1-30 A.M., local time, of the 13th June, and another about 11½ hours later. Both of these were severe enough to have caused great destruction in the central area, had there been anything left to destroy, and were felt as far as Calcutta—the former even as far as Sutna, on the East Indian Railway beyond Allahabad. At 10-40 P.M., of the 13th there was another shock of sufficient extent to be felt at Calcutta, and again at 0-47 A.M., on the 14th. After this there was a falling off in number and violence of the shocks, but on the 22nd June, at 7-24 P.M., and 29th at 10-19 P.M., shocks were again felt in Calcutta. Towards the beginning of August there was a revival of seismic activity, and on the 2nd another shock which was felt at Calcutta at 8-58 P.M. One more was felt on 9th October at 1-40 A.M., and since then there has been no shock severe and extensive enough to be felt at Calcutta.

In the early days following the great shock, the only detailed records I have been able to obtain refer to earthquakes of considerable severity and covering a considerable area, but as more complete records were obtained it was found that those from the central area were not only remarkable for the number of shocks recorded, but also for the fact that a very large proportion of these were distinctly local; shocks being recorded at one station for which no equivalent could be found at a neighbouring one. To a large extent this was doubtless due to inevitable imperfections of the records, but after making every allowance for this there remained ample evidence of the local character of many of the shocks. That is to say, the subsequent earthquakes did not start from one centre, but from a number of centres scattered over a large area.

There is one point of view from which these shocks can be considered, which has an important bearing on the determination of the nature and extent of the seismic focus. This is the distribution in space of the shocks felt in the period immediately succeeding the earthquake.

At Shillong and Tura they were, as has already been remarked, to be numbered by hundreds a day for the first few days. At Kaunia the Station Master reports 41 shocks after the great one, up to the end of 15th June. At Maimansingh the meteorological reporter counted 83, while in north Gauhati, there were no less than 561 in the same period according to a correspondent of the *Assam* newspaper:

From 15th June to 15th July I have records from Kaunia, Kuch Bihar and Maimansingh, and from north Gauhati, on the authority of the correspondent of the *Assam* referred to above; the number of shocks are as follows:

	15 to 30 June.	1 to 15 July.
N. Gauhati . . .	125	84
Kaunia	57	...
Kuch Bihar . . .	64	31
Maimansingh . . .	52	46

These show that the shocks were much more frequent in north Gauhati than would be expected if the centre of the earthquake was wholly within the hills south of the Brahmaputra Valley.

From the latter end of July I have a valuable set of records of earthquakes, kept by the hospital assistants in charge of the dispensary in the Goalpara District, for which I am indebted to Surgeon-Major E. F. H. Dobson, Civil Surgeon of the District. The value of these varies greatly and at some stations the record is obviously incomplete, but the broad lines of the relative frequency of earthquakes may be accepted.

The first point to notice is that they were very frequent at all places near the north foot of the Garo Hills. Thus for the period 1st to 15th August the record for Tura being 124 shocks there are reported—

151	shocks	from	Darangiri,
182	,,	,,	Goalpara,
94	,,	,,	Lakhipur,
94	,,	,,	Krishnai,

while the total number of shocks reported from Dhubri, as the combined record of several observers is only 48 for the same period, and if we go still further west, we have only 12 shocks reported at Kuch Bihar and 28 at Rangpur.

Further north in the alluvial plain we have the town of Bijni in the extreme north of the Goalpara district, where no less than 105 shocks were reported by the hospital assistant, while from Rupsi 10 miles to the N. W. of Dhubri, only 10 are reported for the same period 1st to 15th August. The Rupsi record is probably incomplete, but still there is good reason for concluding that earthquakes were really much less frequent there than at Bijni, and this is confirmed by the reports from Borpeta in the Kamrup district, whence 113 distinct shocks were reported in the period 1st to 9th August.

Apart from these records, which might be considered to be tainted with the inaccuracy attaching to most Indian statistics, I have independent and unquestionable evidence that long after earthquakes had become rare at Gauhati they were still being felt at the rate of several a day at Borpeta.

It is to be noticed that most of these earthquakes were feeble ones, which were not felt over any large area, and were for the most part local. We have consequently an area covering the part of the alluvial valley of Assam on either side of the 91st meridian, where the conditions were very similar to those of the central area in the hills; that is, it was an area where small shocks were frequent and much more numerous than in the country outside.

If we turn to the south of the hills we find a great contrast. Not only are the reported shocks much fewer, the combined records of Sylhet and Sonamganj giving only 20 shocks from 1st to 15th August, but there is no indication of their being markedly more numerous at one place than another in an east or westerly direction.

To the west of the Garo Hills earthquakes are also relatively numerous and, what is more important, there is a strip of country running out into Bengal where the conditions are very like those of the central tract. This is well shown by the records from Rangpur, which appears to have felt quite a number of small shocks that were not recorded at the neighbouring stations, from which regular returns were being received.

An examination of the area over which many of the larger shocks were felt, shows that in most cases the shocks that were felt over the Assam Valley and north-eastern Bengal did not penetrate into Sylhet and Cachar or were only slightly felt at places close to their northern boundary.

Taking these facts into consideration we see that the centres of the aftershocks, in the period shortly following the main shock, were not symmetrically situated with reference to the axis of the range separating the Brahmaputra and Barak Valleys, but that they lay for the most part towards the northern edge of these hills or under the alluvium to the north over an area which extends northwards along and near the 91st meridian of East Longitude.

CHAPTER IX.—RESULTS OF AN EXPLORATION OF THE EPICENTRAL TRACT.

During the fine weather of 1897-98 I had an opportunity of making an examination of the epicentral tract, which could not, unfortunately, be so complete as, for instance, that undertaken by the United States Geological Survey in the case of the Charleston Earthquake of 1886.

The reasons for this are three-fold: firstly, the great area; secondly, the impassable character of much of the country; and thirdly, the limited time available. Of these, the last may be regarded as the corollary of the first; had the area to be examined been only as great as in the case of the Charleston Earthquake, the time would have been ample, but instead of an area with the largest dimension of about 30 miles, the corresponding tract of ground in the present case had a length of about 300. Added to the size of the area was the fact that a considerable proportion of it, and that too where the most extensive permanent changes were produced, is covered by a dense growth of forest or bamboos, through which it is only possible to advance by laboriously cutting every step of the way, once the beaten track is left. For this reason the examination had to be practically confined to the beaten tracks, which were only left when there seemed good reason to suppose that the results would repay the time taken up, in slowly forcing a way through the jungle at a rate of about three hours to the mile.

In describing the results obtained I do not propose to adopt a narrative form. On the map No. II is shown the course actually followed on this tour of examination, and many of the results obtained have already been incorporated in other chapters of this report. The present one will be chiefly confined to a consideration of the evidences of permanent changes of level due to, or perhaps rather the cause of, the earthquake.

Before dealing with these, it may be well here to notice the evidences of a large vertical component of the wave motion which were to be observed throughout the whole of the area examined.

In Captain Howell's report on the earthquake in the Garo Hills it is mentioned that a stone lying on the surface of the parade ground was thrown a distance of three feet, and as, from the description, it is evident that the stone had travelled through the air, and not along the ground, from its original to its subsequent position, it is evident that the impulse given to it must have been upwards as well as sideways.

Many other cases, similar to this, were observed in other parts of the Garo Hills, but they were not so conspicuous as they might otherwise have been, owing to the high and rank vegetation which covers these hills. It is different on the bare plateau of the Khasi Hills, where the combined effects of greater altitude, smaller rainfall and annual fires have denuded the greater part of the hillsides of all vegetation except grass. Here we have grassy slopes on which numerous rounded blocks of weathered crystalline gneiss or granite lie more or less imbedded. Of these, many were driven from their seats and hurled through the air, leaving a sharply cut mould in the soil, slightly broken down on the side towards which the block was projected. These moulds are commonly seen on slopes, as those in Plate XXXI, but are also to be found on level patches of ground, while the fact that the stones were actually projected through the air is shown by the marks of the spot where they fell, at varying distances from their original position, and the absence of any trace in between of their having touched the ground. At Nongstoin I noticed that a piece of granite, about 3 ft. long by 1 ft. broad and 9 inches thick, which had been lying flat on the ground, had been thrown upwards into the air to such a height that it broke across in falling.

Between Mokersa and Nongstoin, I measured the distances to which several of these blocks had been thrown on level ground, and found it varied from 2 ft. to 4 ft. as a rule, and these may be taken as the general limits throughout the tract examined. When the force of the earthquake was sufficient to tear these blocks from their site, it appears generally to have been sufficient to project them about 2 ft., and though smaller distances of projection are not uncommon, they are fewer in comparison than the greater ones.

About 4 ft. is the usual upper limit, though this is exceeded locally. The greatest projection, and the most marked evidence of vertical movement, I saw was about four or five miles north of Rambrai, where a long splinter of granite, 3 ft. long and of triangular section with sides of about 12, 10, and 9 inches,—a naturally weathered fragment which had been lying flat on the surface of the ground—was thrown 8½ft. from its original position. About quarter of a mile from this a group of small Khasia monoliths, some 6 ft. high,

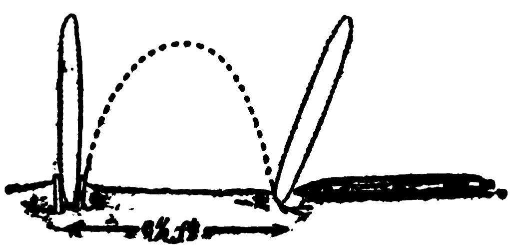

Fig. 14. Disturbance of Khasia monuments near Rambrai.

had been destroyed, not by breaking off, nor by upsetting, but by being shot upwards out of the ground as indicated in fig. 14. One of these had travelled 6½ ft. through the air from the place where it had stood to the place where a deep dent marked the spot at which its lower end had first struck ground. The socket in which its base had been buried was almost uninjured, and the angle at which it was shot upwards could not have been much, if at all, less than 60° with the horizon.

It may be noticed that in almost every case of projection of a block of stone it also turned over in its course, and now lies with its originally lower side upwards. This overturning of objects projected by earthquakes is a commonly observed phenomenon, and may in part be attributed to the nature of the impulse imparted by the earthquake wave. In the case of these projected stones, however, the explanation is probably more simple. In every case where a stone, partially imbedded in the earth, was shot out in a slanting direction, it had to break down one edge of the cup in which it lay, and even where, owing to the form of its under surface no actual breaking away of the earth was necessary, there was a greater frictional resistance than on the opposite side. Consequently that side of the stone, which lay towards the direction in which it was thrown, had a slight drag put on it, and so a spin was imparted to the stone, which made it turn over in its course.

Another point to be noticed is that the stones which were projected were all much of a size and, with very few exceptions, from about 1 ft. to 3 ft. in diameter. The reason of this is not far to seek; each stone, partially imbedded in the ground, was restrained by the adhesion of the soil to the stone, a restraint which had to be overcome by the momentum imparted to the stone by the earthquake wave.

The adhesion is proportional to the surface in contact with the earth, and increases with the square of the dimensions of the stone; the force which tends to overcome this adhesion varies with the mass of the stone, that is to say, with the cube of the dimensions. In the case of very small stones, then, the momentum imparted to the stone is not sufficient to overcome the attachment, but as the dimensions increase a limit is reached, when the pull of the stone is sufficient to allow it to become detached from the soil. The exact size of stone at which this becomes possible depends on several factors, the maximum velocity imparted to the stone, its specific gravity, the nature and degree of moisture of the soil, and the form of the cavity left by the stone. With the conditions prevailing in the Khasi Hills, at the time of this earthquake, the limit was, as has been stated, about 1 ft. in diameter. Smaller pieces were occasionally projected, but this was comparatively rare, except in the case of pieces lying absolutely loose on the surface.

The upper limit of size is due to another cause. The motion of the earthquake wave has to be communicated to the stone through the, comparatively, yielding and inelastic soil, in which it is partially imbedded. But the stone does not take up the motion immediately or without some resistance from its own inertia, which increases with the mass of the stone, and part of the energy of the shock is consequently taken up in compressing the soil under the stone. In the case of smaller fragments this proportion may be small, the stone quickly takes up the movement of the earthquake wave, and the velocity communicated to it may be not much less than that of the wave particle in the rock below the layer of soil. The larger the mass of the stone, however, the slower it takes up the motion of the wave and the greater the work expended in compressing the yielding soil beneath it; after this deduction, the velocity of movement actually imparted to the stone may be insufficient to enable it to leave its bed and travel as a projectile through the air.

This upper limit was about 3 ft. in diameter, the fragments being generally of a rudely spheroidal form. Larger rocks were displaced in abundance, dislodged from their sites, and caused to roll down the hill-sides, but I saw very few cases of stones as large as 3 ft. in diameter which had been actually projected in a free course through the air.

Both at Goalpara and Gauhati instances of objects projected through the air were observed, and at the latter place there is independent evidence of a high angle of emergence. In the centre of the river, opposite Gauhati, rises a small island, commonly known as Peacock Island, which is regarded as sacred, and crowned with an ancient temple. It is stated that before the shock of 1897, though earthquakes had visited and damaged both banks of the river, they had never been able to reach this island, an immunity which was attributed to its sanctity, but finds a rational explanation in the deep channel of the Brahmaputra which surrounds it.

The investigations in Japan[1] have shown how completely the

[1] J. Milne: Trans. Seismol. Soc., Japan, VIII, 98; S. Sekiya and F. Omori, Jour. Coll. Sci. Imp. Univ. Japan, IV, Pt. ii, 249 (1891).

destructive earthquake waves are confined to the surface, and how a trench of only 20 ft. deep is sufficient to cut them off and protect a building by which it is surrounded. In the case of Peacock Island, the channel of the Brahmaputra served as a protection against earthquakes, at any rate against those which originated at a distance and were travelling nearly horizontally. The surface waves were exhausted against the edge of the river bank, and the main wave, passing under the channel of the Brahmaputra, left the island, as it were, in a shadow and protected from anything but an insignificant tremor.

The great earthquake of 1897, however, instead of reaching Gauhati from a distance, was travelling upwards from below. The bed of the Brahmaputra consequently gave no protection, and the temples on Peacock Island suffered as severely as those on either bank of the river.

Before proceeding to a consideration of the permanent changes, which accompanied this earthquake, it will be well to describe briefly the physical geography and structure of the country involved. The group of hills lying south of the Brahmaputra Valley is commonly known in different parts by names derived from the tribes inhabiting it, but no general name has found its way on to maps. In previous publications of this Survey the names of Shillong plateau and Assam range have been proposed and used, and of these the former is the most descriptive of its character, the latter most convenient for general use. It is an elevated tract composed of crystalline gneissic and granitic rocks, with some metamorphic schists and quartzite, which carries a varying thickness of cretaceous and tertiary rocks along its southern edge. These newer beds thin out to the north, not by denudation but by an original thinning out due to deposition on a sloping sea bottom. For about 50 miles, along the north of the Sylhet plain, this hilly region ends abruptly in a uniclinal flexure or as faulted scarp. At its western end there is a fringe of low hills between the edge of the highlands and the plains of Maimansingh. To the east, the line of flexure and faulting bends round to the north-east and appears to become one of the outlying members of the Patkoi or Barel system of disturbance; but too little is known of the geology of these parts to assert this with certainty.

Viewed from one of the higher points the plateau character of this mass of mountains is conspicuous. From Mao-phlang, for instance, the view is one of low, round topped ridges, all rising to the same general level and separated by shallow, open valleys, generally having a flat, peaty bottom. The character of the country is that of one which, to use a term for which we are indebted to the American geologists, has been 'base-levelled,' that is to say, has been worn down by the action of subaerial denudation till rain and river can have but little further effect in altering its form. Such a form of surface could never have originated on these hills in their present form; it points to a much lower elevation, and a change in the character of the hills is even now going on, for everywhere deep, steep sided gorges have been driven into the elevated mass from the lowlands on either side. The contrast between these deep gorges and the open, shallow valleys of the uplands is striking, and what is important to note, as showing the geologically recent date of the upheaval, the transition from one type of valley to another is abrupt. The deep gorges run up into the hill mass, maintaining their depth for a varying, but generally considerable, distance; then comes a comparatively short stretch of steep gradient, waterfalls and cascades, and the valley passes abruptly into the open base-levelled type of the highland plateau, which has as yet been uninfluenced by the altered conditions consequent on the change of elevation.

The deep gorges are not, however, the only places where steep and high slopes are seen. Traversing the plateau are a number of what, seen from one side, appear to be high ranges, all of which agree in the character that the crest of the range is the edge of another plateau sloping away from the summit of the steep ascent. These ranges vary in length and height, for the most part they have a general east and west or east-south-east and west-north-west direction, and die out gradually at either end, though occasionally they end up in a cross range or scarp.

Of this character are the Tura and Arbela ranges in the Garo hills, shown in fig. 15; the high ridge of the Shillong peak, which over-

Fig. 15. View of the Arbela range, from the road to Tura.

looks the lower plateau on which the station of Shillong is built is of a similar character, as also the Maothadraishan (Mauterichan) range, along whose foot the road to Nongstoin runs, and many other ranges. Looking from the summit of any of these ranges it is impossible to doubt that the undulating plateau which stretches away in one direction from the crest, was once continuous with the precisely similar plateau which slopes up from the foot of the range on the other direction. These ranges are in fact fault scarps, due to unequal elevation along faults, by which the rocks composing the range have been split.

The history of the Assam range, consequently, falls into three stages :—First, an old land surface which had long been exposed to denudation and worn down till the agencies of subaerial denudation had almost ceased to produce any further change, and the land surface was reduced to that aspect for which Prof. W. M. Davis has proposed the name 'peneplain.' Then this land surface was elevated, and the elevation was unequal, the rocks were broken through by fissures of which one side was raised further than the other, and instead of a uniform surface the old peneplain was broken up into portions which lay at different heights. Finally, the elevation of the plateau as a whole gave the streams a chance of eroding once more, deep gorges were driven into the range, and in parts the re-shaping of the surface has gone so far that almost all trace of the old peneplain is lost.

One point more may be noticed, that, so far as the main mass of these hills is concerned, the last elevation does not seem to have been accompanied by any marked compression. Undulations of the plateau, sometimes of considerable height, have been formed, besides the fault scarps, and these may indicate some compression. It is possible, too, that the faults are reversed ones, and so indicate compression to a small degree, but on this point there is no evidence available. Any way, the amount of compression which has taken place, if any, must be small in the main mass of the range. On the southern edge, where we come into the region of tertiary and cretaceous sedimentary rocks we also enter a region where there has been a certain amount of compression, as evidenced by the folding of the strata. Though the amount of compression undergone is small in proportion to that which the rocks of the Himalayas have undergone, it is not inconsiderable and points to an approach between the main mass of the range to the north and the portion of the earth's crust which lies to the south. The consideration of the nature and direction of the movement which has caused this must, however, be deferred.

After this brief account of the physical geography and structure of the country concerned, we may proceed to a consideration of the evidence of permanent changes due to the earthquake. These may be classified as follows :—(1) Faults and fractures, (2) differential changes of level, evidenced by interruptions of drainage, unaccompanied by faulting, (3) changes of level evidenced by reported changes in the aspect of the landscape, and (4) changes proved by a re-observation of the triangles of the Great Trigonometrical Survey.[1]

Of the faults and fractures, the most conspicuous example is that of the Chedrang fault, as I shall call it, from the name of the stream whose valley it follows. A sketch plan of part of the course of this fault, showing its effect on the drainage courses it crosses is given on Plate XLII, and in describing it, I propose to start at the point where it dies out, or at any rate beyond which it was not traceable, some six or seven miles SSE from where the Chedrang enters into the plains at Dilma.

At this point the fault is not directly recognisable by any throw at the surface, but the hillside is very much fissured, the vegetation has been much disturbed, and not a few small trees have been snapped off like that depicted in fig. 16, p. 150. Following the line of this disturbance to the NNW the fault crosses a small tributary, with a throw of 2 feet, and shortly after crosses the Chedrang river diagonally. On the upstream side of the fault a depression has been formed which was almost filled up by a deposit of sand.

Quarter of a mile down stream the fault, still running about NNW crosses the stream once more, and has here a throw of about

[1] The results of this re-observation were not received in time for incorporation in the body of this report. A detailed description will be found in Appendix G.

2 feet, the upthrow being, as everywhere else, on the eastern side. After continuing on the east of the river for about half a mile, the fault crosses it once more and, the upthrow being on the down stream side of the fault, the river has been ponded up for a distance of about quarter of a mile upstream. At this point the fault is double, being two parallel step faults separated by about 20 yards.

Continuing to NNW the fault keeps in the valley, close to the main stream, and has given rise to a number of small pools by blocking the side drainage. One of these, which had no outlet, was about six or eight feet deep, to judge by the appearance of the drowned vegetation in it; the bed of the old watercourse was recognisable, and its vertical height above the surface of the water was 20 feet, as determined by an Abney's level. As this old stream bed was formerly continuous with the one now submerged in the pool, the total throw of the fault cannot here be less than 25 feet.

Immediately beyond this pool the fault once more crosses the Chedrang and forms the waterfall shown in Plate XIV. The waterfall is a direct result of the fault, but it does not occupy the exact fault line; this is seen in section on the river side, and the rock on the east is seen to be shattered by a great number of nearly parallel and vertical fissures, which cut the rock into small fragments. These have been washed away by the rush of the stream when in flood, for a distance of about 20 feet back from the fault line, and the fragments dislodged have accummulated below the fall, reducing its height to about 9 feet.

Below the waterfall the fault runs along the stream bed for about half a mile, and the river now flows in a depression on the downthrow side of the fault, while the old river bed lies high and dry, as shown in Plate XV. Here we see on the right the old river bed with its waterworn boulders; on the left is the present channel, and separating the two is the fault scarp, composed in the foreground of rock, and further back of river boulders from top to bottom.

About half a mile below the waterfall, the fault leaves the river bed and runs for a short distance close to, but west of, the river before it enters a broad sheet of water. This pool, whose recent origin is shown by the number of dead trees and bamboo clumps standing in the water, has a maximum depth of 18 feet; it covers the course of the fault, but the inequality of ground level could be traced, by sounding, for some distance into the pool. About quarter of a mile from where it enters the pool, the fault leaves it once more, and here the throw has been reduced to almost nothing. Following the line of fault, it is found to increase in throw and to form a large pool by interrupting the drainage of a tributary valley. The throw increases, in about quarter of a mile, from nothing to 25 feet and a short way on, where the fault rises up on to the hillside, to 31 feet.

Returning to the pool mentioned above, through which the fault runs, it has a length of fully half a mile and a breadth of between 300 and 400 yards. The noteworthy point about it, however, is that it differs from the other pools noticed as yet, in the fact that its barrier is not directly formed by the fault. The pool spreads across the fault, and its outlet in the old channel of the Chedrang lies to the east of the fault line. At the outlet there is nothing in the shape of a barrier visible, the channel of the stream merely gets deeper in an upstream direction, and its bed sinks gradually, with no sudden change, under the waters of the lake. In other words, the natural slope of the channel has been reversed and a depression formed in which the water accummulated. Now, if we return to a consideration of the fault, we see that the maximum width and depth of this pool is where the fault has no throw, while the barrier corresponds to a part of the fault where the throw is rapidly increasing. Hence, we see that this pool, or lake, is not directly due to the fault itself, but to the formation of a roll or undulation in the surface of the ground to the east of, and corresponding in position with, an increase in the throw, of the fault.

Returning once more to the place where the throw of the fault was 31 feet, and where, having temporarily left the valley, it was running up the side of a spur. The spot is close to, but a few hundred yards up stream from, where the Chedrang is joined by a considerable tributary from the east, just where the village of Dalbot is marked on sheet 124 of the Atlas of India. At this place the destructive energy of the earthquake is very marked. Huge blocks of granite, ten and twenty feet in diameter, have been dislodged from their positions and thrown about. One block, roughly cubical and about 40 ft. × 30 ft. × 30 ft., happened to lie across the line of fault and was overturned by it. Clumps of bamboos were bodily overturned, and bamboos and trees, even where still standing, were killed, evidently by the violence of the shock; in such a climate it is impossible to attribute their death merely to a loosening of the soil and consequent drying up of the roots.

Near the junction of the tributary referred to above, and quite 200 feet or more in a direct line from the main fault, the gneiss in the Chedrang river bed was seen to have undergone some disturbance, and along numerous planes of jointing, or old slickensides, a small movement of a few inches had taken place, always with the upthrow on the east.

Proceeding down the main valley, the fault is struck once more, after having crossed a spur of the hills to the west of the Chedrang, and crosses the river obliquely, forming a waterfall. The throw here has sunk to about 8 feet, the upthrow being still on the east and the general course about north-north-west, with numerous local irregularities. The fault keeps close to the river for about half a mile crossing it three times and forming a pool when the upthrow is on the downstream side, or a waterfall where it is on the upstream side; the throw of the fault increases to 18 feet measured, and probably more where there were no means of exact measurement.

The fault has now crossed to the west of the river and continues so for nearly a mile. The throw dies out till it is only traceable with great difficulty, but increases once more, and the fault crosses a series of low spurs, forming three lakelets by blocking the side drainage. Two of these are of fair size, of triangular shape, one about 300 yards in length along the barrier formed by the fault, the other, situated close to where the village of Dilma is marked on the Garo Hills District map and on sheet 124 of the Atlas of India, is rather larger. The fault here has a throw of about 20 feet, and in this lake two Garos are said to have been drowned. According to the account given me, they were travelling along a footpath, which ran down this side valley, when the earthquake took place and the waters collected with such rapidity that they were drowned. If there is any truth at all in the story, it is probable that they found themselves close to the fault line and were stunned either by the violence of the shock or by a falling tree or rock.

Returning to the place where the throw of the fault had fallen to nothing, it must be noted that here again a large pool is formed in the main stream, but altogether east of the fault. Owing to the valley being more open, filled with alluvium, and the gradient lower, this pool is larger than the similar one further up stream. It was more than half a mile long and nearly as broad at its broadest point, even when I saw it in February, and had evidently extended even further on either side, over the almost level alluvial plain, before the outlet was cut down. Its outlet is similar to that of the upper pool, except that instead of a stony bed there is sandy alluvium; the bed simply sinks under the water of the lake, and the change from lake to stream is gradual and unaccompanied by any faulting or sudden break.

Returning to the fault where we left it, it very soon crosses the Chedrang, but the bottom of the valley, being here filled with alluvium instead of having a rocky bottom, no waterfall has been formed. The alluvium has, however, been greatly eroded and a great sandy fan or delta formed immediately down stream.

The fault scarp can be easily traced in the alluvium to the east of the river bed and, about a mile below where it crosses the river, had a measured throw of 32 feet. From here on the fault enters a region where the alluvium is thick, and no longer shows as a broken scarp, but as a short slope. Where this runs through forest the trees have been tilted over in the remarkable manner seen in

Plate XVI, and at the outer edge of the hills, near Kacharipara of the Survey of India maps, it runs through the rice fields, which have been tilted up in a smooth, unbroken slope between the upper and lower levels on either side of the fault.

Here the fault runs out into the open plain, where the thickness of alluvium is very great, and consequently cannot be followed with definiteness, but it does not die out, for its effects, as those of another fault on about the same run, are very noteworthy at Jhira.

The village of Jhira, which owed what importance it had to a weekly fair, was situated on the left bank of the Krishnai, about three miles below the confluence of the Chedrang. The bazar is now flooded, and in February there was about three feet depth of water over it. Northwards from Jhira, and extending to the foot of the hills on the west, there is a broad sheet of water, about a mile and a half long, about three quarters of a mile broad, and some 12 feet deep. At Jhira, the river bed is obliterated by the waters which stand above its banks; following the old channel down stream the banks gradually rise out of the water, which gets shallower till finally the river bed rises in a gentle slope of dry sand. According to the reports of the engineer who was deputed by the Assam Government to enquire into the floods consequent on the earthquake, this barrier rises to a height of about 15 feet above the present dry weather level of the Krishnai and has a length of a quarter of a mile to where the bed again carries water, brought into it by a tributary.

On the east side of the Jhira lake there is ample evidence of change of level, for part of the dry land was formerly *jhil* and perpetually under water, and at one place the remains of an old irrigation channel can be seen, which formerly carried water to the low lands on the east, but now rises steeply from the water level. At the northern end of the lake the drainage now makes its escape in a broad and shallow sheet of water over what was once high land covered with *sal* forest. After a short course of this nature it has found an old drainage channel, of a small tributary, and widened this out, falling into the old course, after a succession of rapids, about a mile and a half from the northern end of the lake, or about three miles in a direct line from Jhira. Between the lake and the junction of the new and old courses, and between them and the low spur to the west, the flood waters have spread over a large area of what was once high land, and are estimated to have killed not less than 50,000 *sal* trees.

The barrier by which this lake is formed, that which crosses the main channel of the Krishnai, appears to be directly due to the fault, which, on account of the great thickness of alluvium, manifests itself as a gentle roll or undulation of the surface and not as a sharply defined scarp. Following the line of the fault it should strike a long spur of low hills which runs out northwards into the alluvium, but I could find no trace of it there, and the fault appears to have died out. Whether it re-appears further on along this line I cannot say, as I had no opportunity of exploring this country. The water, however, now finds its escape over ground which formerly lay at a higher level than the stream bed, and this is now lower than the crest of the barrier across the old channel, though lying on the upthrow side of the fault. From these facts we may conclude that the throw of the fault must have become less, in the neighbourhood of the present outlet of the lake, than at the place where it crosses the old bed of the Krishnai; in other words, that it diminishes to the northwards of Jhira and it is not improbable that it may die out altogether before reaching the low hills to the north and west of that place.

Upstream, or to the southwards of Jhira, the flooded ground extends for about 4 miles, and one of the bends of the Krishnai, where it takes a curve to the east, has been raised and laid dry, the water now finding its course along a depression through what was once forest land. The country along the course of the Chedrang, from where it leaves the hills to where it joins the Krishnai, has also been extensively flooded, in fact the levels of the whole of the triangular patch west of a line joining the issue of the Chedrang from the hills and Jhira have been altered. Large areas have been permanently flooded, but the boundaries of the flooded areas are irregular and principally determined by the original inequalities of the surface of the ground.

Having described the course of this fault in detail there are certain aspects of it, as a whole, which require notice. Firstly, although the throw of the fault varies from over 35 feet to nothing, yet, wherever there is any perceptible throw, the upthrow is always on the east and the downthrow on the west. Secondly, I was unable to detect any pronounced horizontal movement of one side with reference to the other, in other words, the displacement appears to have been simply up or down, so that the fault is a fault pure and simple, and not a heave. Thirdly, wherever the plane of the fault could be seen in rock it was practically vertical, with no pronounced hade in either direction. Fourthly, the displacement appears to have been principally, if not entirely, an elevation of the upthrow side and not a depression of the downthrow side of the fault.

With regard to the last mentioned point it is not possible to speak with the same positiveness as on the first three, for the only measurements that can be made with certainty are differential ones; that is, the present difference of level of two points which were formerly on the same level can be measured, but it is not possible to determine whether one has gone up or the other down. There are, however, some considerations which bear out the conclusion formulated above. The two large pools, which correspond in position to what may be called the nodes of the fault, that is, the places where the throw becomes *nil*, are, as has been explained, due to the raising of a barrier across the river channel, whereby it was given a reverse slope. Now it is conceivable that this might be due to a general and uniform subsidence on the downthrow side, and an unequal subsidence on the upthrow side, whereby certain parts retained their original level while in others the subsidence was equal to that of the downthrow side of the fault. In this way hollows would be formed on the upthrow side in which water would accumulate.

This explanation seems to be excluded in the case of the lowermost of the pools, that at Jhira. Here the rapids between the present outlet of the lake and the point where its waters join the old channel, are of the character of those in a mountain stream, although it flows over alluvium instead of rock. The steepness of the gradient here could be explained by the raising of the water level due to actual elevation of a barrier or to a depression of the old stream bed where it is rejoined by the water. But though, so far as the short reach of rapid current is concerned, we might attribute the gradient equally to a raising of the upper end or a depression of the lower, yet the latter explanation is here excluded by other considerations.

The whole of the alluvial plain of Lower Assam is raised but little above the sea, and the gradient of the rivers is about as small as it could be, so that if, in this area, there had been subsidence, sufficient to account for the gradient of the stream bed, the area depressed could not but be flooded with water. Such depressions have, perhaps, been formed, as will be noticed further on, but so far as I could discover, nothing of the sort has taken place along the Krishnai in that part of its course immediately below the Jhira lake.

For this reason we may conclude that, in the alluvium, there was an actual elevation of the upthrow side of the fault, and by analogy we may extend the same conclusion to that portion of the fault which lies within the hills. At the same time it is possible that there may have been more or less depression on the downthrow side, and that the visible throw at any point is made up of the sum of elevation on the one side and depression on the other..

We have now finished with the description of this fault, which has a visible throw of 35 feet and more in places, and has been followed for a distance of about 12 miles. Whether this represents its total length is not, however, certain, for in the one direction it is lost in the great thickness of the alluvium of the Brahmaputra, and in the other it dies out in thick jungle. In this direction its utmost limit cannot, however, have been as much as 5 miles beyond the furthest point to which it was traced, or it would have been noticed on the route traversed along the head of the Chedrang drainage area Taking the limit of 12 miles for its length, this, combined with the observed throw, would be sufficient to account for a very severe earthquake, and it is fortunate that it was not discovered at the outset of the examination, for it might well have been regarded as a sufficient cause, and the area of the examination much restricted. As a matter of fact nearly all of the observations which follow were made before this great fault was found, and the general result is that the Chedrang fault, though by far the most conspicuous, is but a small fraction of the total of the permanent changes which accompanied the earthquake. It must consequently be regarded as only part of the cause of the earthquake.

About 10 miles due south of the termination of the Chedrang fault is the village of Sámin, past which the main road runs southwards from Damra through the Garo Hills. Just before the road reaches the 'Ronghri River there is an abrupt rise of about 10 feet, and on either side of this a low but steep rise, in the surface of the alluvial gravels, runs in a WNW—ESE direction. At first sight there is nothing to distinguish this from the natural termination of a terrace of valley gravels, except the steepness and broken character of the road where it drops from the upper to the lower level. On the left of the road, however, there are as shown in Plate XIII the remains of an old Garo house. The low cliff just mentioned runs through the centre of this, and one of the posts, which supported the raised platform of the house, can be seen standing below, and another above, the break in the ground level. As the tops of these posts must have been on a level with each other when the house was built and as the top of the one is now 10 ft. higher than that of the other, they show that the throw of the fault, for such it is, was 10 feet at this point.

This Sámin fault is smaller, both as regards throw and length, than the Chedrang fault; its general course is also different, being about E 30° S—W 30° N and the upthrow is on the southern side as indicated in the plan drawn on Plate XLII. To the east of the road it crosses a tributary of the Ronghri, down whose valley the road runs, and has ponded up the water for a length of about quarter of a mile. The fault then crosses a tributary of this stream and, running up over the hills, forms a small lake, whose old outlet is now dry, a new outlet having been formed along the fault line; the fault runs on over a spur and once more crossing the tributary stream has formed a small lake. It can be traced for about a mile further, following the lines of minor drainage, till it dies out and is lost. In the continuation of the run of the fault in this direction some small pools were seen to have been formed, but the fault could not be traced as such.

In the opposite direction it can be traced for rather more than a mile, forming several small pools in its course, and is lost in a broad, grassy plain over which the flood waters of a stream, whose channel had been dammed by the fault, found their way. The total length of this fault is thus about 2½ miles, with a maximum throw of 10 feet, dying off in either direction to nothing.

Leaving for the present the mention of a few smaller faults which were observed, we may proceed to the consideration of the Bordwar fault-fissure, or fracture. I use this term to distinguish it from the faults on the one hand, in which there has been a change in the relative levels of the ground on the one hand, and on the other hand from the earth fissures described in chapter VII, which are the results of the earthquake wave, being in no way connected with its cause. The features to which I give the distinctive name of fracture are of the same nature as those along which faults are formed, differing only in the fact that there has been neither up and-down or sidelong movement along them. Like the faults proper they are directly connected with the cause of the earthquake and are foci of unusual violence of shock.

The largest of those that I saw was what I shall call the Bordwar fracture, from the name of the tea garden through which it runs.

To the south-west of the old bungalow there rises a low hill of gneiss which was reported to have been rent from top to bottom by the earthquake. On examination I found that the statement was correct, though based on an erroneous inference; a line of fissuring can be traced up the north-east face of the hills and across the crest, but it is not the fracture itself which is visible from a distance and led to the report that was made.

The actual fracture is only a few inches wide, it has rent the solid rock and in its immediate neighbourhood the violence of the shock was extreme. Trees have been overthrown or killed as they stood; a huge mass of rock, dislodged from near the crest of the hills has rolled down the slope, scoring the side of the hill. On the opposite side an equally large block has been dislodged, and in its downward course cleared a straight track down the hill; and on the summit a gap has been cleared by the overthrow of trees along the line of fracture. It was this gap and the two scores down the hillsides which appear to have given rise to the report that the hill had been rent from top to bottom; at any rate they were pointed out to me as the course of the fissure.

At first, on seeing what was the true character of the appearances on which the report was based, the natural inclination was to reject it as one of the fables which are narrated of earthquake effects; but the band of trees, killed as they stood, which ran up north-east side of the hill showed that something unusual had happened, and on a closer examination it was found that great slabs of weathered gneiss had been rent in two, and on the crest there was a well marked depression, like a small ditch, running away to south-west.

This fracture is not, however, confined to this hill. To the north-east, on the face of the mass of hills to the east of the alluvium, a line of landslips could be seen, and, on following this up, a zone of fissuring, accompanied by great overthrow of trees and breaking of bamboo clumps, could be traced for about half a mile into the hills before it became too indistinct to be traceable.

The line of this fracture runs almost under the manager's bungalow, which was completely levelled to the ground and numerous earth-fissures opened. Some of them may have been directly connected with the fracture, as the depth reported to have been measured, 45 feet, seems greater than is likely to be consistent with an origin in the manner described in chapter VII.

A feature like this is naturally more difficult to follow than a fault scarp, and for some distance to the south-west it is only imperfectly marked by a number of small landslips and destruction of jungle. About 2½ miles south-west of the hill there is a forest path

Fig. 16. Sal tree in forest near Bordwar, broken by the earthquake.

leading north and south, along which, on the continuation of the line of the fracture, there is a well defined band of about half a mile broad in which overturned trees are much more abundant than on either side, and towards the centre of this band the overturned trees are not only more numerous, but many of the smaller ones, up to 6 inches in diameter, have been snapped across by the violence of the shock, as shown in fig. 16.

Still further to the south-west, at the junction of the Lokia Jáa with the Kulsi, a line of disturbance runs diagonally along and down the hillside, and, where the soil is shallow, many trees have been killed. Still further to the south-west a band of overturned trees can be traced through the submerged forest at Ukiam (see p. 123), but beyond this I was not able to trace the fracture.

The total length for which this fracture has been traced is consequently about 7 miles, and along the whole of this there is nowhere any definite and conclusive indication of movement, whether vertical or horizontal, though at many points there are indications of a small change of level. The amount is nowhere even so much as one foot, but where there is any indication at all, the upthrow seems to be on the south.

Besides the larger fractures, which could be followed for some distance, a number of smaller ones were seen, in the form of small faults of a few inches to a foot or so throw, and lines of fissuring crossing the path. In many cases it was impossible to determine whether these were really faults or fractures, or merely incipient landslips, and it was only towards the end of the tour, and after the larger faults had been examined in detail, that I began to recognise those signs of unusually great, but very local, violence which distinguish faults and fractures, from the fissures which merely mark an incipient landslip.

Looking back over my notes and recollections, I think that many of them must have been crossed in the central part of the Garo Hills, but of those only one was certain enough to be marked on the map. This is a small fault in the lands of Mandalangiri, in the Garo Hills, and about 1½ mile north of the camping ground. This fault crossed the path on the crest of a spur and ran in an WNW-

ESE direction, transverse to the run of the crest of the ridge, with a downthrow of about 2 feet to the south. Off the path the throw could not be recognised, but the line of the fault could be traced through a clearing for about 300 yards before it was lost in dense bamboo jungle.

We come now to the consideration of the second class of permanent changes, the lakes or pools formed by interruptions of the gradient of drainage channels, not directly due to faulting. The principal group of these lies in the north-eastern portion of the Garo Hills District, to the south and south-eastwards of the faults already described. In describing them it will be more convenient to start from the south and take them in the order in which they were actually seen.

The first of those seen by me was in the valley of the Rongtham river, about 3 miles above its confluence with the Samsang or western branch of the Sameswari, and in the lands of the village of Dobukhol. I first saw this at its outlet, and, on being informed that this was the lake of which I had heard, it was difficult to realise that there was anything unusual. To the left, or down stream, the stream bed was ordinary coarse shingle, a natural mountain torrent bed, to the right stretched a pool which at first sight did not differ from the pools which are common enough on mountain streams. I was, however, informed that before the earthquake there had been no pool here, but a reach of rock and boulders exactly similar to the portion of the stream bed below the present pool.

Embarking on a bamboo raft on this pool, I proceeded to explore it. Travelling upstream I found the water gradually deepening, but the bottom still retained the same character of coarse subrounded boulders, characteristic of a stream bed with a rapid current. The deepening was gradual and the presence of a slight deposit of sand and mud over the boulders pointed to a change in the condition of the stream at this point, from those which had prevailed when the bed of coarse boulders was originally formed.

As the water in the pool deepened, the lower line of vegetation on the banks, marking normal high water level, descended to the water's edge, and then trees were seen standing in the water and killed by the submergence of their roots. About 200 yards from the lower end the stream bed takes a bend, and here the greatest depth of water was found to be 12 feet. On the inner or concave side of the bend was a gently sloping terrace of stream gravels, which had been partially submerged, and a number of trees and bamboo clumps had been killed, their dead stems standing up out of the water and proving the recency of their submergence. Here the track from Darangiri crosses the stream and affords independent evidence of submergence, for though there was not ordinarily a greater depth than a foot before the earthquake this is now the deepest part of the pool.

About 200 yards above the deepest point, the stream once more resumes its normal character, and as the water shallows towards the upper end, the bottom can be seen covered with boulders. At the head of the pool is a small deltaic deposit of boulders, due to the checking of the current as it entered the pool. That there is not a larger delta is due to the other pools, to be referred to presently, higher up the stream, by which most of its burden was intercepted.

From the gradual increase in depth at either end it is evident that this pool is due to a bending of the river bed exactly similar to that which gave rise to the two large pools on the east side of the Chedrang fault. In this case no fault was seen, and I do not think that, had there been one on large enough a scale to account for this lake, it could have escaped notice. As regards the amount of the bending that has taken place, the depth of the pool shows that the stream bed has been depressed at least 12 feet below the outlet of the pool; there has consequently been at least that amount of differential movement in a vertical direction. But the stream bed was not originally level; to judge from its nature, above, below, and where it could be seen under, the waters of the lake, it must have had a fall of about 200 feet per mile. Taking only one half of this as the actual fall, between the deepest part of the lake and the outlet, there must have been originally a difference of 12 feet in level, and as the point which was formerly the higher by at least 12 feet is now the lower by the same amount, we reach the conclusion that the total change of levels cannot be less than 24 feet.

About a mile and a half above this is another pool of similar character, though not so long or deep, and about three-quarters of a mile further up is the lower end of another lake, which has a length cf about one and a half miles and a maximum depth of 18 feet.

This lake or pool is situated in the lands of the village of Lenkra, where the stream runs through a patch of soft tertiary shales and sandstones, and the valley is consequently more open and the gradient lower than at Dobukhol. So far as can be judged from the present aspect of the pool, and from the character of the stream bed above and below it, the stream flowed through an old alluvial plain of fine grained muddy silt, on a sandy bottom in a narrow, steep sided channel of some 15 to 18 feet in depth. The gradient must have been small, but the average must have been increased above that of the sandy stretches by occasional barriers of rock.

Travelling up this pool from the lower end, the banks remain high for the first quarter of a mile, and the signs of submergence are not very noticeable. About three furlongs from the lower end there is a depth of 9 feet of water, where a footpath used to cross the stream and the normal depth was less than a foot. Here dead bamboo clumps begin to be conspicuous. Half a mile from the lower end the high banks have sunk beneath the water and the pool spreads out over the surface of the alluvial plain, the outer margin being indefinite, while the channel is bordered on both sides by a tangle of dead and bleached bamboo stems and tree trunks. This continues for about half a mile, the margins of the pool then become more defined and the water gradually shallows to the head of the pool, where there is an extensive deltaic deposit of sand brought down by the stream of the Rongtham.

About 3 miles above Lenkra the Rongtham divides into two branches at the village of Dobu, and in the western of these, just above the junction, a pool of about half a mile long and a maximum depth of 10 feet has been formed.

From Dobu I crossed into the drainage area of the Ronghri and at Náphak found a group of three lakes, in a series of parallel valleys having a general course of about north and south. Of these the central and western flow north and unite below the lakes, the eastern on the other hand drains to the south and joins the central stream above the lake in it.

The easternmost of the three lakes is in the valley of a small tributary which apparently carried no water in the dry weather, at any rate the water was absolutely stagnant, there being no current over the barrier at the outlet. This valley had an alluvial bottom which has been flooded for a maximum width of about 100 yards and a depth of certainly not more than 12 feet, a sounding of 9½ feet being obtained at the only place where I could get well out into the centre. Owing to the character of the valley there is no clear channel through the lake, but the whole width of the water is occupied by a thicket of dead saplings and bamboos. At the outlet the alluvium of the valley is very much fissured.

The central lake is larger and more open, the latter fact being largely due to its having been formed in a *jhum,* or forest clearance for temporary cultivation. It is about a mile long and about 12 feet maximum depth. The outlet at the lower end is over crystalline gneiss, and the water deepens gradually to the lake.

The western lake is rather smaller but of the same type.

The barriers of these two lakes might be ascribed to a single roll or fold striking about NW and crossing both the valleys which drain to the northwards. The barriers of the eastern lake must, however, be attributed to a different fold, for the valley drains to the south and the whole pool lies to the south of the line joining the barriers of the two other lakes.

With the exception of the two small pools east of Sámin referred to above (p. 148), these are all the pools, not directly due to visible faulting, which I saw in the Garo Hills; but there is at least one other, which appears to be larger than any I saw, at Sidugiri on the boundary of the Garo and Khasi Hills Districts. According to accounts received from Captain Howell and Mr. J. C. Arbuthnott, C.I.E., it has a length of over a mile, a width of 150 to 200 yards, and was too deep to be bottomed with a 20-foot pole.

In spite of careful enquiries made by myself and through the local authorities I could obtain no intelligence of the existence of any other pools either in the Garo Hills or in the north-western portion of the Khasi Hills Districts. I do not, however, regard this as showing that there are no such pools, beyond those mentioned, for I only heard of two of the four pools in the Rongtham valley, and of the many ponds formed by the Chedrang and Sámin faults. I only got intelligence of the one large one at Sámin and the two large ones in the Chedrang. Of these, I only got definite intelligence when close by while the many smaller pools were not only not reported, but their existence was positively denied till I found then myself, and was then quietly informed that they had not been mentioned as they were too small to count.

Taking this into consideration, I think that while the existence of any large lakes or pools in the country off the track followed by me is unlikely, it is probable that there are many smaller ones.

This conclusion is supported by the fact that, about 50 miles to the east, I found three small pools of the same type in the northern Khasi Hills between Rambrai and Nongkhlao.

The first of these is about a mile westwards of the Landomodo Station of the Great Trigonometrical Survey. The water in the Wenging stream is ponded up in a small patch of alluvium, and stood bank high in the dry weather. Lower down the stream resumed its normal character, and it was evident that the deep pool was of recent origin. In reply to an enquiry of my guide I was informed that there was no pool here before the earthquake.

The next case was at Sinya. East of the village a patch of alluvium, at the bottom of a small valley, which had been taken into cultivation and made into rice fields, was flooded to a depth of 3 or 4 feet, evidently by an alteration of the general slope of the valley.

The third was at the village of Kanrut, again in a valley with an alluvial bottom, partly converted into ricefields. Here the plain had been submerged for about half a mile, and the old ricefields could be seen, covered by water about 4 feet deep.

It will be seen that the changes here are on a much smaller scale than in the north-eastern Garo Hills, but they are of the same character, and the recurrence of the same conditions in this region lends great support to the supposition that similar features would be observed in the intermediate country, which it was not possible to visit.

Besides the direct and conclusive evidence of permanent deformation which have been detailed, I was able to collect certain evidence, of less value, pointing to changes of level, as inferred from changes in the appearance of the landscape.

The first of the places where such evidence was noted was at Mao-phlang on the road from Shillong to Cherrapunji, where Mr. Evans informed me that, after the earthquake, he noticed a considerable change in the appearance of the hills to the west. In part, the statements were general and might be attributed to imagination or defective memory, but two definite facts can hardly be explained in this manner.

Beyond Mao-phlang is another mission settlement at Mairang, and on such occasions as the missionary there visited Mao-phlang a look-out for the arrival of the party was naturally kept by Mr. and Mrs. Evans. Before the earthquake, I was informed that only a short stretch of the road was visible, where it rounded a spur at about 3 miles off; the crest of an intervening ridge hiding the road before it came out round the next spur. Now a much longer stretch of the road is visible, and it can be seen rounding the next spur, where I was positively informed the road could not be seen before the earthquake.

The second fact is that a few days after the great earthquake Mr. Evans took a piece of board and nailed it to a stout post in such a position that its upper edge was sighted on to the crest of a ridge about one and a half mile to the west. When I saw it, at the end of December, six months after the earthquake, the top edge of the board no longer pointed to the crest of this ridge, but to some way down its slope. The angle subtended between the point where the edge of the board then pointed to, and the crest of the hill was about 1°, as determined by an Abney's level, and the change might be due to a displacement of the post, though there was no appearance of such. Apart from this, Mr. Evans informed me that when the board was put up he could only just see the top of the next ridge, beyond that on which the board was sighted; now a considerable stretch of this can be seen and according to Mr. Evans much more than was visible soon after the earthquake.

These facts are of interest as suggesting that no inconsiderable fraction of the total movements which have taken place, were accompaniments of the large number of severe aftershocks.

The next place where similar evidence was obtained was on the road through the Garo Hills to Damra, where it crosses the high ground north of Cheran and just before descending into the valley of the Bangshi. Here I was informed by the mouzadar accompanying me that before the earthquake it was only just possible to see the Brahmaputra over an intervening hill, while now the whole width of the river was visible. As this statement was a voluntary one, not made in reply to a leading question, and as a change of relative level of the hill and the road of 20 feet at the outside could be sufficient to account for the facts, I think it is not improbable that there has been a change here. It may be noticed that this spot is near the continuation of the line of the Chedrang fault, and less than 5 miles from the most southerly point to this which was traced.

The third case was at Tura. This has already been referred to in Captain Howell's report[1], and I took the opportunity, when passing through Tura, to interrogate some of the military police on the matter. A system of signalling by heliograph is in use by the battalion of military police stationed in the Garo Hills, and one of the stations, with which communication is made direct from Tura, is Rowmari, on the bank of the Brahmaputra. Before the earthquake it was just possible to do this from a certain spot by a grazing ray over an intervening hill. Now there is no difficulty at all, and instead of Rowmari being just visible over the hilltops, a broad stretch of the plains east of the Brahmaputra is visible. I was also pointed out other hills which were said to have moved up or down since the earthquake, but attach little importance to those statements. The statements regarding the changes on the direct line between Tura and Rowmari deserve more attention as on this line it would be essential for the signallers to be thoroughly acquainted with the aspect of the country, and any change would be readily noticed. Having noticed a change on this line, and so become familiarised with the idea, it is easy to understand how others, possible purely imaginary, would be noticed in directions where there had not been the same necessity for an accurate knowledge of the configuration of the hills.

Though I made careful inquiries, I could hear of no case of the drainage of the hills to the west of Tura having been interrupted, nor did I see any on the road between Tura and Rowmari, except in the alluvium where they were probably secondary effects of the earthquake. It may well be that such changes as have taken place are too small, and extend over too great a horizontal distance, to have altered the gradients of the streams to an appreciable extent, and it is to be hoped that the supposed change of levels may be confirmed or refuted by a retriangulation of this country. Meanwhile it may be accepted as probable that there has been a change in the height of Tura or some of the hills to the west of it.

[1] Chapter II, p. 14.

Reviewing the facts collected, we see that the permanent change accompanying the earthquake are not confined to one spot or one line, but extend over the northern part of the Assam hills for a distance of 100 miles from east to west. Another point to notice is that, at the limits of this area the evidence points to the changes being of the nature of long, low rolls, the change of slope being insufficient to cause any appreciable change in the drainage channels. Then comes a zone in which the surface changes are more abrupt, the slopes of the stream beds have been altered so as to cause conspicuous changes in the nature of the streams; but any fracture or faulting which may have taken place has died out before the surface was reached. And north of this, close to the edge of the hills, the rocks have been fractured and faulted right up to the surface.

The changes which have taken place are most conspicuous in the Garo Hills just west of the 91° meridian, and it is here where the greatest permanent displacement has taken place. The passage of a zone of folding unaccompanied by faulting into a zone of faulting and folding is conspicuous, as also the fact that the biggest of the faults is also the most northern.

On the eastern line the folding, and consequent interruptions of drainage, is much less, but here too we find the great Bordwar fracture to the north of this zone—a fault, except in the absence of noticeable throw.

Seeing then that the permanent disturbance becomes more accentuated to the north, and reaches its maximum at the northern edge of the hills, we may assume that it does not abruptly cease along that line, but extends out under the alluvium of the Goalpara and Kamrup districts. Here, however, we enter a region where the secondary effects of the earthquake wave, described in Chapter VII, are so extensive as to mask the primary changes of the nature of those described in this Chapter. For this reason, it is impossible to get any certain proof of changes of level, other than those due to shiftings of the superficial layers of the alluvium, but there are certain facts which point to the conclusion that such have taken place.

All down the course of the Brahmaputra the floods of 1897 were more extensive and rose higher than they had been known to do before, but nowhere were they so long continued and so disastrous as in the Borpeta subdivision. Not only were the floods severe during the wet weather, but even after the dry weather had set in, and the rivers fallen to their lowest level, large tracts of country, usually dry, remained under water. It is not to be wondered at that this unusual flooding was attributed to subsidence of the land, but though, as will be seen, there seems good reason to suppose that subsidences and elevations of deep seated origin took place, the greater part of the unusual flooding must be attributed to the superficial changes described in Chapter VII, which were produced by the earthquake.

The regions in which the floods were worst are, it must be noticed, those where the filling up of river channels, and the shaking down of the high river banks, was most marked. The effect of these changes was threefold. First, the subsidence of the high land bordering the river channels, caused it to sink below flood level and, apart from anything else, these lands, which are ordinarily left dry, were submerged in 1897. Secondly, the sinking of this barrier along the river channel allowed its waters to spread more freely over the low land away from the river. Thirdly, and this was the most important, the raising of the beds of the drainage channels blocked the usual means of escape of the greater part of the flood waters, and necessitated their spreading over the land.

To these three causes the greater part, if not the whole, of the unusual floods must be attributed. To them is due the fact that the resthouse at Mankarchar, which stands above ordinary flood level, was submerged, with a depth of 3 feet of water over the floor, and that the floods extended over vast tracts of land, which had not been submerged before, in Sylhet, to the west of the Garo Hills and in Goalpara and Borpeta.

In investigating the facts and their interpretation it is almost impossible to separate out from the result of these vastly preponderating influences, the effects of such permanent changes of level, as may have taken place. One or two facts, pointing to such changes having taken place may, however, be noticed.

At Gauhati, a river gauge, fixed on the rocky bank, is regularly read and a record kept of the height of the river. The peculiar sudden rise, and subsequent slower fall, of the rivers has already been noticed[1] and for some months, the river levels appeared to be normal; that is to say, the daily variations in level were too great to allow any small permanent change to be noticed. In the months of January and February, however, the water level is ordinarily very steady and at its lowest. The readings for these months in 1898, show that the water level was about a foot higher than usual, and consequently point to a small permanent change in level, or in the gradient of the river below Gauhati. No great dependence can, however, be placed on this till the observations of several years have been accumulated, for the difference is so small that it might be due to a difference in the season, or more probably, to the fact that the bottom of the river channel, which must have been raised through a length of 200 miles, has not yet been completely scoured out to its old level.

More definite indications of a change of level are to be found at and below the hill of Hathimora. Here the river banks during the dry weather were 10 to 15 feet lower than usual, or in other words, the river bed was that much higher than usual, as compared with the crest of the banks. In part this is due doubtless to a sinking of the banks, but not wholly, for a rock which used to stand out of the water near Hathimora is now covered by the sandy bed of the river, showing that the river bed has been raised, as compared with the hill. This banking up of the river bed may be due to a subsidence of the underlying rocky floor and consequent accumulation of

[1] Chapter VII, § 107.

sand, or to a barrier being formed lower down, on whose upstream side sand has accumulated.

Lower down the river there is a stretch of channel which has caused much trouble in the navigation of the river, the channels have been ill-defined, constantly shifting, and frequently too shallow to be passable by steamers of even 3 feet draft. The stretch presents all the characters of a region of deltaic deposit, and immediately below it comes the Kholabandha district, where the floods were unusually deep and extensive. There is here every appearance of a depression having been formed, which has not yet been completely filled up by the river.

From here down to Dhubri there has been no particular difficulty in the navigation, but below Dhubri there is another stretch of river where the channels are shallow and shifting.

These facts, for which I am indebted to Mr. R. R. Morgan, Superintendent of Pilots, point to the conclusion that there have been unequal changes in the level of the ground, affecting the river gradient, which are too extensive to be attributed to superficial effects of the earthquake on the alluvium. They cannot, however, be regarded as conclusive, and are discounted by the fact that, though the river below Hathimora is said to be worse than it has been in the recollection of the oldest commander of the river steamers, the same statement is made with regard to the river above Disang Mukh to Dibrugarh, especially at Sissi Mukh. Here the change cannot be attributed to any general and deep seated change of levels, but to the ordinary action of the river, complicated by the effect of the earthquake on its bed, and it is open to question whether the cause of the difficulties lower down the river may not be the same.

Whether there has been any general, or local, deep seated change in the levels of the Brahmaputra valley, north of the Garo and Khasi Hills must, consequently, remain an open question until such time as a reobservation of the stations of the Great Trigonometrical Survey in the Brahmaputra valley can be undertaken.

Chapter X.—THE POSITION AND EXTENT OF THE SEISMIC FOCUS.

Having completed the description of the data necessary for the purpose, we may now proceed to a discussion of the nature, situation, and depth below the surface, of the focus from which the earthquake started.

All earthquakes are of the nature of a shock or disturbance communicated to, and propagated through, the earth. This disturbance may originate in many ways: some small earthquakes are believed to have their origin in the falling in of underground caverns; others have been attributed to underground explosions of steam; others again to volcanic explosions; but the commonest cause, and that to which all great earthquakes appear to be due, is a sudden relief of strain.

According to the generally accepted theory of the constitution of the earth, it consists of a highly heated central mass, which is continually losing heat, and consequently contracting, covered by a comparatively thin surface layer which has already cooled as far as present conditions permit, and is not capable of further contraction to an appreciable degree. Consequently, as the central core contracts, the outer shell is left partially unsupported, and so thrown into a state of strain. The relief of this strain may be gradual, or sudden; in the latter case it takes the form of a fracture, or a sudden shift along a preexisting fracture, and is accompanied by an earthquake, whose extent will depend on the amount of strain which has accumulated before yielding took place. Where the earth's crust has no great power of resistance, the strain will not accumulate, and earthquakes will be frequent and small. If, however, the constitution of the earth's crust, at a part which is subjected to strain, is such that it does not yield readily, the strain will accumulate, and, when it becomes too great to be borne any longer, there will be a sudden and violent relief, accompanied by fracture and giving rise to a severe earthquake. Whatever may be thought of the theory of the constitution of the earth outlined above, it is certain that the actual conditions and processes of nature are more complicated than indicated, but there also can be no doubt of the fact that the surface rocks can be, and are, thrown into a state of strain. Instances are given in almost every text-book, and it is easy to understand that, if this strain increases beyond the power of the rock to resist it, there will be a sudden fracture, giving rise to an earthquake-wave; and also that the longer the strain accumulates, and the greater the power of resistance, the greater will be the ultimate shock when yielding does take place.

Turning now to the consideration of the facts which have been recorded in the foregoing chapters, the first point to notice is that this earthquake was not the result of a mere explosion or of the rending open of a fissure. The evidences of permanent displacement are too numerous, and it may safely be said that, whatever the nature of the origin of the earthquake may have been, it was intimately bound up with a very considerable shifting of one part of the earth's crust relative to another.

The next point to be noticed is that these indications of displacement are not confined to one spot or one line, but are scattered over a large area. We may consequently regard the earthquake either as a compound one, having a number of separate foci, that is to say, as being not one earthquake, but a number of earthquakes which happened to take place at the same time. Or, as a more probable alternative, we may regard what appear to be foci as offshoots from the true focus, which was deep seated, and from which, what may be called, offshoots ran up to the surface.

There is one form of structural disturbance, consistent with the latter hypothesis, which will afford an explanation of the facts observed, and that is what is known as an overthrust. An overthrust is in effect a reversed fault, but differs in the fact that the fissure along which movement takes place is nearly horizontal instead of nearly vertical, or steeply inclined. Such thrust-planes, as they are called, have now been recognised as a common structural feature, and they seldom, if ever, occur by themselves, but are accompanied by a number of reversed faults of ordinary type, running upwards, at steep inclination, to the surface.

In fig. 17 is reproduced a portion of the section east from Quinaig, as drawn by the Geological Survey of Scotland,[1] showing the thrust-planes T T and the minor thrusts, t t. If this were

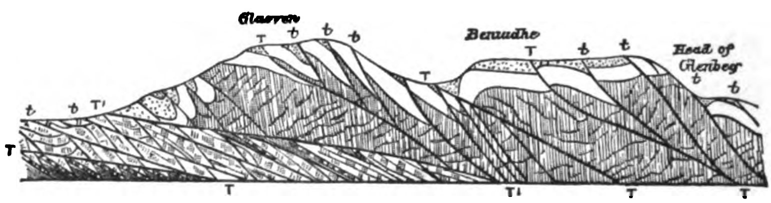

Fig 17. Section running east from Quinaig, in the northern Highlands of Scotland.

enlarged to the scale of the Garo and Khasi hills, we should have something very like what has already been described as their structure.

If now there were produced, by any cause, a considerable movement along the great thrust-plane corresponding to T'—which it must be recollected is buried deep below, and does not reach, the surface—there would be smaller movements along the secondary thrust-planes T T and the tertiary ones t t, which might reach the surface as actual faults, but would very probably die out and give rise to mere changes of level like those to which the pools in the Garo and Khasi hills were due; while the movement along the thrust-plane would give rise to the horizontal displacements observed in the trigonometrically fixed peaks in the Khasi hills.[2]

We have, consequently, an hypothesis which satisfies all the conditions of the case. It accounts for the permanent change

[1] Quart. Jour. Geol. Soc., XLIV, 418 (1888).
[2] See appendix G.

being scattered over a large area; it accounts for the faults, the fractures and the local changes of levels; it accounts, at the same time, for the horizontal shiftings which have been observed; and it accounts for the absence of any definite centre of maximum violence as well as the existence of several local centres of maximum violence within a general central pleistoseismic area.

At the same time, it introduces no condition which is at variance with or unsupported by observed facts, and we may safely accept it as the true theory of the origin of this earthquake.

Though apparently the most probable, this is not the only posible, hypothesis. The surface features of the Assam range, described in the last chapter, are compatible with, in some respects they suggest, the idea that these hills are what the German geologists call schollengebirge,[1] that is mountains which have originated from straight up and down thrusts, instead of from lateral compression, like the Alps and Himalayas. If this is so, the faults by which the fault scarps are formed would be normal faults, and so far from there having been any compression, the elevation of these hills would have been accompanied by an extension of the surface. The state of strain too, which preceded the earthquake would have been one of tension and not compression.

The mechanism of the production of this form of mountain is not properly understood, and a condition of tensile strain in the crust of the earth would be still more difficult to explain, but the fact of the existence of such mountains and structure cannot be gainsaid, so the possibility of the state of tensile strain they imply must be allowed.

If such is the nature of the Assam range, and of the cause of this

[1] There is no English equivalent of the word 'scholle' as used by German geologists. The German precedent has been followed by some authors in America and England, and the German words rendered as 'block' and 'block mountains.' The practice seems inconvenient as it might easily happen that the same word, block, was required in its ordinary and its special sense in the course of the same sentence. This would lead to confusion, and I suggest the word *plax*, from the Greek word for a block of stone, as a satisfactory equivalent for the word 'Scholle' or 'block,' in its special sense.

earthquake, there would be no thrust-plane underlying it, and the focus of the earthquake would have to be regarded as a complex one. That is to say, there would be no general focus, but a number of independent ones, along each fault, and the magnitude of the earthquake experienced would be due to the simultaneous occurrence of a number of earthquakes of various degrees of severity.

Whether we regard the focus as a thrust-plane, or as a network of faults, it practically covered an extensive area. The hypothesis of a thrust-plane is the simplest to work with, as also the most probable, and it is that which has been adopted in the following pages.[1]

Having established the nature of the focus of this earthquake, the next point to determine is the approximate horizontal extent and boundary of the thrust-plane, or of that portion of it over which movement took place. This reservation is important, for it is quite conceivable that the movement may have taken place along a pre-existent plane of fracture, whose whole extent is much larger than that portion over which movement took place. If this is so, it is obvious that, though we may be able to determine the limits of the latter area with some approximation to accuracy, there is nothing whatever to guide us to a knowledge of the whole extent of the old fracture.

It has already been pointed out that the changes which accompanied the earthquake can be traced right up to the northern edge of the Garo hills, and that this alone might lead to belief that similar changes took place under the alluvium of the Brahmaputra valley. It has also been shown that there are independent suggestions, if nothing more, of changes of level along the course of the Brahmaputra river.[2]

[1] There is one hypothesis which might explain many of the observed effects, and that is the injection of a laccolite or sheet of molten rock. This would account for elevations at the surface and for unequal elevations, it might not be inconsistent with horizontal shifting, and the strain on the overlying crust might in places lead to fracture or faulting. Our knowledge of the physics of igneous intrusion, small though it be, is, however, opposed to the idea that such an intrusion could take place with the suddenness necessary to account for the earthquake, and when we consider the large area and the thinness of the intrusion required to fit in with the facts observed at the surface, this explanation may be dismissed as physically impossible.

[2] Page 162 ff.

These indications of a northern extension of the thrust-plane are further supported by the very large number of secondary earthquakes recorded at Borpeta and Bijni, which point to an extension of the focus in that direction. We may, accordingly place the northern limit to the north of Borpeta with some degree of certainty. Further east the observations of the Great Trigonometrical Survey show that Shillong lay within the limit of the area over which permanent displacement has been observed, which may be taken to practically coincide with the epicentre. It is not impossible that this may have extended as far north as Gauhati, which was certainly not far beyond the limits; but however this may be, the area over which displacement has taken place broadens rapidly a short way to the west of Shillong and, as shown in Chapter IX, Bordwar, at the northern foot of the hills, is within the epicentral area. Between here and Borpeta we have no certain indications of its boundary, and to the west of Borpeta the indications are even more imperfect.

It is evident, however, from the observations in the Garo Hills, that the zone of maximum permanent change lies just west of the 91° meridian, and it is reasonable to suppose that the zone of maximum displacement would correspond to the greatest width of the area of displacement, that is of the epicentre. Assuming, for the moment, that the displacement was mainly in a north and south direction, we should expect the northern boundary to trend south and west from about 91° E. longitude, in a manner corresponding to its southerly and easterly trend to the east of that line, while, to judge from the accounts of the effects of the shocks in the Borpeta subdivision and in the Bhutan hills, it would seem that the northern limit of the epicentre must have reached nearly to the foot of the Himlayas, even if it did not run still further north, on this meridian.

Turning now to the southern boundary. This may be approximately fixed with some approach to accuracy, though we have no direct evidence.

In the first place, it is reasonable to suppose that this earthquake was directly connected with the tectonic processes to which the origin of the Assam range is due. The elevation of this range has been shown to be of recent date,[1] and its leading features are so largely dependent on its structure that the elevation may well be still in progress. But the sharply marked southern boundary shows that, whatever the process to which their elevation is due, its geographical limit coincides with the southern edge of the hills, the northern limit of the alluvial plains of Sylhet. It may be expected, then, that the thrust-plane has approximately the same limit, and as pronounced displacement has been detected more than half way across the hills from north to south, we might, on this ground alone, draw the southern boundary of the epicentre along the edge of the hills as far as the Sameswari river and thence westwards along the southern edge of the high hills.

There is some evidence that this course is the correct one, for in the Sylhet valley there is no indication of an extension of the epicentre under the plain. The destructiveness of the earthquake was about the same from east to west, as far east as Sylhet, and there is no place in the southern alluvium at which the after-shocks were more abundant than at other places east and west.

The marked contrast in these two respects between the northern and southern valley points to the conclusion that the southern boundary of the epicentre did not make a sweep to the south, corresponding to that on the north, but was a nearly straight line, coinciding or parallel with the southern edge of the hills.

The eastern limit has already been referred to in part, when describing the northern boundary. East of Shillong the exact limits cannot be followed with certainty, but the epicentre appears to run out under the plain to the north of Sylhet. This tract was not visited by me, but information collected points to some changes of level. I was informed that the land on the north bank of the Barhil or Mangai river, below Dauki (Dowke) which sloped very markedly up to the foot of the hills before the earthquake, has now apparently a much

[1] Chapter IX, p. 135 ff.

less slope; and the low lying portions of a tea garden, about four or five miles to the south, which in ordinary years were regularly flooded, remained dry during 1897. More important is the testimony of Mr. H. H. Brownlow of Sandai (Sundye) to the north of Jaintiapur; writing on the 3rd August he says: "A very strange thing on the 12th June was the suddenness with which the water lying on the plain disappeared. Just before the earthquake about one third of the area within easy vision of the hills was covered with water; 20 minutes afterwards, when I looked, a single small pool was all I could see."

The apparent change near Dauki, and the change in the tea garden south of it, might be, the first imaginary, the second superficial, and due to displacement of the alluvium by the earthquake. The drying up of the waters south of Jaintiapur cannot be so explained: it is the reverse of what happened elsewhere, where the raising of the beds of river channels and ponds and the formation of vents, caused water to increase on the surface of the ground, and I have satisfied myself by enquiries that the drying up observed by Mr. Brownlow was not a general phenomenon. There is no reason, however, to doubt the specific statement made, and it is obvious that, if it was due, as is probable, to a change of level, it must have been local, for any general change of level would not have led to the water flowing away from one part towards another.

There is support for the supposition that the epicentre tailed off in the direction of Jaintiapur in the great violence of the shock at that place, where it seems from the accounts to have been quite as bad as at Shillong. At Sylhet, too, the severity of the shock was very great, but to the eastwards it died off rapidly.

Taking all things into consideration, I consider that the eastern termination of the epicentre took much the form shown on Map No. I.

Turning now to the western termination, it seems certain that the epicentre extended into the alluvial plain west of the Garo hills, but how far it is difficult to say. Considerations of symmetry would suggest that the western end had much the same form as the eastern, and there is a certain support for this in the great destructiveness of the shock at Rangpur, and along the Kaunia branch of the Eastern Bengal State Railway. The breaking of the stone fence-posts described by Mr. Hayden[1] is a phenomenon which can only be paralleled in, or close to, the epicentre of this earthquake, and the fact that the greatest destruction on the main line of the railway was at and between Nilphamari and Haldibari, all point to there being a narrow tongue of epicentre running out westwards, to correspond with that on the east. This supposition is, besides, supported by the great number of after shocks felt at Rangpur and Kaunia, and by the fact that some months after the great shocks small after-shocks were being felt at these places, which seem to have been of local origin and not to have been felt elsewhere.

I have now discussed the evidence which can be made use of in determining the limits of the epicentre, and on map No. I will be seen depicted what I believe to have been its probable approximate form and extent. It must be understood that this is only approximate, and that the boundary could not have been so simple and symmetrical in reality. There are, however, no means for an accurate delimitation of the boundary in detail, nor would this, if possible, be likely to lead to a serious change in the general shape and size.

Taking the dimensions drawn as about the real ones, we find that the thrust-plane must have had a length of about 200 miles, a maximum breadth of not less than 50 miles, and an area of between 6,000 and 7,000 square miles.

It is these dimensions alone that give any reason for doubting the correctness of the conclusions regarding the cause of the earthquake which has been propounded, as the area far exceeds that of any known thrust-plane. But in making a comparison it is necessary to remember that, when a thrust-plane has been laid bare by denudation, all we can know of it is the line of its outcrop. For a few miles into

[1] See appendix A.

the earth and a few miles of what has been removed we may be able to infer, with a greater or less degree of certainty, but apart from this all we can know is the extent in one direction. Even here the information may be incomplete, for denudation may have removed, or not yet exposed, that part of the thrust-plane where its dimensions were greatest; or the continuation may be covered up and hidden by newer deposits.

From this it will be seen that in attempting a comparison we can only take one dimension, and must leave area out of consideration. If we do this, it is not necessary to go beyond the great 'Faille du Midi' in Belgium, a thrust-plane which has been traced for 120 miles, for an instance comparable in size with the thrust-plane inferred as the cause of this earthquake.

There remains now only the determination, so far as is possible, of the depth below the surface at which this thrust-plane lay. In attempting this there is only one method, of the many proposed by different authors, which can be applied in the present case, and that is the method proposed by Dr. Aug. Schmidt[1] based on the observed rates of travel.

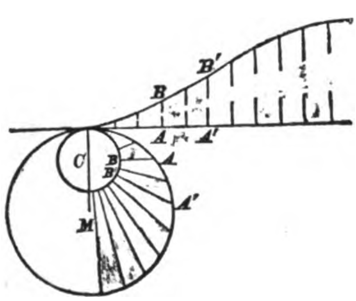

Fig. 18. Schmidt's modification of Seebach's hyperbola.

The principle on which this is based is illustrated by fig. 18, copied from Dr. Schmidt's paper. In this the outer circle represents a section of the earth, and C the focus of an earthquake, the depth from the surface being much exaggerated to bring out the principle

[1] Jahresheft. Ver. f. vaterl. Naturk. in Wurttemberg. XLVI, 227 (1890).

of the method more clearly. The small circle represents a coseismic line corresponding to the moment when the earthquake first reaches the surface at the epicentre. On the assumption that the earth wave travels with equal speed in every direction, the earthquake will have reached every point of this line at the same moment, and the portions of the radii BA, B'A' which lie outside the circle represent the intervals of time which elapse between the time when the earthquake first reaching the surface at the epicentre, and when it reaches the points A A'. If now we draw a straight line through the epicentre at a tangent to the outer circle, and lay off along it distances equal to the arcs of the outer circle contained between the epicentre, and the points where the radii from C cut it, and from each of them draw a perpendicular line equal to that portion of the corresponding radius which lies between the two circles, then by joining the ends of these perpendiculars we get a hodograph, or time curve, of the earthquake.

Now, it is to be noticed that for each equal interval along the surface of the earth from the epicentre outwards the time interval increases, that is to say, the apparent rate of travel decreases until we reach the point where the radius which runs at right angles to the seismic vertical cuts the surface. Beyond that, the time intervals begin to decrease once more, or in other words the apparent rate of travel increases. As, from the method of construction of the hodograph, the line is more steeply inclined in those parts where the apparent velocity is less, and less steeply where it is greater, the hodograph will be divided into two parts, one concave upwards, the other concave downwards, and the point of passage from one curve to the other corresponds to the place where a line from the focus, at right angles to the seismic vertical, strikes the surface.

Consequently, if we have the hodograph, the depth of the focus can be determined by drawing a line through the point of flexure at right angles to the seismic vertical, when the distance cut off will represent the depth of the focus from the surface.

In other words, the depth of the focus is the versed sine of the angle whose arc is the distance of the point of flexure of the hodograph from its centre.

As we have seen in chapter IV, the hodograph of this earthquake shows just those features which it should according to hypothesis, and the point of change from one curve to the other is situated at about 280 miles from the centre. A distance of 280 miles on the surface of the earth corresponds to the arc of an angle of a little over 4°, and the versed sine of 4° amounts to 9·3 miles.

It must, however, be remembered that this result is to be taken merely for what it is worth. The method, however accurate in theory, is subject to too many sources of error in practice to be thoroughly depended on in the present case, as the time observations are too few and too imperfect to allow the hodograph to be drawn with perfect certainty.

A more important source of error may be consequent on the form of the focus. If we suppose that yielding first took place in the centre of the thrust-plane and spread outwards from thence, no great change would result in the hodograph, as the rate of spread of the fissure would probably be much the same as that of the propagation of the earthquake disturbance. But if, as is conceivably possible, there was a preexistant fissure, yielding might have taken place practically simultaneously at more than one point and spread from more than one centre over the focal area. In this case the hodograph, as drawn, would no longer give the true distance of the point of flexure from its centre; an unknown amount would have to be cut off from the right hand side of the curve and the resulting depth focus correspondingly diminished.

There is, however, one consideration, not yet referred to, which would have an opposite effect and would more than counteract any diminution in the deduced depth of focus resulting from the supposition referred to in the last paragraph. In fig. 18 and its explanation it is assumed that the earthquake travels at the same rate in every direction and at all depths. It is certain, however, that the waves travel faster at greater than at less depths and, as pointed out by Dr. A. Schmidt,[1] of Stuttgart, one consequence of this would be that the wave paths, instead of being straight lines, would be concave upwards. Another consequence would be to throw the point of junction of the two contrary curves closer to the centre of the hodograph, that is to say, the focus would be at a greater depth than the versed sine of the angle contained between the point of reversal of the curve and the centre.

If then the curved line on plate XXXIX represents the true hodograph or time curve, the depth of the focus must be more than 10 miles. But it has already been shown[2] that the records admit of another and totally different interpretation, and we have seen that the dotted line is that which more probably represents the true hodograph, or speed curve, of the earthquake, and is in accordance with what is probably the true theory of the propagation of the earthquake.

Accepting this theory and the corresponding speed curve as the true ones, it is evident that the time observations can give no clue to the depth of the focus, and we must reject the estimate, improbable in itself, of 10 miles. This, however, leaves us without any definite indication of the depth, and we have to attack the problem by the aid of general principles.

Assuming the earth to consist of highly heated matter, and to be cooling down by a slow conduction of heat outwards, we have it divided into three portions. First, an outermost skin of rock which has attained a constant temperature and no longer cools or contracts any further ; second, a shell of rock which is gradually cooling and contracting; and third, a central mass which has not yet been affected by the loss of heat from the surface. Now, the loss of heat by the second of these zones causes a general reduction of bulk, and the rock composing the first or outermost zone is thrown into a state of compression. The materials of the second zone, however, are contracting in every direction, not in a radial direction only, but also

[1] Jahresheft Verein f. vaterl. Naturkunde in Wurttemberg, XLIV, p. 2:8 (1888).
[2] Supra, p. 74.

circumference of each circle, and where this zone passes into the central mass, which will not yield to its contraction, it must obviously be thrown into a state of tension, as the tyre of a wheel, which is put on hot, is thrown into a state of tension, while it compresses the framework of the wheel.

From this it appears that while the outermost layers of the earth must be in a state of compression, there is a certain depth at which this state of compression is replaced by one of tension, and somewhere at the passage of the one to the other, there must be a "level of no strain." Now it is evident that an earthquake, being the consequence of a sudden relief of strain, can originate either above or below, but not at, this level of no strain, and, practically, we may say above only. At great depths both pressure and temperature increase, and the effect of either is such as to introduce conditions unfavourable to a sudden relief of strain. Under great pressure it has been proved experimentally that solids flow like fluids in the direction of least pressure, and high temperature introduces a condition of plasticity, even at the surface, which is not conducive to a gradual accumulation of strain and a sudden giving way.

For this reason we may take it that all earthquakes originate above the level of no strain and, what is more, at some considerable distance above that level, as compared with its depth below the surface. It should, therefore, if we had any thoroughly trustworthy method of determining the depth of the focus, be possible to determine a minimum value for the depth of the level of no strain.

No method has, however, been proposed which is thoroughly trustworthy, and instead of using earthquakes to determine the depth of this level of no strain, we must use its depth, as independently calculated, to fix a maximum depth for the focus of an earthquake. According to the calculation of Rev. O. Fisher, the depth of the level of no strain is not more than about 2 miles from the surface.[1] Mr. C. Davison, however, has pointed out that this estimate is based on

[1] Physics of the Earth's crust, 2nd edition, 1889, p. 98 : Phil., Mag 5th, series, XXXVIII, 135 (1894).

the assumption that rock expands to an equal degree for an equal increase of temperature at all temperatures, and that, if allowance is made for the increase of the coefficient of expansion with an increase of temperature, this estimate must be raised to nearly 8 miles.[1]

In both these mathematical investigations a number of assumptions have necessarily to be made which either do not, or are not known to, accurately represent the facts of nature, so that neither can be accepted as a rigidly accurate estimate. But, after making allowance for all these sources of error, it is evident that the level of no strain lies at a depth of only a few miles from the surface; and as it is highly improbable that in the depths below it the conditions are such as will allow of the production of an earthquake, we may take it that all estimates of the depth of focus, which exceed some five or six miles must, *ipso facto*, be regarded with suspicion.

In the case of the earthquake at present under consideration the faults described in Chapter IX show that, in part at least, the focus extended right up to the surface, and the presumption is that the great thrust-plane, which may be looked upon as the principal focus, does not lie at a very great depth. A similar conclusion might be drawn from the local irregularities of the permanent displacements of level and position which have been detected over so large an area, and it is probably an outside estimate if we suppose the principal focus to have been as much as 5 miles below the surface.

There is one indication which points to a great depth of origin, and that is the alleged simultaneous arrival of the aftershocks at Shillong, Sylhet and Gauhati, as described in Mr. T. D. LaTouche's report.[2] This statement was so striking that an application was made to the Telegraph Department to have the observations continued and extended. They were carried on over two months, but unfortunately, owing to a failure on the part of the Telegraph Masters to appreciate the real object of the observations, have only

[1] Phil. Mag, 5th series, XLI, 136 (1896).
[2] Appendix A.

been of value in the case of Shillong and Gauhati. Details of these are given in Appendix F, from which it will be seen that the alleged simultaneity, when critically investigated, means intervals of from 4s. to 1m. of time. It must be noticed, moreover, that the records are not concordant; for instance, the shock of 5-48 A.M. (Madras time) on 25th October is reported by the Shillong office to have been felt at the same time at Gauhati, while the Gauhati office reports that it received the signal from Shillong one minute before the shock reached Gauhati.

From this it is evident that the time intervals were not always so short as to necessitate a great depth of focus. They might be accounted for by the focus lying between the two stations or to one side of the line joining them, in such a way that the distance to be travelled was nearly the same in either case. In those cases where the shock is reported to have been felt simultaneously at three stations, it is possible that a large area was set in motion, practically simultaneously, along a horizontal thrust-plane.

Taking everything into consideration, there is nothing to necessitate the assumption of a great focal depth, if this is inconsistent with the conclusion arrived at by other lines of reasoning.

Summing up, then, we may say that the earthquake of 12th June 1897 was caused by a movement along a thrust-plane or thrust-planes and along secondary thrust- and fault-planes, which had a maximum length of about 200 miles and a maximum width of about 50 miles. The depth of the principal fissure cannot be determined, but was probably not so much as 5 miles below the surface, and numerous secondary faults and fractures rose from it towards, and in some cases as far as, the surface of the ground.[1]

[1] This chapter was written before the results of the reobservation of the triangulation of the Khasi hills was received. I still consider it represents the most probable explanation of the earthquake, but the revision of the triangulation has shown that it may possibly be incorrect. These results were received too late to be incorporated in this chapter, they are discussed in Appendix G, at the end of which will be found a statement of the extent to which the conclusions drawn in this chapter are rendered uncertain, though not disproved.

CHAPTER XI.—THE RECORDS OF THE BOMBAY MAGNETIC OBSERVATORY.

At Bombay, though the earthquake was not felt, it left its impress, as has already been mentioned (Chapter IV), on the records of the magnetic instruments in the Observatory at Colaba.

The instruments affected were the declination, horizontal force, and vertical force magnetographs, and the barograph. Reproductions of the traces of the first three will be found on plate XL, and the following description, extracted from the account published by Mr. N. A. F. Moos,[1] Director of the Observatory, in his report for the year 1896, may with advantage be repeated here:—

3. It must be noted here, that the disturbance fortunately occurred just after 16 hours—the time of hourly *eye observations*; a valuable opportunity, therefore, was secured, and it became possible to note and study the peculiar behaviour of the instruments during their disturbances, some of which by the rapidity of their movements could not have been photographed. There may be some doubt as to whether the disturbance in the Magnetographs was due to mechanical or magnetic action, but no such doubt can exist for the Barograph. The disturbance of this instrument must have been caused by distortional waves, or due to tilting of the instrument. It will be noticed that the maximum effect of the disturbance, as photographed in the Barograph trace, followed the largest wave shown by Declination and Vertical Force Magnetographs by about one minute.

4. With regard to the disturbed trace of the Declination Magnetograph on the other hand, it is difficult to conceive how condensational or distortional waves could affect the suspended magnet under an exhausted receiver so as to set up large vibrations in it, simulating magnetic action. The magnet was disturbed mechanically, no doubt, by the seismic waves, and these disturbances were typical of *mechanical* action. The three motions (besides the vibratory motion) observed in the Declinometer at the time of disturbance, showed (1) motion of the whole magnet parallel to itself (East and West), (2) motion of the magnet as a whole (North and South), and (3) the slight bobbing motion of the ends of the magnet up and down. But neither of these motions would show increase of the scale reading, nor would vibratory motion, if set up by mechanical causes, continue for some time to show

[1] A short note on the disturbance of the magnetical and meteorological instruments at the Colaba observatory during the earthquake of 12th June 1897. Magnetical and Meteorological Observations made at the Government Observatory, Bombay. 1896: 4° Bombay, 1897. Appendix, pp. (1)—(7).

increase or decrease of declination. It may be noted that the intensity of the mechanical disturbance was feeble, and the motion *observed* at the time of the disturbance showed no evidence of any great, much less violent, movements. Finally the peculiar character of the trace of this instrument, as will be seen later on, leaves no reasonable doubt that the disturbance was due to magnetic action, which must have accompanied the seismic disturbance, possibly as effect of a cause.

5. The case of the Horizontal Force Magnetograph is, however, different. From the peculiar nature of the bifilar suspension, it becomes obvious that the tension of the wires being a principal factor in the general formula for the condition of equilibrium, it must be affected by any sudden displacement of the points of suspension. A distortional wave, for instance, suddenly lifting the points of suspension would result in increasing the tension, and any sudden depression would for a moment reduce the tension. A lateral movement, also, is likely to temporarily alter the conditions of equilibrium, and this Magnetograph, therefore, appears to have been disturbed by the combined action of both mechanical and magnetical disturbances; in this instance more perhaps by the latter than by the former, which was feeble as stated above. The trace shows some evidence of being affected by two causes superimposed upon each other, specially at the end of the disturbance, where the blurred trace, probably due to change in the focal distance caused by a slight displacement of the mirror, appears suddenly to pass from a faint to a somewhat deep impression, bounded by *convex* curves.

6. Movement in the Vertical Force Magnetograph now remains to be inquired into. That the centre of gravity and point of support of the magnet in this instrument, do not coincide, and may cause rotation, and, therefore, movement of the magnet, is self-evident; but from the conditions of the magnet and the quantity of motion observed, it does not seem probable that the motion was due to mechanical causes. This instrument is under an exhausted receiver but its knife edge is somewhat faulty, and this Magnetograph, therefore, is peculiarly sensitive to shocks,—an accidental fall of a lamp-chimney, heavy tread of visitors, and even a slight knock of the hand results in *dislocation* of the curve. And such dislocations being frequent, special care is always taken to guard the instruments from such accidents. And yet no dislocation of the curve is noticed during the earthquake, which more or less establishes the fact that movements of the earth must have been very feeble. But the instrument does show vibrations, which naturally leads to the inference that they must have been caused by some magnetic action, the first vibration of which is timed to have taken place exactly when the Declination trace is just lost by the second wave.

7. And it would thus appear as if the seismic convulsion was in some way the cause of the magnetic action, the latter phenomenon running parallel to the former, increasing as it increased and subsiding as it subsided, every seismic wave having its companion effect in a magnetic wave.

8. With regard to the direction. Since the Barograph would not show any indication of direction, nor the Magnetographs, all of which appear to have been disturbed by magnetic action, it is difficult to come to any definite conclusions. Except, perhaps, in the case of Declination, the suggestive explanations given later on, if true, would point at least that the direction of the magnetic

waves, and, therefore, of the seismic waves was inclined more to "East to West" than to "North to South." From the mechanical disturbance of the magnets of the two instruments Declination and Horizontal Force, which are suspended at right angles to each other, the more pronounced motion *observed during the disturbance in both*, was from East to West. The focal distance of the latter instrument also appears to be slightly affected, due to motion of the mirror East to West. It, therefore, strengthens the presumption that the Direction of the waves must have had a strong Easterly component, and the comparative feeble motion of both the magnets parallel to North and South direction, shows that the Northerly component was present, but was feeble. We shall now examine each trace separately.

9. *Declination Magnetograph.*—The photograph shown here is a copy (enlarged about 2½ times) of the trace obtained from the Declination Magnetograph at the Colaba Observatory. The time of vibration of the magnet is 5·33 seconds, and the original trace allows of an accuracy up to one minute in the determination of time. The scale value of the instrument is 28′·72 for an inch of tabulation in the original curve. The curve shows a part of the trace of the 12th June. The regular break seen on the trace is due to a metallic fan, which automatically cuts off light every two hours for four minutes and a quarter. The middle of this break, therefore, represents 16^h on the 12th June. The usual sensitiveness of the photographic paper used at this Observatory has been ascertained by experiments with a steady light, and found that an exposure of about 4^s to the usual kerosine burners (of about 4 candle power intensity) used, is enough for action; and with regard to impression of light during the vibration of the magnet, it is found that oscillations of amplitude of 3½ divisions of the scale, equal to a displacement of about 28 minutes of declination and upwards, are not recorded; the velocity of the speck of light, together with the motion of the paper, a little over half an inch in one hour, precludes photographic action unless the amplitudes are brought within the above limit, and naturally the first impressions produced are at the extreme ends of the amplitude, where the velocity is a minimum. It is only when the vibrations fall to within about 1½ divisions of scale, that the paper shows the impression of light in the middle of the curve, that is, where the velocity is a maximum.

10. It is assumed in what follows, that every seismic wave was accompanied by a temporary disturbance of the magnetic circulation. The first wave, which appears to have just commenced the disturbance *in the instrument* must have passed Colaba at about 5 minutes past 4. The seismic disturbance then seems to have grown in intensity, and about 7 minutes past the hour the increased amplitudes (which by the way, it must be noted, were first performed about a higher zero showing a decreased easterly declination, movement of the curve in the downward direction showing an increase) passed the limit above referred to, and the trace is entirely lost. Immediately after this, however, the impulsive force appears to have ceased, and the damper of the magnetograph reducing the amplitudes (the logarithmic decrement has been ascertained to be about to be =·035), bring them within the limit of photographic action, and the trace is just photographed at about 9 minutes past sixteen. This marks the time of temporary lull, for immediately afterwards the trace is lost, to appear faintly again but more

strongly than before at about 11m. This goes on, but the magnetic action now becomes less and less intense (presumably therefore the cause of the disturbance of the seismic waves also) and the amplitude of the vibrations falling within the limit of photographic action, the record runs beautifully clear after this, and every wave is registered following its predecessor with more or less rhythmic precision the intensity of the disturbance getting less and less till, at about 34 minutes past the hour, the disturbed trace runs into normal curve once more.

11. However, one singular feature in the trace, which is clearly visible in the latter part of the disturbed curve, must also be explained, *viz*: the running of the vibration lines into each other by a zig-zag kind of trace. The most plausible explanation appears to be the following:—

12. Assuming the normal curve to be the zero for the time, ordinary vibrations, caused by momentary disturbance, would take place above and below this zero with *equal amplitudes*. But from the nature of the appearance of the zig-zag curve it seems as if the advancing seismic wave of condensation caused a decrement in the declination and compelled vibrations about a displaced zero *higher* up the curve, while during the receding wave (as it passed away) the reverse and opposite effect followed, the declination increasing, the vibrations were caused about a lowered zero each phenomenon of course having its maximum and minimum effect. Fourteen such waves in all can be detected on the trace, the 2nd or 3rd of which, more possibly the 2nd, was the most intense, and each complete wave was followed by another after an average interval of about 2 m. The maximum effect of the advancing and the retreating parts of the wave being recorded at the average interval of about 1 m.

Disturbance in Declination Magnetograph.

Wave.	Maximum effect showing decreased declination.		Maximum effect showing increased declination.		Commencement of disturbance.	
	h.	m.	h.	m.	h.	m.
1st	16	6	16	7	16	5
2nd		8.5		9·5		
3rd		10.5		11·5		
4th		12.5		13·5		
5th		15		16		
6th		17		18		
7th		19.5		20·5		
8th		21 5		22·5		
9th		24		25		
10th		26		27		
11th		28		29		
12th		30		31	End of disturbance.	
13th		31·5		32·5		
14th		33·5			16	34

13. It will be seen that the beginning of the seismic disturbance, as recorded by this instrument, shows that it was somewhat sudden and abrupt, and the rise to the maximum after the commencement was within 3 to 4 minutes, while, the falling off, as shown by the clear trace, appears to have taken place gradually and steadily till normal conditions were reached. From the very regular trace it appears that the time of vibration of the magnet must bear a certain relation to the period of disturbance, the exact time of vibration being some even multiple of submultiple of the period, otherwise the regularity of the vibrations would be disturbed by "*interference.*"

14. The *average* displacement of the declination East or West during the 4th wave, which is well defined, would equal that due to a change of ·00034 C. G. S. units in terms of force.

15. If by producing the curves on each side we get the *probable* amplitude of the most intense wave where the two curves meet, the *average* displacement appears to be ·16 inch, equal to ·00051 C. G. S. units in terms of force, and this shows that the second wave was the most intense.

16. *The Horizontal Force Magnetograph.*—The trace here shows the disturbance in the Horizontal Intensity, which appears to have commenced early, about 2½ minutes after sixteen, while the instrument shows that the disturbance did not end before 36 minutes past sixteen. This must be due to the extreme sensitiveness of the instrument. The sudden displacement of the curve at the beginning shows that the vibrations must have been performed about a displaced zero above the curve, showing increased intensity equal to about ·00004 C. G. S. units, and the action appears, therefore, more magnetic than mechanical, though both actions seem to be superimposed upon each other. At 5½^m past sixteen the vibrations pass the limit of photographic action and this perhaps marks the time of commencement of the more intense oscillations. The trace appears faintly at about 19½^m past the hour, less faintly at the extreme ends of the amplitudes than at the middle of the curve, and it continues faint till about 26^m past the hour, when the trace suddenly darkens but continues disturbed till 36^m past sixteen when the normal curve is resumed. The time of vibration of the magnet has been ascertained to be 8^s, and obviously as this factor, together with the period of disturbance, must influence the motion of the magnet, the irregularity in the trace is perhaps to a considerable extent due to that cause. The scale value of the original trace is 28′ 67″ for an inch of tabulation, and the clear length of suspension of the magnet is about 12 inches.

17. *Vertical Force Magnetograph.*—The trace shown here is that of the vertical force magnetograph. As pointed out elsewhere, this instrument is very sensitive to shocks resulting in dislocations of the curve. No such dislocation is detected during the earthquake. The unusual thickness of the vibration trace shows that the cause of the disturbance could not have been instantaneous, but must have acted for some considerable time, for vibration of the above amplitude, if caused by, say, momentary action of a deflector, would die out within ½ a minute, while the movements shown in trace lasted each for over three minutes. The first wave appears to have commenced the disturbance at 6½^m, attained the maximum at about 8^m, and ended about 10^m past sixteen. The second commenced immediately after this, reached is maximum effect at about 12^m and ended at 14^m past four.

19. The Observatory has two Vertical Force Magnetographs, both of which show the two waves clearly. The maximum effect of the first disturbance coincides in time with the greatest disturbance in the Declination Magnetograph. The amplitudes of the vibrations above the curve are somewhat smaller than those below the curve (this is more clearly shown in Vertical Force No. 2) which shows a slight decrease in Vertical Force during the time of disturbance. It may be noted that the time of vibration of this magnet is 5·35 seconds, about the same as that of Declination magnet.

21. *Summary.*—Disturbance of magnetical and meteorological instruments at Government Observatory, Colaba, Bombay, during the earthquake of 12th June 1897.

		Hour.	Minute.
Declination, 1st shock	Commencement	16	5
	End	16	7
Most intense, 2nd shock, maximum effect		16	8·5
End of Disturbance		16	34
Horizontal Force, 1st shock	Commencement	16	2·5
	End	16	5·5
End of Disturbance		16	36
Vertical Force, 1st shock	Commencement	16	6·5
	End	16	10
2nd shock	Commencement	16	10
	End	16	14
Barograph, 1st shock	Commencement	16	5·5
	Maximum effect	16	9·5
	End	16	12·5

I have here reproduced only so much of Mr. Moos' account as deals with the observed facts; it will be seen that he attributes the effect to magnetic causes in the main, and in the original this is treated at greater length. The matter is one of importance, as it affects the question of whether the time records obtained from the disturbance of magnetic instruments by earthquakes may be taken as accurately representing the passage of the earthquake wave.

The disturbance of magnetic instruments by earthquakes has been frequently observed, but the cause has been a matter of discussion, and experiments have been made to determine whether it was purely mechanical or wholly or in part magnetic. M. Moureaux, Chief of the Magnetic Observatory of Parc Saint-Maur, Paris, had a duplicate of his horizontal force magnetograph prepared, substituting a copper bar for the magnet, and found that three earthquakes, which affected the magnetograph, did not affect the copper bar. But no certain conclusion can be drawn from this, for, as pointed out by Prof. Agamennone,[1] the mechanical conditions of a magnet and a copper bar, on which the earth's magnetism has no influence are so different that they could not be expeced to respond in a similar manner, even to a purely mechanical disturbance in which magnetism had no part.

Turning to a consideration of the instruments at Bombay, which are similar to those at any other magnetic observatory, we have three types devoted to recording, (1) vertical force, (2) horizontal force, (3) declination.

The vertical force instrument consists of a bar magnet suspended in a nearly horizontal position on two knife-edges which allow it to turn in a vertical plane, but not to turn horizontally. This magnet bears a small mirror, on to which a ray of light is cast from a lamp and reflected back on to a slowly travelling band of sensitised paper, and in this manner a record is kept of the varying inclination of the magnet due to variations in the vertical magnetic force. As noted by Mr. Moos, the centre of gravity of the bar does not coincide with that of the knife-edges; in the first place it is lower, so as to place the magnet in a state of stable equilibrium, and in the second place it has to be a short distance to the south of the knife edges to counteract the dip and keep the bar approximately horizontal. As a consequence the effect of the inertia of the bar would tend to cause a disturbance if it were displaced in either a vertical or horizontal direction; and if the disturbance was an alternating one, and the period corresponded with that of the natural swing of the magnet, these disturbances, might accumulate to a considerable amount. The amount of the displacement of the centre of gravity from the line of suspension is, however, so small, that this effect may probably be rejected, as has been done by Mr. Moos in explaining the observed disturbances,

[1] Atti. acc. R. dei Lincei, 4th series, VI, pt. i, p. 21 (1890).

but there is another way in which the disturbance of the trace may be accounted for on mechanical grounds alone. If the instrument as a whole is tilted, the lamp and recording paper are raised or lowered, but the magnet retains its' original inclination, and the position of the spot of light on the sensitive paper is consequently shifted. This is, in fact, exactly what happened, and it would be possible to explain the appearances produced by a gentle undulation, or alternate up and down tilting, of the recording apparatus while the magnet remained steady. The absence of any interruption in the curve, in the case of an instrument so extraordinarily sensitive to the slightest shock as this is described to be, cannot be held to militate against such an explanation, as it would not be exposed to anything of the nature of a shock.

The horizontal force instrument consists of a magnet suspended by two silk fibres, fastened about ½ inch apart from each other on the magnet, and about 12 inches long. The upper attachment of these fibres can be, and is, turned round, till the magnet, instead of pointing north and south, points east and west; in the case of the Bombay instrument, the upper pair of suspension points are turned through about seven-eighths of two right angles. As a consequence of this mode of suspension the magnet is very sensitive, and a movement, either horizontal or vertical, or a tilting in any direction except that at right angles to the upper pair of suspension points, will affect the two fibres unequally and cause the needle to twist more or less till it resumes a position of equilibrium. Here again we find that the appearances might be accounted for by purely mechanical causes, and the earlier commencement and later cessation of the disturbances might be accounted for by the greater sensitiveness of the instrument to purely mechanical disturbance from the passing earthquake-waves.

The declination instrument consists of a simple free swinging bar magnet suspended by a branch of silk fibres and free to swing in any direction. Here, as in the vertical force instrument, a slight displacement of the centre of gravity is necessary to counteract the magnetic dip, but the displacement is so small that the centre of gravity lies practically within the area of the small bundle of fibres from which the magnet is suspended, and it is difficult to understand how an angular swing could be imparted to the magnet by its inertia, while a tilting of the instrument as a whole would have no effect in producing an angular displacement of the needle. The only form of mechanical displacement which would account for the effect of the earthquake on the trace, is a twisting of the instrument as a whole, or a side-long motion of the recording paper relative to the magnet. As in the case of the vertical force instrument when tilted, the magnet would retain its original position, and the spot of light would reach the paper on one side or other of the position properly due to that of the magnet. Apart, however, from such twisting of the instrument as a whole in a horizontal direction, it is difficult to conceive any explanation, other than magnetic, to account for the angular displacement of the needle.

I know of no means of directly testing whether there was any such horizontal twisting of the instrument. The vertical force instrument gives no check, for, the motion of the paper being in a horizontal direction, the only effect of such displacement would be to cause a slight uncertainty in the time determination, but the amount of the angular displacement of the declination needle recorded—exceeding as it does 28′ of arc—makes it improbable that any such displacement took place; moreover, though it would be impossible to recognise the effect of a small horizontal displacement on the trace of the vertical force instrument, it is difficult to believe that so large a horizontal angular displacement as half a degree of arc would not introduce anomalies in the trace, which it would be impossible to overlook.

There is one supposition by which a large disturbance of this needle might be explained, and that is a succession of small alternating angular twists, whose period was either identical with, or a small of aliquot part of the natural period of vibration of the needle. In this case it is conceivable that they might, if sufficiently prolonged, in time give rise to a swing of the needle, much in excess of the actual angular disturbances, but this supposition is improbable, for it is probable that the wave motion was by no means uniform and the required ratio between the period of the wave and that of the magnet would not last for long enough to produce the observed effect.

On the whole, therefore, it is probable that the disturbance of the magnetic instruments was partly, if not principally, magnetic and not mechanical; but it is evident, from the time at which they were felt, that they had no direct connection with the electric disturbances described in the next chapter. We have already seen (Chap. IV) that the magnetic disturbances were felt at Bombay at the exact time when the earthquake-wave must have passed under it, and, consequently, if the apparently magnetic disturbance at Colaba was really, as is probable, magnetic, it must have originated locally, and as a direct consequence of the passage of the earthquake-wave. This conclusion is also in agreement with the facts recorded in Chapter XV, regarding the general agreement of time of the disturbance of such magnetic instruments in Europe as were affected, with that of the passage of the earthquake waves, and with the absence of a close agreement of the times at which the magnetic traces were affected with any of the phases of the mechanical disturbance.

CHAPTER XII.—ELECTRIC EFFECTS.

Changes in the electrical state of the atmosphere and earth currents, causing a temporary interruption of telegraphic communication, have been observed to accompany other earthquakes, but in none, so far as I know, have the latter been so conspicuous and severe as in the present instance.

Among the reports received from the Telegraph Department several mention interruptions of communication at about the time of the earthquake; but it is very doubtful whether they were in any way connected with it, except in so far as they might be due to injuries to the wires by falling trees, houses, etc. From Shillong, however, the reports are of a different nature and the facts sufficiently striking to justify their being recorded.

Nothing is known of the first great shock, the destruction was too rapid and complete to allow of any observations being made, but when communication was being restored, four days after the earthquake, it was found that the aftershocks, then still going on, were accompanied by electric currents of sufficient force to cause severe shocks to the operators, and sparks on the instruments.

It will be best to reproduce the original reports. The first of these is from Mr. J. G. Morgan, Assistant Superintendent of Telegraphs, Shillong Sub-Division, in a letter to the Director General of Telegraphs, dated 12th July 1898:—

"As stated before I noticed no thunder or lightning on the evening of the 12th. But when I was at the office, trying to restore communication, in handling the wires, the Telegraph Master, Signallers and I experienced many electric shocks, some of them of considerable severity. Nearly all these shocks were sometimes preceded but more often followed by an earth tremor. Owing to the testing instruments and indicators being buried under the office ruins, I was unable to find the direction of these currents. At Nangpoh too, while I was working Shillong on the evening of the 16th, I noticed much the same thing. The line was being worked in closed circuit with copper to earth at Shillong, and I observed insulation several times lasting for periods, varying from a few seconds to a couple of minutes, in every case an earth tremor made itself felt almost and immediately after. No thunder or lightning was noticed by me at the time."

The second is extracted from letter No. 80 of the Telegraph Master, Shillong, to the Director General of Telegraphs, dated 20th July 1897:—

"I should, however, like to note the peculiar phenomenon experienced on the evening of the first day on which communication was restored, *viz.*, on the 16th June between 19 and 20 hours. Though working continuously with Gauhati from 14 to about 19 hours (on the closed circuit with batteries at both ends) without any stoppages, frequent insulations were now noticed varying in duration from 5 to 13 minutes. This continued for about an hour before I discovered that in each case the insulation occurred with a shock of earthquake and that the insulation continued until the next shock restored the current on the line. It then appeared to me that natural c·rrents of great intensity and alternating polarity were being generated by each shock of earthquake, which had the effect of neutralising and restoring the battery current. There being a second line available, it was made use of as a return wire, when no further trouble was experienced in working. Since then earthquake shocks have not had the least influence on our work though repeatedly felt up to the time of my writing.

In conclusion I would beg to add that between the 12th and 16th June, before communication was restored, repeated attempts were made by me to get Gauhati and Sylhet, and it was noticed that severe electrical shocks were felt, often accompanied by flashes, and in every instance simultaneous with the earthquake rumble, which immediately preceded each shock."

Leaving out of consideration the explanation proposed, this account, like the first, shows that there were marked electric currents accompanying the after shocks in the neighbourhood of Shillong, which rendered it impossible to utilise the earth as a return for the current. The intensity of these currents was too great for them to be explained as a purely mechanical result of the disturbance of the soil in contact with the earth plates, though this is known to produce slight electric currents, and the cause must be looked for at a greater depth and more directly connected with the origin of the disturbance.

CHAPTER XIII.—THE EARTHQUAKE SOUNDS, WITH SOME REMARKS ON THE BARISAL GUNS.

Like everything else connected with this earthquake, the sound phenomena, which are so usual an accompaniment of earthquakes, were exhibited on an unusual scale. Yet, probably on account of the greater impression left by the more obvious and awe-inspiring effects of the earthquake, it has not been possible to collect information which will add much to the solution of the many vexed questions connected with the origin of the earthquake sounds.

Almost the only definite fact to be noted in this connection is that the earthquake was distinctly heard, though not felt, in the mines of the Raniganj coalfield. In this same region the earthquake, as felt above ground might almost have been called severe; it was universally felt and caused some damage to buildings.

It is well known that the earthquake movement, which can be felt, is comparatively superficial, and that, away from the epicentre, it rapidly diminishes in amount, even at small depths. That the sound was heard underground, though the movements were insensible, seems to show that the small and rapid vibrations to which it is due, were not the result, direct or indirect, of the surface undulations, but travelled directly through the body of the earth.

Apart from this, the observations are neither sufficiently numerous nor concordant to lead to any results of value. It has been impossible even to determine, in many places, whether the sound did or did not precede the movement of the ground; from one and the same place I have received accounts stating that the earthquake was preceded by a loud roar, and others which are positive that no sound of any kind was to be heard till the earthquake had become severe.

Of the loudness of the sounds in the epicentral tract we have already had evidence in the account of Mr. J. G. Morgan, Assistant Superintendent of Telegraphs at Shillong,[1] who found that the crash of houses, falling within thirty yards of him, was completely drowned by the roar of the earthquake, and all the accounts from the epicentre and its neighbourhood speak of the loudness of the sounds heard at the time of, and immediately after, the earthquake.

Like the loudness of the sounds the extent of the area over which they were heard was unusually large. Throughout northern Bengal and the Gangetic delta many reports mention a rumbling sound as preceding, accompanying, or following the earthquake. In Calcutta the accounts of different observers are contradictory on this point, some asserting that the earthquake was preceded by a rumbling noise, others being equally positive that the only noise to be heard was that due to falling buildings and furniture. As there is good evidence to show that the rumbling sounds were very generally heard round about Calcutta and to the south in Midnapur, Balasor,

[1] See p. 6.

and even as far south as Coconada, there is every reason to suppose that a similar sound could have been heard in Calcutta, and that those who assert that there was no sound to be heard, either did not notice it, or confounded it with the crash of falling plaster and brick-work.

To the west the sounds were distinctly heard throughout the Santal Parganas, as far west as Gaya and Palamau. At Allahabad, Jabalpur and Bhartpur rumbling sounds are said to have been heard, and even as far off as Kotgarh[1] the earthquake was accompanied by a sound like that of the passing of a cart. To the east they are reported from several stations, the most easterly being Bhamo, though at other stations it is distinctly stated that no sounds were heard. At Mandalay the reports all state that no sound was heard, though some also state that the severe secondary shocks which occurred at about 1 A.M. and 1-30 P.M. of the following day were accompanied by distinct rumblings. To the north it is unknown how far the sounds were heard, but they were very noticeable in the Darjiling district, and even at the frontier station of Yatung.

Over the area roughly indicated in the foregoing paragraph, rumbling sounds appear to have been very generally heard, though there are many places from which negative reports were received. The reported absence of sound may be merely due to its not having been noticed, but it may also in some cases represent a real fact, for it is conceivable that within the area over which the sounds were generally audible, there may have been places where the local conditions were such that the rapid vibrations were damped, or for some other reason failed to make themselves sensible as sounds.

So far, mention has only been made of sounds of the ordinary type, which are variously described as resembling distant thunder, the passage of a train or cart, or similar sounds; the simile employed being usually a sound with which the reporter was most familiar.

[1] In the case of Kotgarh which is in the Himalayas, it is possible that the sound waves may have been due to a local sympathetic shock, started by the passage of the earthquake waves.

All accounts agree in selecting some sound of deep pitch, near the lower range of audibility, of the nature of a continuous rumble or rattle, prolonged and, as a rule, increasing gradually in loudness and subsiding as gradually into silence. Besides these sounds, however, the reports from certain places mention explosive sounds, short and loud, commencing suddenly like the report of a cannon-shot.

Sounds of this kind have been noticed before, in connection with earthquakes they have recorded in the case of two previous earthquakes in India, that of 1869 and of 1881; in the latter case they were mistaken for signals of distress, and the station steamer at Port Blair was despatched to search for the supposed wreck.

In the case of this earthquake, the accounts from Kohima mention that shortly (one account says fifteen minutes) after the passage of the shock three loud explosive sounds were heard, which seemed to come from the south or south-west. Similar sounds are said to have been heard at Wokha and Lumding.

Another account, which may be quoted, is that of Mr. A. E. English, I. C. S.

Date, from looking at my diary, it must have been the 12th June: time, between 5 and 6 P.M. On return from a stroll after game, at jungle camp on bank of 'Theingale,' which is some 7 miles south-west of Kyouko village, and about 19 miles east of Tagaung, I noticed the water in the tank, which was an old river course containing about 300 yards of shallow water, lapping up against the bank below my tent. My hunters said it must be elephants bathing, but on looking there were none at the other end. Some one then pointed to the trees shaking, and we knew it must be an earthquake. To the best of my memory, about ¼ hour or less after this I heard one or two distinct booms like cannon shots, and came out of my tent and joined my hunters and followers who had also come out and were listening and counting the booms. We counted about 25 distinct booms at intervals of about 3 or 4 seconds. The booms were about as loud and distinct as a shot from a 7lb. gun turned away from one at, say, four miles or more, if the country was very flat.

After these 25 booms there were some less distinct rattling noises.

We speculated on the cause, and self and hunters all concluded it must be heavy guns firing from a steamer at Tagaung or on the river. At the time no one thought the sounds were caused by an earthquake.

On asking some cartmen (Maung Bya of Pongon) who arrived next morning from Pongon (2 miles S. E. of Tagaung) if they had heard the noises and what they were, they said 'Yes, cannon firing at Tigyaing or on the west of the river.'

At Tagaung I heard that the noises had been heard from the N. W. It was only when I made enquiries on board the I. F. Co.'s Steamer *Mogaung* that, on hearing there had been no firing of big guns, I concluded the sounds must have been caused by an earthquake.

At the time of occurrence I thought the firing must have been practice or in connection with the coming Jubilee. It rained *very* heavily on 11th, 12th, 13th and on to 15th.

The shocks were not felt, and except for fthe lapping of the water, would not have been noticed.

The sounds came to us from west-north-west of Theingale.

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The sounds were not at all like the rumbling of earthquakes I have heard before, and quite deceived me and my hunters, who were all especially intelligent in jungle matters and noises.

* * * * * * *

Similar sounds are said to have been heard at Sigyaing and Mawlu in the Katha district. At the former place, four loud reports were heard before the shock; at the latter, they were heard afterwards.

Other accounts, from places in Northern Bengal, mention sounds like the reports of distant artillery, but no reference to them will be made here, as it has not been possible to make out from the accounts whether they merely refer to the ordinary rumble, or to the peculiar sounds now being dealt with.

It will be seen that the short explosive sounds referred to here, like those accompanying the earthquakes of 1869 and 1881, were comparatively local in their distribution, the areas over which they were heard were well separated from the epicentre, and the explosive sounds, though evidently connected with the earthquake, followed it after a lapse of many minutes.

The cause of these sounds is at present unexplained, and, though several suggestions might be made, fuller and more detailed information is required before it will be possible to express a definite opinion. One thing, however, seems clear; that the delay between the passage of the earthquake shock and the hearing of the explosive sounds is too great to be explained by the slower rate of travel of the sound wave through the air, as in the case of the interval between a lightning flash and its thunder clap. Were this the explanation it would place the origin of the sound at a distance of hundreds of miles from the place where it was heard, and, even if it were possible that the sound waves could travel this distance, it would necessitate a loudness at the place of origin, and an extent of country over which they must have been heard, which is much in excess of what there is any evidence for assuming.

More information is to be gathered from the numerous small after shocks which were accompanied by, and in many cases consisted only of, sounds. It may be noticed that these sounds were not, as has sometimes been stated, confined to the rocky ground but were heard equally in the hills and on the alluvial plain. I have good evidence that nearly all the shocks which originate under the Borpeta plain are accompanied by distinctly audible rumblings, and this even in the case of those very feeble shocks which are barely perceptible, and being unrecognised at other stations, appear to be of local origin and small extent.

During my tour through the epicentral tract I had numerous opportunities of observing these sounds, which were of frequent occurrence and in some places almost continuous. Some idea of the frequency of these sounds may be gathered from a record, kept on 21st, 22nd and 23rd January, of the times at which they were heard at Naphak, in the Garo hills:—

21st Jan.	22nd Jan.	23rd Jan.
16-8	10-47	14-15
16-15	11-8	14-28
16-25	11-16	14-39
17-15	13-33	15-8
17-25	13-52*	15-12
18-4	13-57*	15-29
18-9	...	16-3
18-35	15-54	18-3
19-15	16-25	18-30
20-12	16-35	18-33
21-33	17-6	20-42
21-44*	18-7	
22-0	18-12*	
22-9	18-33*	
22-26	18-55*	
22-32	19-51	
22-39	20-30	
22-41*	20-33	
	22-45	
	22-49	

Thus, in the 23 hours over which the record extends, 48 distinct rumbles were heard, or at the average of about 50 per diem; and of these only the 7 marked with an asterisk were accompanied by a shock that could be felt.

This degree of frequency was much greater than I observed elsewhere, and it was noteworthy that at my next camp at Samin, which was close to the fault described in chapter X, sounds were much less frequent, not more than 8 or 10 in the day, and mostly accompanied by distinct shakes. From Samin I marched northwards to the neighbourhood of Damra and found the sounds more frequent again. When working along the great Chedrang fault I again noticed the fewness of sounds, and more especially of those unaccompanied by shocks that could be felt. In other words, the sounds, unaccompanied by shocks, appeared to be more common where the surface disturbance had taken the form of bending, than where fractures had extended to the surface.

This conclusion, and most others regarding the sound phenomena, must be taken merely for what they are worth. It was impossible to test them by comparison of simultaneous observations at different places, and it is possible that the results might have been different had I been at my different camps on dates other than those on which I actually was at each particular place.

With regard to the nature of the sounds there was great variation. As a rule, they began as a low, almost inaudible rumble, gradually increasing in loudness, though to a very varying degree, and then gradually dying out after having lasted anything from 5 to 50 seconds. It cannot be said that there was any connection between the duration and the loudness of the sounds, some of the most prolonged never becoming loud, and some of those which lasted a shorter period being as loud as ordinary thunder at a distance of two or three miles.

Frequently, instead of commencing gradually, the sound commenced abruptly at its maximum loudness and then, after a prolonged rumble, died slowly off. Occasionally the sound commenced abruptly and ended soon, resembling the sound of a small cannon, or in some cases of a shot-gun loaded with black powder and fired at a distance of quarter of a mile.

I tried to discover if any variation in the pitch of the note was observable, and though it did seem in a few cases that the pitch, as opposed to the volume, was highest at the commencement and sank as the sound increased in volume, yet no general rule of this sort could be noticed ; variations in pitch were seldom noticeable, and when they were, occurred without any regularity of order. The sounds are in fact so close to the lower limit of audibility that there is little room for variation of pitch. They are indeed less a note than a rumble, and resemble nothing more than distant thunder. Of this I had a good proof, for on the morning of the 26th January when marching from Samin to Cheran, a thunderstorm came up from the south-west, and I found it impossible to distinguish between the earthquake sounds and the thunder at a distance of one to three miles.

Very frequently the sound had not the continuous nature of thunder and was rather a very rapid succession of short sounds, a rattle or rumble in fact, not unlike the sound made by a cart driven rapidly over a rough pavement.

An interesting point to determine is whether the sounds travel through the air, or originate locally. If they travelled any distance through the air it is obvious that the apparent duration of the sound would not correspond with the real duration of the earth vibrations by which it was caused. The rate of travel of sound through the air is much slower than through rock and, after the sound vibrations communicated to the air in the immediate vicinity of the observer had ceased, he would still hear the sound due to the vibrations which were communicated to the air at a distance and gradually reached him by the slower route of travel.

Were this the case, we should expect that the sound would be at its loudest shortly after its commencement and gradually die away. To a certain extent this is the case, but the final dying out of the sound is usually so short in comparison to its total duration, that, if explicable in this way, the real duration of the sound waves in the ground must be within a few seconds of the apparent duration of the sound.

Another objection to the idea that the prolonged duration of the sounds is due to its gradual arrival, through the air, from more and more distant origins, is its lowness, the word being here used with regard to the volume, not the pitch of the sound. Quite nine-tenths of the sounds I heard were never loud enough to travel even half a mile, about as far as they could travel in 2½ seconds, and remain audible. Hence it is evident that durations of 10 or 20 seconds cannot be explained, as in the case of a prolonged thunderclap, by the varying distances that the sound has travelled through the air.

As another argument leading to the same conclusion, it may be said that the sounds appeared to be much more noticeable indoors than out of doors. On the hypothesis of local origin this is easily understood, for not only would the walls and ceiling of a room serve to confine, and so intensify, the sound, but they would themselves be set in vibration and communicate these vibrations to the air of the room. It even seemed to me that the sounds were noticeably more audible in a tent than in the open; here the tent walls could not communicate sound-waves to the air, but they would serve to concentrate those communicated by the ground.

From its very nature this last argument is based on an impression which is incapable of proof, as it is impossible for the same observer to be both in and out of doors at the same moment. The number of earthquake sounds heard during the four months I was in Assam was, however, so great that a certain amount of comparison was possible; it was moreover a point to which I paid special attention and I believe that the statement in the last paragraph represents a real fact.

The general conclusion come to as the result of observations made by me during the cold weather of 1897-98 was that the earthquake sounds very seldom travel through the air, and then only to a small distance; and that, though probably heard in the air, they have travelled through the earth, and are only communicated to the air in the immediate vicinity of the hearer.[1]

It would be impossible to close this Chapter without some reference to those mysterious sounds known as the 'Barisal guns,' which there seems good reason to suppose are seismic in their origin, and to which several correspondents have made pointed reference in connection with the earthquake. A full account of them is, however, impossible; the amount that has been published on the subject is so great and the various hypotheses which have been propounded so numerous, that a full discussion of the subject would occupy more time and space than can here be devoted to them.

The earliest published reference to the 'Barisal guns' known to me is in an account of the Antiquities of Bágerhát by Babu Gourdas Bysack presented to the Asiatic Society and published in the Journal of that Society in 1867,[2] in which they are stated to be regarded as supernatural salutes fired in honour of a local saint. The subject came before the Asiatic Society again in 1870, and several communications will be found in the 'Proceedings' of the Society for that year. In 1888 Babu Gourdas Bysack presented a further paper on the Barisal guns to the Society, and as a result of it a special committee was appointed by the Society to collect information and draw up a report on the facts and to discover, if possible, the cause of the phenomenon. This report was published in the Proceedings of the Society for 1889.[3]

[1] The fact that the sounds generally seem to come from a distance is no real argument against this conclusion; it only means that the impression produced is similar to that produced by loud sounds with which we are familiar, such as thunder, when these originate at a distance.

[2] On the Antiquities of Bágerhát; Jour. As. Soc. Beng. XXXVI, 126-135 (1867).

[3] Report on the 'Barisal guns' made at a meeting of the Sub-committee held on the 17th July 1889 to consider the observations recorded during the year 1888; Proc. As. Soc. Beng. 1889, pp. 199-209. Some further communications regarding the Barisal guns will be found in the Proceedings for 1890.

Various are the theories which have been propounded, in the numerous communications to the Asiatic Society, in explanation of the phenomenon. First among them may be placed that which can best be described as sceptical. According to this the 'Barisal guns' are nothing but the sound of firearms, or of pyrotechnic bombs, exploded on the occasion of marriages or other rejoicings, or of distant thunder.

This explanation may be rejected. In individual instances it may be impossible to distinguish between the sound of fireworks at a little distance and the true 'Barisal gun,' yet the universal belief in the reality of this last shows that we have to deal with a phenomenon distinct from the familiar sounds by which its explanation is attempted.

Another explanation attributes the 'Barisal guns' to electric discharges or the release of explosive gases under water. This hypothesis is too vague to explain anything, and till some definite indication is given of the nature of the discharge or explosion, it cannot be accepted, especially as there is another and adequate explanation.

Of the more definite explanations, which are very probably also partially true, the most popular appears to have been that which ascribes the sound to the breaking of surf on the sea shore. This appears to have been adopted because the 'Barisal guns,' in the Gangetic Delta, seem to come from the south, and the Proceedings of the Asiatic Society contain more than one explanation of how a large roller breaking on a flat shore, could produce a sound which, in certain positions, would resemble that of a distant gun, and some accounts of how such sounds had actually been heard, the result of a heavy surf.

This explanation, however satisfactory it may be for places not too for removed from the coast, cannot be accepted in the case of the precisely similar sounds heard far inland in northern Bengal. Here another explanation becomes more applicable, that the sounds are due to the falling in of river banks. When the Gangetic rivers are rising in flood the high river banks are largely undermined and fall into the river with a crash which, according to some accounts, is at times undistinguishable from the sound of a distant cannon. This explanation, however, fails, like the last, as an universal one since the sounds are heard at places and at times when it is inadmissible.

The subcommittee of the Asiatic Society, saw this difficulty and attributed the sounds to reflection. That is to say, they were taken to be sounds originating at a distance so great that they are inaudible till the sound waves had been reflected from a concave river bank or hill side and rendered audible by being brought to a focus.

The acceptance of this hypothesis seems to have been mainly determined by the fact that the sounds were at times only heard by one of two neighbouring observers and not by the other. This is explicable on the supposition that the one who heard the sound was in the focus of the reflected sound waves, while the other was not.[1]

The last explanation to be noticed is that which regards the 'Barisal guns' as earthquake sounds. We shall return to this, and all that need be said here is that the peculiar local distribution of the sounds which led the subcommittee of the Asiatic Society to attribute them to reflection, is not inconsistent with their being seismic. It seems, however, doubtful whether the supposed fact is a real one; preoccupation, disturbance in the household, distraction from whatever cause, or even mere inattention, might lead to the sound not being noticed by one observer. But even if the sound was inaudible, and not merely unheard, at one place of observation, this would not be difficult of explanation.

I have already explained that the earthquake sounds do not seem to travel any great distance through the air, but to originate locally in the immediate neighbourhood of the person by whom they are

[1] It may be noted that this explanation was rejected by one member of the subcommittee on the grounds that the sounds were heard in places where it was inapplicable on account of the absence of high river banks to reflect the sounds.

heard. Now it is a well established fact that the larger and slower vibrations which cause an earthquake proper, may vary in amplitude and period, even at two places only a few hundred yards apart, and it is reasonable to suppose that the same may be the case with the more rapid vibrations which make themselves audible as sounds. The lowest note which can be heard by the human ear corresponds to a rate of about 32 vibrations a second, anything slower than that being inaudible; as the sound of the 'Barisal gun', like that of earthquake sounds in general, is of very deep pitch, and but little above the lower limit of audibility, it is easy to understand how the sound might be heard at one place, while at another not far off the vibrations might be just too slow to be audible.

In all the accounts noticed as yet the phenomenon is treated as a local one, and though in the later papers it is recognised that the sounds are not confined to the Bakarganj district, or even to the neighbourhood of the sea face of the Gangetic delta, yet the explanations offered have all reference to the special conditions of the Gangetic alluvium. No attempt seems to have been made to utilise the experience of other parts of the world where similar sounds are heard.

The 'Barisal guns' are in fact no local phenomenon, but have been observed in many places. In 1822 the inhabitants of the island of Meleda, off the Dalmatian coast, were startled by a succession of explosive sounds, which lasted for some years, and caused so great alarm that a special commission was appointed by the Austrian Government to investigate and report on them. The report[1] is an interesting and valuable document, not only as a record of the facts and a careful description of the nature of the sounds—which were evidently exactly like those of the 'Barisal guns'—but also as containing a full account and examination of all the theories that had been proposed to account for them. The final result of this

[1] Paul Partsch, Bericht über das Detonations Phänomen auf der Insel Meleda bey Ragusa etc. 8° Wien, 1826.

examination is a demonstration that they were of seismic origin, and that no other hypothesis would satisfactorily account for the facts.

The 'guns' of Meleda appear to have lasted for about five years and then ceased. It is definitely stated that none had been heard before 1822, and there is no published account, that I am aware of, of their recurrence after 1827. It may be that outside these dates they were merely too infrequent to attract notice, but if the limitation is correct, they fall into a numerous category of outbreaks of explosive sounds in other parts of Europe and in America. There are, however, at least two regions where sounds like the 'Barisal guns' are well known locally and may be regarded, like those of Bengal, as a permanent phenomenon.

Of the Flemish coast explosive sounds known as *mistpœffer* have been studied by Van den Brœck, who has published a number of accounts of them[1]; and still more recently Professor A. Cancani has published an account of the very similar sounds known as *marina* in the mountains of Umbria.[2]

It will be impossible here to examine all these accounts in detail, but a brief notice of the points in which they agree or disagree will be necessary. In all cases and places there seems to be a general consensus that they are only heard in calm weather. This probably only means that when there is a strong wind blowing the sounds are drowned by those directly due to the wind. Apart from this, there is no agreement as to the time of year, of day, or of the state of the weather. The accounts from different places differ widely in these points, and even different accounts from the same place differ radically from each other.

These discrepancies are not difficult to understand. Except the short lived observations instituted by the Asiatic Society in 1888, no attempt seems to have been made to test impressions by actual

[1] Ciel et Terre XVI, XVI, *passim* (1895-96).

[2] A Cancani. "Barisal guns, Mistpœffers, Marina," Boll. Soc. Sismol. Ital. III, 222-234 (1898).

observations extended over a sufficiently long period of time. Impressions are frequently founded on a very slight basis of fact; thus the recurrence of a few 'guns' in the early morning, or in foggy weather, might start an impression that these were the circumstances in which the sounds were most frequently heard, and, the impression once started, all cases agreeing with it would, as human nature is constituted, be more noticed than those which did not agree with it, and so, unless there was a very great preponderance of the latter the impression would remain. So too, at a subsequent date, another person might be struck by the recurrence of 'guns' in the late afternoon, and the impression would arise that they most frequently occurred at that time.

Taking this into consideration, there does not seem to be any good evidence that the 'guns' are specially associated with any time of day or season of the year, or that they are accompanied by any particular form of weather, except, as has been noticed, that they are not generally heard when there is a high wind. Nor is there even any good reason to suppose that in the case of each individual district, there is any such connection between a special form of weather and the hearing of the sounds as would imply their being due to peculiar atmospheric conditions.

There is one point on which all accounts are agreed, that the sounds are seldom heard singly. They appear to be almost universally heard in groups of three or more, separated by comparatively short intervals of time, each group being separated by a comparatively long interval. This is an important point, for in it the 'guns' agree in mode of occurrence not only with earthquakes which can be felt, but also with those minute and rapid tremors which cannot be felt but only make themselves known as earthquake-sounds or sound-earthquakes.

This brings us back to what appears to be the only explanation universally applicable, that is to say, the 'Barisal guns' and similar sounds heard in other parts of the world, are seismic in their nature.[1]

Among the many communications I have received regarding the great earthquake of 1897 there are some facts recorded which point to the seismic origin of the 'Barisal guns.' One is that they are reported to have been very numerous and noticeable about Haldibari and Jaipur Hát, which are close to the western limit of the epicentral tract, previous to 12th June 1897. The other, which has come to me from several independent sources, that they were not noticed in Barisal during the latter half of 1897, and were certainly much less numerous than usual.

It is easy to understand that so great a displacement in the earth's crust as that which gave rise to the great earthquake of 1897 would lead to a redistribution of strain in all the surrounding regions. In the deltaic region of eastern Bengal, this redistribution seems to have taken the form of a relief of the preexisting strains which gave rise to the small movements that may be regarded as the cause of the 'Barisal guns', and hence, till this strain is reestablished, they will be less frequent than before.

In ascribing a seismic origin to the 'Barisal guns' it must be distinctly understood that other causes are not excluded. It may be that some of the sounds classed as 'Barisal guns' are due to fireworks or firearms, or to distant thunder. It may be too that in some cases they are due to surf breaking on a flat coast or to the falling in of river banks; and it is even possible that they are at times due to the concentration of sound by reflection, as suggested by the sub-committee of the Asiatic Society. But behind and beyond all these causes there is another which is not confined to one spot, nor limited to the Gangetic delta, but is world-wide and perennial. This can

[1] It may be noted that this explanation would account for the impression prevalent in the deltaic districts, where these sounds are heard, and borne out to some extent by the observations in 1888 recorded by the subcommittee of the Asiatic Society; that they are more prevalent in the latter part of the rainy season than at other times of the year. At this time the soil of lower Bengal is completely waterlogged, and in this condition forms a better conducting medium for sound-waves than the dryer and more porous soil of other seasons of the year.

hardly be other than seismic, using the word in its widest sense; that is to say, the sounds are due to disturbances in the interior of the earth, caused by readjustments of the distribution of the material of its crust, and taking the form of elastic vibrations, which are transmitted to the surface and there become sensible as sounds.

CHAPTER XIV.—THE ROTATION OF PILLARS AND MONUMENTS.

That pillars and other similar objects may be left standing, but with one part twisted round upon another, has long been known as a fantastic effect of severe earthquakes, and even in some cases of earthquakes which can hardly be called severe. There has, however, been no instance where cases of this kind have been so numerous, and so various in the nature of the objects rotated, as the earthquake now under consideration, and advantage has been taken of this to collect all the information possible, and to apply the data so obtained in testing the sufficiency of the various theories which have been advanced by different authors to account for the phenomenon.

In treating this branch of the investigation of the earthquake, I shall first of all describe those instances of rotation which have come under my observation, and then proceed to an examination of the theories which have been advanced.

The description, however, requires a few words of introduction. In order to determine exactly what has happened we require to know (1) the amount of the twisting, (2) its direction, and (3) the amount and direction of the lateral displacement of the upper portion as a whole, that is to say the distance and direction that its centre of gravity now lies with regard to its position before the earthquake. The first and third of these require no explanation, but the second is one in which confusion is possible; in the case for instance of a square pillar whose sides now stand at an angle of 40° with their original direction it is obviously important to know whether it has been turned 50° in one direction or 40° in other. This cannot always be made out from the plans, but can always be seen on the spot, as it is easy enough to determine which side of the upper portion originally coincided with which side of the lower. The direction of rotation was, consequently, determined in every case by observation and is stated in the following description as positive or negative; by *positive* is meant rotation with the sun, or in the same direction as the hands of a watch lying face upwards on the ground, by *negative* is meant rotation in the opposite direction.

The most imposing and striking of the numerous instances of twisting is that of the monument to George Inglis, erected 1850, at Chhatak. This conspicuous landmark takes the form of an obelisk and rising from a base 12 ft. square, must have been over 60 ft. high before the earthquake. It is built of broad, flat bricks, or tiles, laid in mortar and plastered over, and is represented, in its present state, in the frontispiece, while a plan and elevation will be found on Plate XXXV.

Owing to the size it was impossible to get exact measurements. The height was determined by means of an Abney's level, and the position of the twisted portion had to be determined by perpendiculars dropped from its corners on to the pediment. With these qualifications the following particulars may be accepted as substantively accurate.

The topmost 6 ft. 2 in. was broken off and fell to the south, while the next 9 ft. was thrown to the east, as shown in plan on Plate XXXV. Of the remainder, the top 22 ft. has been separated at a height of about 23 ft. from the ground, and twisted *negatively* through 30°. The centre of the upper portion lies 1·2 ft. to N 55° W of the lower, and the section at the fracture is 9 ft. square.

The upper part has evidently rocked on the lower, as there is splintering at the corners and edges, and below the fracture a slice of masonry about 15 in. thick, which was not bonded into the main mass, has separated on account of the pressure on its upper end. This separation is on the east side, and is shown in the frontispiece.

At Cherrapunji there are more instances of twisted objects. At Inglis' bungalow a square masonry pillar, originally intended to carry an aqueduct across a small water-course, 7 ft. 9 in. high by 2 ft. square in section, oriented N 30° E, has twisted *negatively* 5°. The centre has shifted 3 in. to N 55° E.

Close to this is a pillar rising from the top of the compound wall. The wall is 3 ft. 6 in. high, and the pillar rises 5 ft. above it, with a section 2 ft. 2 in. square, oriented N 58° E; this has twisted *positively* 4°. The centre has shifted 1½ in. to S 40° E. Plans of these two pillars are given on Plate XXXV.

David Scott's monument has about 6 ft., of the part left standing, broken off and twisted about 1° *negatively*. The corners of the stones at the plane of twisting have been flaked off owing to the pressure brought to bear upon them.

At Shillong the gate pillar of the Ferndale Hotel (Plate XXXIV) was twisted *negatively*. The pillar was oriented originally N 8° E. It has turned *negatively* on its base 4°, and again above the lowermost stone through another 2°. The centre has shifted slightly to N. W., but as each block has an iron pin fixed in its upper surface, which fits loosely into a hole in the base of the block next above it; no great lateral shifting was possible.

The gate pillars of Beauchamp Lodge, represented in the lower half of Plate XXXIV, have both been twisted. They were 8 ft. high by 2 ft. 9 in. square, oriented N 15° E. One pillar has twisted *positively* 3°; the centre has shifted 4 in. to N 36° W. The other pillar has twisted *positively* 4°, the centre having shifted 1½ in. to N 70° W.

At Gauhati are the largest number of twisted objects. Views of some of these are given in Plate XXI, elevations on Plate XXXVI, and plans at the plane of twisting on Plate XXXVII.

Beginning with the group of tombs represented on Plates XXI and XXXVI we have—

First, an obelisk on the left, No. 3 broken at its base and twisted *negatively* 2°; centre shifted ½ in. to W 20° S; section at fracture 2 ft. square.

Second, the tomb No. 2 of the same type, but broken higher up and twisted *positively* 48°; the centre has shifted 2½ in. to N 80° W; section at fracture 1 ft. 6 in. square.

Third, the cylindrical fluted column No. 1. The twisting of this can be recognised by the fluting, but more distinctly by the present oblique position of the name tablet, which was doubtless originally placed in the same line with the rest of the tombs. As the undisturbed tombs close by only vary in orientation of the corresponding sides between W 15° S and W 18° S, while the tablet on the column bears W 24° S, it is evident that this has been twisted *negatively* at least 7°; the centre has shifted ¾ in. to N 20° E; the section at the fracture is 2 ft. 1 in. diameter.

Besides these, the tomb of Samuel Fleming, of the same pattern as those marked 1 and 2 above, has been broken across the pediment, and twisted *negatively* 4°; the centre has shifted ½ in. to N 20° W.

We may now turn to the gate pillars of the telegraph signallers' quarters, one pair of which are represented in Plate XXI, fig. 2. These are all square pillars 2 ft. 3 in. across at the plane of fracture, and about 7 ft. high, oriented N 20° W. In the case of the eastern gateway represented in Plate XXI, the plane of fracture was 1 ft. 3 in. from the ground; in the case of the single pillar of the western gateway left standing, it was 2 ft. 6 in. from the ground. They have all been twisted *negatively*.

The E pillar, E gate, through 5°; centre shifted 1 in. to S 20° E.

The W pillar, E gate, through 12°; centre shifted 1 in. to W 25° S.

The W pillar, W gate, through 6°; centre shifted 2½ in. to N 25° W.

At the entrance to the compound of the Commissioner's house were two large square pillars 10 ft. high by 2 ft. 5 in. square, oriented N 20° W. The northern pillar has twisted *negatively* 6°, and the centre has shifted ¾ in. to W 20° S.

Besides these, there must be mentioned the pillar in the wall of the compound W of the Deputy Commissioner's bungalow[1], which was oriented N 25° W, and twisted *positively* 10°.

At Tezpur, a small iron safe, standing on a four-legged stool in the corner of a room in Surgeon-Major Macnamara's house, was turned *negatively* through about 40°; a despatch box resting on a similar stool in the opposite corner of the room was also twisted *negatively* through nearly 90°. In both cases the stool turned with the safe or box resting on it, and, so far as could be judged, almost on its axis. A newly built porch of this house was broken down and the brick pillars supporting it twisted negatively, also nearly on their axis, so far as I could judge from the description.

At Darjiling we have the tomb described by Mr. Hayden (Appendix A) and represented on Plate XXXII, fig. 1, the plan at the plane of twisting being shown in fig. 31. The orientation of this was E 40° N; it was twisted *positively* 2°, and the centre shifted ¼ in. to E 40° N. The section at the plane of twisting was 1 ft. 6½ in. square.

At Calcutta some of the pinnacles of the High Court, of octagonal section, are reported to have been broken across, and the upper part twisted round. Unfortunately no measurements were made before these were repaired, and it is not possible to say in what direction or to what extent they were displaced.

In addition to these instances of the rotation of untramelled pillars, the case of the thermometer shed at Dhubri may be mentioned (see fig. 24, Appendix A), where a set of brick pillars supporting a thatch roof were broken off, and rotated *positively* from 9° to 12°. At the Borjuli tea garden, in the Tezpur district, a leaf house whose roof was supported on brick pillars was affected in the same way; the pillars were all broken off and twisted *positively* from 6° to 10°. I was informed that the same thing had been noticed on several

[1] See Mr. LaTouche's report, Appendix A: the monuments and pillars at Cherrapunji, Shillong and Gauhati, referred to in the text, were mentioned in his report and afterwards re-examined by me and measured with a special view to determining the amount and direction of the displacement of the centre of gravity of the rotated portion.

other gardens, even as far as the Sibsagar district, but have no further particulars.

The earliest instance of the rotation of objects by an earthquake, of which I can find any published record, is in the account of the Calabrian Earthquake of 1783 by Michele Sarconi, Secretary to the Neapolitan Academy of Science and Letters.[1] His figures of the dislocation of the obelisk-shaped pillars at either end of the façade of the Certosa di S. Bruno have been made classic by their reproduction in Sir C. Lyell's "Principles of Geology," and in the description is stated, what appears to have been overlooked by most of his successors who have proposed or accepted other explanations, that one of the obelisk-shaped pillars was twisted from right to left, and the other from left to right, while the twisting is accepted as evidence of the "*orrizontale vorticoso*" nature of the shock. This explanation, the only one prevalent at the time, remained unquestioned, till the publication of Charles Darwin's "Naturalist's Voyage round the World," where (Chapter XIV), after noticing the effect of the earthquake of 20th February, 1835, in causing the rotation of some square objects on the coping of the Cathedral walls at Concepcion he says:—"This twisting displacement at first appears to indicate a vorticose movement beneath each point thus affected; but this is highly improbable." He suggests as an explanation that it was caused by a tendency in each stone to arrange itself in some particular position with respect to the lines of vibration in a manner somewhat similar to pins on a sheet of paper when shaken.

The next attempt to explain this phenomenon is that of Mr. R. Mallet,[2] who, rejecting the vorticose theory and the suggestion of Mr. Darwin, proposed an explanation of his own which has found its way into most text-books, and may be given in his own words.

"If a stone, whether symmetrical or otherwise, rest upon a given base, and motion be suddenly communicated horizontally to that base in any direction, the

[1] 'Istoria de Fenomeni del Tremoto avvenuto nelle Calabria, e nel Valdemone, nell' anno 1783; posta in luce dalla Reale Accademià delle Scienze, e delle Belle Lettere, di Napoli. Folio, Naples 1784, p. 62 and Pl. XXI.

[2] Jour: Geol. Soc. Dublin III, 138-144 (1845). See also his paper on the Dynamics of Earthquakes: Trans. Roy. Irish Academy XXI, 51-105 (1846).

stone itself will be solicited to move in the same direction. The measure of force with which the movement of the base is capable of affecting the stone or other incumbent body is equal to the amount of friction of the latter upon its base, a function of its weight, which, without the intervention of cement, may be from one-fifth to one-tenth of the weight of the body, for cut stone resting on cut stone, but may be increased to any amount by the intervention of cement. The stone, however, is possessed of weight, and therefore of inertia, that is to say, being at rest, its whole mass cannot be instantly brought into motion by the plane on which it rests; and if the amount of adhesion between the stone and its bed be less than the inertia due to any given velocity of horizontal movement of the bed, the bed will move more or less from under the stone, or the stone will appear to move in a contrary direction to that of the motion of its bed.

Now the inertia of the stone, which is here the resisting force, may be considered to act at its centre of gravity. The impelling force is the grasp of the stone which its bed holds of it by friction or adhesion, and this may also be referred to some one point in the surfaces of contact, which we may call *the centre of adherence.*

If, then, a stone, or other solid, rest upon a plane which is suddenly moved with sufficient velocity to produce motion in the incumbent body, three several conditions of motion of the body may occur, according to the respective positions of its centre of gravity and of the centre of adherence:—

(1) The centre of gravity of the body may be at such a height above the base that it shall upset by its own inertia. This is the case with houses, towers, walls, etc., etc., when they fall by earthquakes, accompanied, however, by dislocation of their parts.

(2) The centre of adherence may be in a point of the base plumb under the centre of gravity of the body, or in a vertical plane passing through its centre of gravity, and in the direction of motion of the base.

In this case the stone will appear to move in the opposite direction to that in which the base has moved, that is to say, the body may have acquired more or less the direction of motion of the base, according as the motion of the latter has been of longer or shorter continuance, or less or more rapid; but in so far as the movement in opposite directions has taken place, the base in reality has slipped from under the body.

(3) The centre of adherence may neither be plumb under the centre of gravity of the body, nor in the plane of motion passing through its centre of gravity, but in some point of the base outside the line of its intersection by the plane; in which case the effect of the rectilinear motion in the plane of the base will be to twist the body round upon its bed, or to move it laterally, and twist it at the same time, thus converting the rectilinear into a curvilinear motion in space. The relative amount of the two compounded motions being dependent upon the velocity and time of movement of the base, and upon the perpendicular distance measured horizontally at the surface of adherence between the centre of adherence and the centre of gravity of the body.

This latter case is that which appears to have twisted the stones of Calabria, South America and Greece, and affords, as I feel assured, the true explanation of the phenomenon."

(2·3)

Subsequently, when investigating the Neapolitan earthquake of 1857, he found that at the Certosa de St. Lorenzo, near Padula, a number of pinnacles had been twisted all in the same direction, and recognising the inapplicability of his former hypothesis, proposed an alternative one, as follows [1]:—

"Now there are two distinct trains of earthquake causation, by either of which bodies may be twisted on their bases. First, by the action of a *single* shock, when the centre of adherence of the base of the object, lies to one side or other of the vertical plane passing through the centre of gravity, and the line of the wave-path. Second, by the conjoint action of *two closely successive* shocks. By the first shock, the body is tilted up from its base, but not overthrown, so that for a time, greater or less, it rests wholly upon one edge of its base; while thus poised if another shock bear upon it, in any direction transverse to the first, it acts as usual, at the centre of gravity of the body, to displace it by inertia, in the contrary direction to the wave transit; but the body is held, more or less, by friction *at the edge momentarily in contact* with its support, and there only; but this edge must

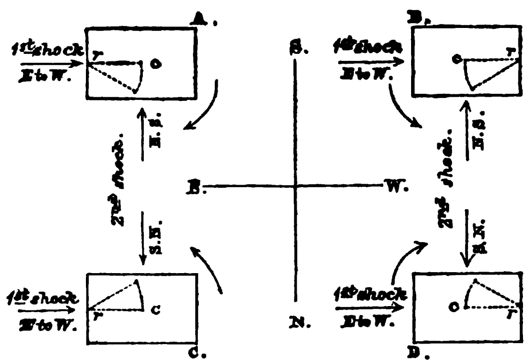

Fig. 19. Diagram (after Mallet) to illustrate the effect of two shocks in causing rotation.

always lie to one side of the vertical plane passing through the centre of gravity in the direction of the wave-path : hence the tilted body, *while relapsing upon its base, also rotates*, round some point situated in the edge of its base upon which it had been tilted, and thus it comes to rest in a new position, having twisted more or less round a vertical axis.

[1] R. Mallet. The great Neapolitan earthquake of 1857. London 1862, Vol. I, p. 376. The same explanation is given by R. Falb, apparently independently arrived at, in his Gedanken und Studien über den Vulcanismus, 8°, Graz, 1875, p. 223.

If the observer look due south at a square pyramid, for example, whose sides stood cardinal, and it be tilted by the *first semiphase* of a shock from east to west, the pyramid will tilt or rise upon the eastern edge of its base; and if, before it has had time to fall back, it be acted on by another shock from north to south, the pyramid will rotate, upon the bisection or on some other point, of the edge on which it momentarily rested, and will hence come to repose, after having twisted from left to right, or *with* the hands of a watch.

If the tilting up, had been produced by the *second semiphase*, of the same shock from east to west, then the pyramid would have risen upon the western edge of its base, and the *same* direction (north to south) of second shock, would have produced rotation upon that edge, but in a *contrary* direction to the proceeding or from right to left or *against* the hands of a watch.

Again, if, on the first supposition, the *first semiphase* of the east to west shock had tilted the pyramid upon its *eastern* edge of base, but the second shock had been from south to north, in place of the reverse as before, then the rotation would have been from right to left; and if tilted by the *second semiphase* on the *western* edge, the second shock, south to north, would produce rotation left to right.

It would, therefore, appear at first impossible, to determine the *direction* of motion in transit, of either shock, from such an observation: we can, however, generally discover upon which edge of the base any heavy body of stone or masonry has tilted, by the abrasion or splintering of the arris, and the rotation must have taken place round some point in that edge. If, therefore, we know the direction of either one of the two shocks, we can always discover that of the other, by the rotation observed, and if the time of oscillation of the body be ascertainable, we are enabled to calculate a major limit, for the interval of time that must have elapsed, between the arrival at the twisted body of the first and of the second shock, when both the wave-paths are known.

With a single instance of such twisting, it may be impossible to decide whether the twist has been due to one shock (1st case), or to two shocks in succession (2nd case); but when several bodies alike or dissimilar, at the same locality, are *all found twisted in one direction*, it is certain to have been *the work of two distinct shocks*, for it is beyond the reach of probability that several bodies should *all* happen to have their respective centres of adherence, at the *same side* of their respective centres of gravity, and unless they have, some will rotate in one, some in the other direction by any single shock; rotation thus produced, being always by the centre of gravity moving contrary to the first or second semiphase of the wave and carried round the centre of adherence, by the line joining them as a radius vector; the inertia of motion at the centre of gravity, and the resistance of the point of rotation in the edge of the base, or of the centre of adherence, forming in every case, the extremities of the dynamic couple."

There remains one more explanation to be mentioned which, on account of its simplicity, has been very generally adopted. It is that of Mr. Gray and contained in Professor J. Milne's account of the Japanese Earthquake of 22nd February, 1880. After mentioning a number of instances of tombs that had been twisted, he goes on to say [1]:—

"Although fully recognizing the sufficiency of two transverse shocks to produce the effects which have been observed in Yokohama, I will offer an explanation of this phenomenon which was first suggested to me by my colleague Mr Gray, which appears to be simpler than any with which I am acquainted.

If any columnar-like object, for example a prism of which the basal section is represented by A, B, C, D (see fig. 20) receives a shock at right angles to B C, there will be a tendency for the inertia of the body to cause it to overturn on the edge B C. If the shock were at right angles to D C, the tendency would be to overturn on the edge D C. If the shock were in the direction of the diagonal C A, the tendency would be to overturn on the point C. Let us, however, now suppose the impulse to be in some direction E G, where G is the centre of gravity of the body. For simplicity we may imagine the overturning effect to be an impulse given through G in an opposite direction, that is, in the direction G E. This force will tend to tip or make the body bear heavily on C, and at the same time to whirl, round C as an axis, the direction of turn being in the direction of the hands of a watch. If, however, the direction of impulse had been E—G, then although the turning would still have been round C, the direction would have been *opposite* to that of the hands of a watch.

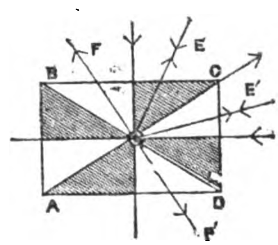

Fig. 20. Diagram to illustrate Gray's theory of rotation.

To put these statements in another form imagine G E, to be resolved into two components, one of them along G C and the other at right angles G F. Here the component of the direction G C tends to make the body tip on C, whilst the other component along G F causes revolution.

Similarly G E may be resolved into its two components G C and G F, the latter being the one tending to cause revolution.

From this we see that if a body has a rectangular section so long as it is acted upon by a shock which is parallel to its sides or to its diagonals, there ought not to

[1] J. Milne. The Earthquake in Japan of February 22nd, 1880. Trans. Seismol. Soc., Japan, I., Pt. II, pp. 33 35 (1880).

be any revolution. If we divide our section A, B, C, D up into eight divisions by lines running through these directions, we shall see that any shock the direction of which passes through any of the octants which are shaded, will cause a *positive* revolution in the body; that is to say, a revolution corresponding in its direction to that of the movements of the hands of a watch; whilst if its direction passes through any of the remaining octants, the revolutions will be *negative* or opposite to that of the hands of a watch.

From the direction in which any given stone has turned, we can, therefore, give two sets of limits between one of which the shock must have come.

Further, it will be observed that the tendency of the turning is to bring a stone, like the one we are discussing, broadside on to the shock; therefore, if a stone with a rectangular cross section has turned sufficiently the direction of a shock will be parallel to one of its faces, but if it has not turned sufficiently it will be more nearly parallel to its faces in their new position than it was to its faces when in their original position.

If a stone receives a shock nearly parallel with its diagonal on account of its unstability, it may turn either positively or negatively.

Similarly, if a stone receives a shock parallel to one of its faces, the twisting may be either positive or negative, but the probability is that it would only turn slightly, whereas in the former case, where the shock was nearly parallel to a diagonal, the turning would probably be great."

We have then four alternative hypothesis, for the suggestion of Mr. Darwin is too vague and indefinite to rank as an hypothesis or explanation. These are:—

(1) The theory which is implied in the term vorticose, and attributes the rotation to a rotary or circular motion of the ground during the earthquake.

(2) Mallet's theory, which attributes the rotation to the centre of resistance and the centre of gravity not being in the same vertical plane with the direction of the wave motion, and to the stone being consequently dragged round.

(3) Mallet's second theory, which attributes the twisting to a second shock, affecting the object twisted while it is tilted on one edge or corner by the first. The second shock being oblique to the first, causes the object to rotate on the edge on which it is tilted.

(4) Gray's theory, which attributes the rotation to the centre

of gravity, and the corner on which the object is tilted not being in the same line with the direction of the shock and to the object, being consequently swung round on that angle.

In discussing these theories will it be convenient to take them in the reverse order to that in which they are stated above.

Commencing with Gray's, it will be noticed that, whereas this demands that the rotation should be round one of the corners of the object rotated, a study of the plans on Plates XXIV-XXVII will show that such was not the case in a single instance. Besides this it fails to account for one of a number of monuments all similarly oriented being rotated positively while all the rest were turned negatively.[1]

Mallet's second theory could be made to account for these cases, but it demands that the rotation should be round one of the edges of the surface at which it took place. Now every case of rotation may be explained by a single revolution round a fixed centre, and the radius of the circle in which the centre of gravity may be supposed to have revolved, in order to bring it from its old to its new position, is easily calculated.

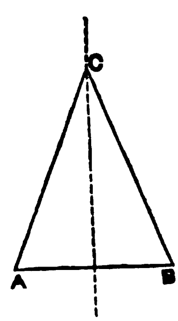

Fig. 21.

To determine this let A and B, fig. 21, be the old and new positions of the centre of gravity. Then the required centre must be somewhere on the line which bisects A B at right angles, for it must be equidistant from A and B. But in moving the centre of gravity from A to B, the rotated object has also turned on its axis through an angle which we will call. If then two lines are drawn from a point C so that

[1] The plans on Plate XXXVIII appear at first sight to favour this hypothesis. The monuments, however, are so low in proportion to their base that it is very doubtful whether any tilting took place, and the displacement was probably due to the vertical components of the shock, and was of the nature of a projection. It is possible, however, that these cases may be due to a single oscillation of greater power and extent than the rest, for the possibility of the action involved in Gray's explanation cannot be doubted. Though it cannot be accepted as a complete explanation.

each may make an angle of $\frac{1}{2}$ with the central line, and cut the points A and B, respectively, we have an isosceles triangle, whose apical angle is, and whose two equal sides are radii of the circle in which the centre of gravity may be assumed to have moved, to enable it to pass from its old to its new position, while turning through the angle A C B $=\theta$. If this radius be represented by r, and the distance A B by d, then

$$r=\frac{d}{2}\div\sin\frac{\theta}{2}$$

According to Mallet's theory, r should equal the distance of the centre of gravity from the point or edge on which the object rotated, that is to say it should be equal to, or lie somewhere between, the semidiameter and semidiagonal, and should not materially differ from them in excess or defect.

In applying this test it will be necessary to reject those cases where the apparent shifting of the centre of gravity and the angle of rotation are both small. Neither can be measured with very great accuracy, and when either is small a very slight absolute error would be a very large one proportionately, and lead to great errors in the result. Applying the test to those cases where it may be expected to give a reasonably accurate result, we have, in the case of Inglis' monument at Chhatak, $r=27{\cdot}8$ in., while the semidiameter is 52 in. In the case of the monument No. 2 on Plate XXI, fig. 1, $r=3$ in., while the semidiameter is 9 in. In the case of the W pillar E gate, and the E pillar W gate of the telegraph signallers' quarters at Gauhati $r = 5$ in. and 24 in. respectively, while the semidiameter is 12½ in. in both cases.

From this it will be seen that there is no correspondence between the calculated radius of revolution and that required by the theory.

Mallet's first theory, though undoubtedly an explanation, is insufficient as it does not account for the fact that a number of similar objects are similarly rotated in the same neighbourhood; nor does it seem probable that there would be so great a divergence between the positions of the centre of gravity and the centre of resistance, and what is more important, so complete a check to lateral movement at the latter, as would account for the observed rotations in many cases.

There remains but the first mentioned explanation, that of vorticose motion, and with regard to this it seems that the objections raised are based on an unnecessarily restricted interpretation of the term. It has been supposed necessarily to imply a rotation round an axis, by which a similar rotary or top like movement is given to the objects rotated.

This is evident in Darwin's objection to the theory, and is even more forcibly put by Mallet, who wrote [1]:—

> "The sagacity of Darwin showed him that the vorticose hypothesis was improbable, and that in order to its being at all tenable, a separate vertex must be admitted for every separate stone found twisted, the axis of rotation of the vortex having been coincident with that of the stone. Besides this paramount improbability, therefore, a little further reflection would have led either Lyell or Darwin to estimate the inconceivable angular velocity of motion at the extremity of the radius of one of these vortics, even if assumed at no more than a few hundred feet, necessary in order that its velocity within a few inches of the centre should be so great as to wrench out of its mortared bed, and twist a block of masonry by merely its own inertia."

Here we have the assumption that what is called vorticose motion must necessarily be a twisting round an axis, and the absurdity to which it leads, both clearly expressed.

But though, interpreted in this way, the term vorticose leads to an untenable hypothesis it must not be forgotten that, while popular interpretations of natural phenomena are frequently incorrect, they almost invariably represent a real substratum of fact. That the vorticose should have been for generations regarded as a distinct type of earthquake movement points to there being a real difference between it and the types which are classified as 'horizontal,' 'undulating' or 'palpitating.' Abandoning the restricted interpretation, it is not difficult to see that it might well be applied to movement of a totally different character, that is to a movement of the wave-

[1] Jour. Geol. Soc. Dublin, III, 138 (1845).

particle in a more or less circular course. Here there would be no angular rotation, but over a larger or smaller area the whole ground would be caused to move in small circles, and a pillar or similar object fractured from its base, would be caused to tilt and roll round on its edge and so rotate with regard to its original position.

It does not seem, however, that the term 'vorticose' is necessarily restricted to so simple a form of movement as this, for I find in Mr. Mallet's account of the Neapolitan earthquake a statement that the Syndic of Padula, was of opinion that the shock was 'vorticose' or at least in various directions transverse to the main one and so close together in time that it was impossible to regard the earthquake as other than a prolonged and irregular succession of oscillations, lasting several seconds.[1] From this it is evident that the term vorticose is applied to shocks in which no definite direction of movement can be noticed, but where the apparent direction seems to vary or revolve. This interpretation finds its explanation in the diagrams of the seismographs which have been invented and taken into use in Japan.

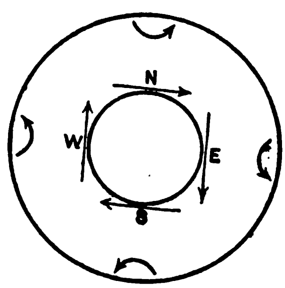

Fig. 22. Diagram of vorticose motion.

To take the simplest case first, suppose the movement of the wave particle to be circular, neglecting for the moment any move-

[1] Great Neapolitan Earthquake, 1857, I, p. 368.

ment there may be in a vertical direction. In fig. 22 let the outer circle represent the ground plan of a cylindrical column, and the inner circle the path of the wave particle, that is to say, the track of a point on the ground, all other points in the neighbourhood describing similar circles. At N the movement of the ground is eastwards, causing the column to tilt up on its western edge; when the base motion has progressed so that the particle at N has reached E, its motion is southwards and the column will be tilted on to its northern edge. But it had been tilted up on its western edge, consequently in being thrown on to its northern it will be revolved slightly in a negative direction. So when the point N has reached S, the movement will be west and the column tilted on to its eastern edge and again revolved slightly in a negative direction, and so on. For simplicity of treatment an abrupt change of motion from east to south and from south to west has been supposed, but the effect of a gradual change would be the same, a continual tendency to alter the point on which the column was tilted and to cause it to rotate in the opposite direction to the course of the wave particle.

It is also to be noticed that the centre of the column will describe a spiral line round its original position, as each change of tilt will carry it a little further out, but its final position will be closer to its original one than would be the case, had the same amount of twisting taken place by a single tilt on one edge, and a simultaneous sidelong displacement. In other words the virtual radius of revolution would be less than the semidiameter; being thus in better agreement with facts than either the third or fourth hypothesis.

There is another type of earthquake motion, more common than that required by the preceding explanation, which may equally well give rise to rotation. This form may be diagrammatically represented in fig. 23, supposing the movement to start from 1, then in the path from 1 to 2 the column will be left behind and caused to tilt towards 1, while the change of direction between 1 and 2 may give it a slight positive rotation. As soon, however, as the direction

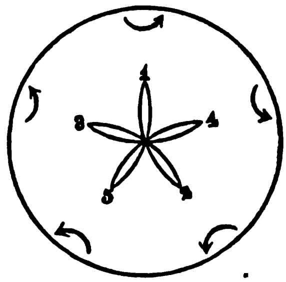

Fig. 23. Diagram of rotation by vorticose motion.

of the movement changes and the particle begins to return from 2 to 3, a much more powerful tendency to rotate the column in a negative direction round 1 will be set up, and the column at the same time tilted over on its edge towards 2. The same thing will happen when the particle returns from 3 towards 4 and so on, each successive tilt being accompanied by a further twist in a negative direction. As before, the distance of the centre of the column from its original position will be less than it had there been merely a single tilt and twist.[1]

Of these two explanations the latter seems more in conformity with the facts observed than the former. The first would require that the crushing of the edges should be tolerably uniform all round,

[1] This chapter was written and set up in type before I was aware of a paper by Mr. C. Davison on the theory of vorticose earthquake shocks (Geol. Mag., dec 2, IX, 257—266, 1882), which would otherwise have been referred to in the text. He explains the vorticose shock much in the same way as that adopted in the text, *i.e.* as a movement to and fro in a gradually changing direction, and points out how such must necessarily result with a focus of any size, in the neighbourhood of the epicentre, from the fact that the impulses reaching a spot at successive intervals of time come from different parts of the focus and hence from different directions. The manner in which such a form of movement leads to the rotation of solid objects is not discussed, but it is held (p. 264) that the objection to the vorticose theory urged Mr. Darwin (in 1839) that under every object so turned there must have been a separate vorticose movement, loses its force on the view there presented. It is evident, however, from the extracts quoted in this chapter that the vorticose motion, as understood by Darwin and Mallet, was something very different to that whose possibility has been demonstrated by Mr. Davison, whose existence has been proved by the researches of Prof. Milne and others in Japan, and whose actuality is adopted in this memoir as a satisfactory means of explaining the rotation of objects by an earthquake.

while it was noticeable that this was not the case. As a rule, only certain parts showed signs of crushing, while others were left sharp-edged and intact. This might, of course, be due to unequal powers of resistance of different parts of the borders of the plane of fracture and twisting, but is more probably due to differences in the pressure brought to bear on them.

In the foregoing passages I have, for simplicity's sake, assumed a circular section of the column twisted, but the explanation is equally applicable to objects of square or angular section. In this case the first tilt would necessarily be on one side or one angle, and Gray's principle would come into play, but all succeeding tilts would take place along one of the sides of the lower part of the column, or at one of the points of intersection of the sides of the lower and upper portion, after the former had been twisted from its original position. In this way may be explained the fact that some of the corners show quite clear cut and uncrushed fractures, while on the sides close by there may be very palpable signs of the effect of great pressure.

It may be noticed that the explanation which has been proposed is but an amplification of Mallet's second explanation. Instead of only two shocks it postulates a series of successive shocks in successively varying directions, and by regarding the rotation as due, not to a single twist round a single centre, but to the accumulated effect of a succession of small twists round a succession of different centres, it allows a considerable rotation to be accompanied by a much smaller shifting of the centre of gravity than could be the case if the same amount of rotation was due to a single effort of twisting.

If we modify Gray's explanation in so far as to regard the rotation as due not to a single tilt, but to a series of successive tilts on opposite sides of the base, we might get a large rotation accompanied by a small shifting of the centre of gravity, but it fails, even with this modification to explain how two similarly oriented objects close together may be rotated in opposite directions. We have two cases of this: one of the two pillars at Inglis bungalow, Cherrapunji, and a more striking one in the old cemetery at Gauhati. In both these cases it is to be noticed that the height of the centre of gravity of the displaced portion above the plane of fracture is smaller in the case of one direction of rotation than of the other.

Now, in the explanation it was assumed that the column once tilted on to 1 would remain so till the motion of the wave particle ceased at 2, and the return movement from 2 to 3 set in. This would generally be the case, but the smaller the height of the displaced portion, the more quickly will it recover its position of stability, and the less easily will it be displaced, for the same section of base. As a consequence there comes a stage at which, as the height of the displaced part diminishes, it will only be tilted as the wave particle attains its maximum acceleration, which may be put at about one-quarter of its path from 1 to 2. Before the wave particle has reached 2, the displaced part will have fallen down into its base again, retaining what positive rotation it may have acquired owing to the gradual change of direction of the path of the wave particle, or to the direction of this with regard to the diagonals of the rotated portion and by a repetition of this process acquire a gradually increasing angular displacement in a positive direction.

But there would almost certainly be more than this. Instead of merely falling into its base the displaced part would probably be tilted up, by its momentum, in the direction of 2, or of somewhat towards 5 from 2, before the wave particle reached 2. It would then be subjected to a displacement due to the movement from 2 to 3, that is to say, it would be rotated in a positive direction, or the opposite to that which would be impressed on it if it had been tilted towards 1 while being acted on by the movement from 2 to 3.

From this we see that the direction in which the displaced part will be rotated depends not only on the relation between the width of, and the height of its centre of gravity from, its base, but also on its absolute dimensions. In other words, it depends on the quickness of recovery of the displaced portion when tilted. It has not been possible, for want of a sufficient number of suitable objects, to fully test this hypothesis, but the cases of the Gauhati old cemetery and of the two pillars at Cherrapunji are explicable by this, and by none of the other hypotheses.

We have consequently an hypothesis which explains—

(1) Why a number of similarly oriented neighbouring objects are generally twisted in the same direction.

(2) Why in certain cases we may have an object twisted in one direction, while others similarly oriented but of different proportions are twisted in the opposite direction.

(3) Why the displacement of the centre of the displaced portion from its original position indicates a centre of revolution which does not coincide with the outer edge of the surface of displacement.

It explains, in short, all the observed facts, while it involves nothing which is inconsistent with them. We may take it, then, that the rotation of objects is the consequent of a rotary movement of the ground, which may take the form of either a more or less circular path of the wave particle, or a succession of backward and forward movements, each of which takes place in a fresh direction different to the previous one.

Other explanations are not, however, excluded by this. Gray's is indubitably a possible cause of twisting, while the statement of Michele Sarconi, that of the two similar pillars at either end of the façade of the Certosa di S. Bruno one was turned from right to left and the other from left to right[1], points to the conclusion that Mallet's first the explanation is good in some cases. All that can be claimed is that the existence of a movement of the ground which may be called verticose does exist, and that it is a cause of the rotation of objects by earthquakes; probably it is usually the correct explanation, though in individual cases the twisting may be due to other causes and not inconsistent with a rectilinear movement of the wave particle.

[1] Istoria de Fenomeni del Tremoto avvenuto nelle Calabria, &c., Naples 1784, page 62.

CHAPTER XV.—THE UNFELT EARTHQUAKE.

Beyond the limits of the area over which the earthquake was recognised without instrumental aid, its effects were impressed on the records not only of instruments which have been set up for the special purpose of detecting the imperceptible tremors and undulations which traverse more or less the whole of the earth, after great earthquakes, but also on those of self-recording magnetic and electric instruments. After the earthquake every endeavour was made to obtain as complete a set of these records as possible, and I have to acknowledge the readiness with which information was rendered, and even photographs and laborious tracings of the records, made and sent.[1]

The unfelt disturbances due to distant earthquakes are commonly referred to as microseismic, but the term is hardly applicable to undulations which, in the case of this earthquake, had a length of 34 miles and caused the ground to rise and fall 20 inches.[2] Instead of microseismic I would introduce the term cryptoseismic as more suitable; it implies nothing except that the movement is not obvious, and is useful to distinguish between the unfelt movements due to a distant earthquake, and the movements due to an earthquake of so small an order of magnitude that it never becomes sensible, except to very delicate instruments; to these the term microseismic might well be restricted.

The records vary much in value according to the nature of the instruments employed. In many cases these were in reality too deli-

[1] A very detailed account of the records of this earthquake, obtained in Europe, has been compiled by Dr. G. Agamennone and published in the Boll. Soc. Sismol. Ital., III, pt. ii, pp. 249—293. In this details are given of some records which I was unable to obtain. The account of those referred to is also more detailed and lengthy than that printed in this chapter. In some instances the times differ slightly but no alteration has been made in those printed, which are the times as originally communicated to me, as the changes were too slight to justify the labour of recalculation. For the same reason the details regarding records at stations from which I had not previously obtained information have not been incorporated in the chapter, with a few exceptions specifically referred to.

[2] These figures are taken from Prof. Agamennone, Boll. Soc. Sismol. Ital., IV, pt. i, 66 (1898). They are intended to apply specially to Italy but are equally true for the whole of Europe.

cate, and, under the influence of so exceptionally great a disturbance as was set up by this earthquake, the record of all but the beginning and end was lost. In other cases the rate of travel of the recording surface was so slow that the time cannot be accurately determined. From the magnetic observatories the replies were mostly negative, and in other cases the disturbance was of such a nature as to preclude the possibility of exact time determinations. In the following pages it has not been considered necessary to refer to these cases, and only those records which have given tolerably trustworthy determinations of time are referred to. The times as given in the original record have in every case been converted into Greenwich mean time.

The records of the cryptoseismic disturbance fall naturally into two classes,—those of instruments specially and solely intended to record disturbances of the ground, and those of magnetic or electric instruments, not intended to record movements of the ground on which they are set up, though giving evidence of earth movements by an irregularity or break in their record. Foremost among those of the first class I must place the valuable series of records for which I am indebted to Prof. Grablowitz, and not only for the records but also for a discussion and comparison of them, from which the nature of the series of disturbances is clearly deduced.

Proceeding in the first place to the description of the facts recorded, I shall afterwards discuss their meaning and interpretation.

Casamicciola (Ischia).—I am indebted to Prof. G. Grablowitz, Director of the well equipped geodynamic observatory at Casamicciola, for a most interesting account of the effects of the earthquake on his instruments. These are—

(1) A pair of horizontal pendula, arranged so as to complete an electric circuit, on the smallest disturbance, by which an alarm is sounded, a time-signal impressed on the record of No. (3), and No. (4) set in motion. It acted at 11h. 19m. 3s. G. M. T.

(2) The 'vasca sismica,' a circular cistern 1·56 metres diameter and 1·10 m. deep excavated in the basement of the observatory and filled with water to the depth of 1 m. On this there is a float 1·5m. diameter, the movements of which are registered, with an amplification of 92 times, on a recording surface moving at the rate of about 33 cm. per hour.

(3) Consists of a pendulum of 1m. length and a weight of 10 kgm. It is intended to register sensible earthquake, and the record, which is started by (1), only lasts for one minute.

(4) A simiar instrument, but with a weight of 20 kgm. and a continuous record. The recording surface moves at the rate of 10 cm. per hour, and on it, besides the, record of this instrument, the time at which (1) closes circuit is also marked.

(5) A pair of delicate spirit levels, set N-S and E-W, which are directly observed by eye.

(6) A spiral spring of 7m. length supporting a weight of 150 grammes.

(7) Self-registering geodynamic levels. These consist each of a pair of cylindrical receptacles 30 cm. diameter and 25 cm. high, connected by a tube some 2 m, long and 15 cm. diameter. There are two, set N-S and E-W, and the movement of the water surface is recorded, with an amplification of 50 times, on a surface moving 11 mm. per hour.

(8) A pair of horizontal pendula, with weight of 12 kg. recording their movements with an amplification of 1 to 8 on a smoked paper moving at the rate of 30 cm. per hour. The period of vibration of the N-S pendulum was 13·5s., and of the E-W one 13·0s., on the 12th June.

(9) A similar but improved instrument with three pendula of a weight of 3kg· oriented at 60° to each other.

Of these instruments Nos. 1 to 6 are set up at the Grade Sentinella, Casamiccola, and 7 to 9 at the Port of Ischia.

All these instruments acted on the 12th June. No. (1) gave the alarm at 11h. 19m. 3s. Greenwich mean time.

No. (2) shows a sudden commencement of rapid oscillations at 11h. 17m. 13s., which give place to slow oscillations of a complete period of about 20s. at 11h. 42m. 33s. These attain their maximum at about 11h. 47m., whilst for a couple of hours the diagram shows a much smaller but continuous movement.

It may be noticed that both the first rapid oscillations and the subsequent slower ones show a considerably greater amplitude in the E-W component than in the N-S; specially so in the case of the former. On the copy of the diagram of this instrument, for which I am indebted to Prof. Grablowitz, I find that the E-W component is three times the N-S in the case of the first, and one and a half times in the case of the second.

The record of (3) is of little interest as it is limited to a period of one minute only. No. (4) shows a slight thickening of the line of the E-W component for a few minutes, but there are records of repeated closures of the circuit by (1) for nearly an hour.

The instrument (5) was observed immediately after the sounding of the alarm. The E-W level was specially disturbed and was making oscillations of not less than 1″ of arc during the first phase. The movement had almost ceased when, at 11h. 42m. the oscillations became considerable, reaching, at 11h. 47m., an excursion of 4·5″ of arc from E to W, and 3·0″ from N to S, with a complete period of 15s. to 20s. After 12h. the oscillations diminished and at 12 h. 20 m. there was only a movement of about 0·3″ on each level.

The spring (6) showed, after 11¾h., vertical oscillations of not more than 2 mm.

Fairly satisfactory diagrams were obtained from (7) and (9), considering the slowness of travel of the record.

No. (8) gave by far the clearest and most prolonged diagram, for as late as 22h. there were still oscillations, showing that the earth only came to rest after eleven hours; it is probable that these were the effect of later shocks, registered by this, but not by the other instruments.

From the combination of these records, and especially those of (2) and (8) we may obtain with certainty the following results:—

	H.	M.	S.
Commencement of the rapid vibrations	11	17	13
Maximum of ditto	11	19	3
Commencement of the slower movement[1]	11	26	0
Commencement of large undulations	11	42	33
Maximum of the same	11	47	0
Decrease of the same	11	57	0
End of phase of sensible movement	13	0	0

With reference to the above results Prof. Grablowitz points out that there are two principal phases deserving special examination, the maximum of rapid motion, at 11h. 19m., and the maximum of slow movement, of a complete period of about 20 seconds, at 11h. 47m.

The amplitude of movement in the two phases varies much in the different instruments, but if their different conditions are considered,

[1] Maximum of this phase 11h. 27m. 40s.; Boll. Soc. Sismol. Ital, III, pt. ii, p. 26. The time of commencement is given as 11h. 25m. 48s.

as well as the various instrumental amplifications, the results are such as to lead to the conclusion that the problem of the seismic motion requires a different solution in each case.

In the first phase the measured amplitude, after allowing for the respective instrumental amplifications, is as follows:—

	Rapid movement of 11h. 19m.			Slow movement of 11h. 47m.		
	E—W.	N—S.	Res.	E—W.	N—S.	Res.
	mm.	mm.	mm.	mm.	mm.	mm.
(2) Vasca sismica	0·20	0·05	0·21	0·038	0·027	0·047
(3) Seismometograph	0·10	0·00	0·10	0·040	0·000	0·040
(5) Spirit levels	2·00	?	2·0	9·0	6·0	11·0
(7) Water levels	0·040	0·014	0·042	0·010	0·000	0·010
(8) Horizontal pendula	0·19	0·12	0·23	5·50	2·85	6·20

These linear amplitudes may be converted into angular values, on the basis of the equivalent lengths of a single pendulum to which the instruments correspond, which is given in the first column of the table printed below.

	Equivalent length of pendulum.	Angular values.	
		11h. 19m.	11h. 47m.
	Metres.	"	"
(2)	0·75	57·8	13·0
(3)	1·00	20·8	8·2
(5)	412·00	1·0	5·5
(7)	1·10	7·9	2·1
(8) E. W.	41·7	1·0	27·2
(8) N. S.	45·2	0·6	13·0
(8) Resultant	......	1·1	30·1

Of the two modes of interpreting the records of the first phase, that of regarding them as representing angular movements presents enormous differences between the results obtained from the different instruments, while, if they are regarded as representing linear displacements, they merely exhibit differences explicable by the varying natural and mechanical sensitiveness of the instruments. On the other hand, the measures of the second phase present very great differences of linear, but not so great of the angular values, in which they follow an evident law, that the values are higher as the instrument from which they are derived is mechanically freer from friction or resistance.

The interpretation of this may be that the earlier disturbances are, at any rate largely, the effect of inertia, due to horizontal movement (condensational waves), while, those at the later period were due principally to an actual tilting of the surface, consequent on movement of the nature of an undulation (distortional waves).[1]

As a consequence, Prof. Grablowitz considers that the maximum inclination of the surface at Ischia was 2″, that registered by the water level, the only instrument in which adhesion to the sides could completely, or nearly so, extinguish the disturbance of the horizontality of the surface of the liquid by waves of such period, and the effects of inertia felt by other instruments; while the excess observed on the other instruments, even in the spirit levels, is probably to be ascribed to inertia consequent on horizontal displacement. The oscillation of the spiral spring as observed seems to be sufficiently confirmatory of this hypothesis, as it agrees in time with the arrival of the undulatory waves, which were accompanied by a considerable amount of vertical movement.

I have reproduced the substance of Prof. Grablowitz's account of his instruments and the conclusions he drew from their records, not merely on account of their intrinsic interest, but also on account of the assistance they gave in the interpretation of the records from

[1] These are different to the distortional Plane waves transmitted *through* a solid.

other observations. The two important points are (1) the sudden commencement of the nearly horizontal movements of short period, and their subsequent gradual dying out, and (2) the gradual coming in of the slower movements accompanied by an actual tilting of the surface, in which the horizontal was combined with vertical motion. These increase to a maximum and then diminish again, but continue for about an hour and a half. As will be seen when the records as a whole come to be discussed, Prof. Grablowitz's second is really a third phase, as there is another recognisable, intermediate in time, between the two discussed by him.

Rome.—R. Osservatorio Geodinamico di Rocca di Papa.— I am indebted to Dr. Cancani for photographs of the records obtained in this observatory from (1) a horizontal pendulum instrument of which the N-S pendulum has a period of 14s. and the E-W of 12s.; and (2) of a simple pendulum of 15 metres length and a bob weighing 250 kilogrammes.

The photograph of the trace of the vertical pendulum does not contain the commencement or the end of the disturbance. Slower undulations with an increased amplitude, marking the advent of the second phase, commence about 11h. 25m. 58s. and the long undulations at 11h. 41m. 50s., attaining their maximum at 11h. 47 m. 8s. As at Ischia, the largest movement is in the E-W direction.

A copy of the diagram of the horizontal pendula is reproduced on Plate XLI. From this it will be seen that the commencement of the disturbance is very distinct on the E-W component at 11h. 17m. 40s. The pen of the N-S component was not writing properly and its trace is very faint till 11h. 27m. 51s., when the line becomes distinct once more; in spite of the faintness of the trace the commencement of the disturbance can be recognised. The second phase is not well marked by this instrument, but its commencement can be recognised by an increase of amplitude and more open character of the waves at 11h. 25m. 54s. The great undulations are very conspicuous on this diagram, commencing at 11h. 41m. 40s. and attaining their maximum on the N-S pendulum at 11h. 47m 8s. The maximum on the E-W component is somewhat later, but the maximum of the resultant of the two coincides very closely with that on the N-S component. The trace continues disturbed till 14h.

Rome.—Ufficio centrale di Meteorologia e di Geodinamica.—A very detailed account of the records obtained at this observatory is published in the Boll. Soc. Sismol. Ital., III, pt. ii, pp. 253-267, from which the following has been abstracted :—

Sismometografo medio (8m., 100 kg., amplification 10 times)—Commencement abrupt at 11h. 17m. 5s. ± 5s., maximum displacement 2·5 mm. NW-SE, 3·0 mm. NE-SW; resultant nearly E-W. After coming to rest the disturbance due to the second phase commenced between 11h. 24m. and 11h. 24m. 20s., the maximum displacement being 3 mm. shortly after the latter time. The great undulations began at 11h. 43m. 30s. and reached their maximum of 10mm. at 11h. 47m. 30s. The disturbance ended at 12h. 5m.

Sismometografo grande (16m., 200kg, amplification 12 times).—Commencement at 11h. 17m. 20. ± 5s., maximum of first phase 5mm. at 11h. 20m. 20s., decreasing to almost extinction. The second phase commenced at 11h. 25m. 20s. reaching a maximum at 12h. 28m. 15s. on the NE-SW component and at 11h. 27m. 30s. on the NW-SE. The great undulations commenced at 11h. 43m. 8s. and reached their maximum at 11h. 46m. 58s. or shortly after.

Padua.—In the University of Padua two microseismographs have been set up by Prof. Vicentini; one a simple pendulum of 1·5 metres length with a bob weighing 100 kgm.; the other a simple pendulum of 10 metres length and 400 kgm. weight.[1] A reproduction and discussion of the diagram obtained from the first of these is given in a paper by Dr. M. Baratta.[2] As at Ischia, the first movements were of a rapid to and fro nature; they commence somewhat abruptly at

[1] For a detailed description and illustrations of these instruments, see a paper by Dr. Giulio Pacher, Atti del R. Instituto Veneto de scienze lettere ed arte, 7th series, VIII, 1896-97, and also in Boll. Soc. Sismol. Ital., III, pt. i, 65-131 (1197).

[2] Boll. Soc. Geog. Ital., 1897, fasc. viii.

11h. 16m. 47s. G. M. T., and have a maximum between 11h. 22m. and 11h. 24·5m. The second phase commences at 11 h. 26·75 m. and reaches a maximum at 11h. 28·25 m. Dr. Baratta points out that after 11h. 35m. there is a marked change in the character of the curve, and instead of the oscillations of the pendulum being made evenly on either side of a central line, they are made on either side of a sinuous line such as would be due to a slow tilting of the whole instrument backwards and forwards. The well marked slow undulations set in at about 11h. 42m. 30s. and attain their maximum at 11h. 47m. 10s. The disturbance continued till 13h. 30m. G. M. T.

The long pendulum of 10 metres gave a diagram showing the commencement of the disturbance at 11h. 17m. and its cessation at about 15h. G. M. T. The greater duration of the disturbance on this instrument is due to its greater sensitiveness.

The horizontal displacement of the pendulum bob during the first phase amounts to as much as ·5 mm., and between 11h. 27 and 11h. 33m. the maximum displacement attained is ·47mm., or nearly as much. The displacement at 11h. 47m., if wholely due to tilting of the instrument, shows a tilt of 22″ of arc from the vertical.

Catania.—I have received from Prof. A. Ricco, Director of the Royal Observatory, three copies of the records of his two seismographs; one of these only gives a record of one minute duration and the diagram is consequently not of great interest. The other has a continuous record; it is, like most of the Italian instruments, a simple pendulum, of 25·30 metres length and 200 kg. weight, whose movement is magnified 12·5 times and recorded on a paper moving at the rate of 0·6 metres per hour.[1] The components are registered in NE-SW and NW-SE directions.

The disturbance of the trace, which is reproduced on Plate XLI, commences at 11h. 17m. 23s. the total displacement of the weight being ·3 mm. from the vertical. The commencement of the second

[1] A description of this instrument, written by Prof. Ricco, will be found in the Atti dell. Ac. Gioenia de Sci. Nat. in Catani, 4th series, X.

phase is well marked at 11h. 25m. 44s. on the NE-SW component, and at 11h. 25m. 55s. on the NW-SE component, the character of the trace becoming more open, and the travel of the pendulum bob rises to 1·1 mm., the character of the curve indicating oscillations of the normal period of the pendulum, 5·2s., superimposed on undulations of longer period. These correspond to the violent oscillations of the Padua pendulum between 11h. 26m. and 11h. 30m. Converted into angular measurement, the excursion of the pendulum corresponds to a tilt of 10″ of arc from the vertical. The larger undulations set in about 11h. 45m.; their maximum is at 11h. 48m., but as the components are NE-SW and NW-SE instead of N-S and E-W, the diagram cannot be readily compared with the others, and it is possible that the apparently late beginning of these is due to the E-W component not showing up as well as it does in the other diagrams. The disturbance lasted till about 14 h.

Siena.—I am indebted to Prof. Silvio Lussana, of the University of Siena, for a photograph of the diagram made by his instrument. This closely resembles on a small scale that of Prof. Vicentini's instrument at Padua. Disturbance commenced at 11h. 17m. G. M. T., rapidly attained a maximum at 11h. 19½ m. and then died down. The second phase is marked by an increased displacement from 26m. to 28m., with a maximum at 27m., but instead of being nearly equal to the original displacement, it does not amount to more than one-sixth of it. The trace after this shows a number of minute undulations, and at 46m. they increase in size, attaining their maximum at 48 m., and then diminishing once more. I have no information as to the total duration of the disturbance.

Pavia.—From Dr. Emilio Oddone, of the Royal Meteorological and Geodynamical Observatory at Pavia, I have received a tracing of the record made by his microseismograph, a simple pendulum of 4·5m., length, and 40kg weight; the movement of the bob is magnified ten times, and recorded on a paper moving about 10 cm. per hour.

The disturbance commenced at 11h. 18m. 17s. G. M. T., and at 45m. 43s. there was again an increase in the travel of the recorder, reaching its maximum at about 11h. 48m., the disturbance of the trace ceasing at 12h. 9m. The second phase appears to be marked by a large increase in the travel of the recorder of the E.-W. component at 11h. 27m., but the trace is not open enough to allow this to be decided with certainty.

On this trace it must be noticed that the N-S component is about double the E-W in the first phase. There is a maximum at about 11h. 20m. and another large one at 11h. 23m. The other increase in the travel of the pointer after 45m. 43s. evidently corresponds to the large undulations of other records. At Pavia the period of these undulations was about 30s.; in the first phase the oscillations were very rapid.

Grenoble.—A microseismograph here recorded the earthquake. Beyond the fact that the disturbance commenced at 11h. 28m. 26s., Paris time, or 11h. 19m. 5s. G. M. T.[1], I have no information as to either the nature of the instrument or of the remainder of the record.

Strassburg.—Dr. Gerland informs me that his instrument, consisting of three horizontal pendula set at angles of 120° with each other, was violently affected by the earthquake. The disturbance began at 11h. 18m. 32s. G. M. T. without any tremors, with sudden and very great oscillations, of 14 cm. amplitude; these suddenly ceased at 12h. 45m., but were succeeded by a very long series of diminishing tremor-like oscillations, dying out at 14h. 30m. G. M. T.

Potsdam.—A horizontal pendulum, with a boom 20cm. long and a weight of 10 grammes, supported by a quartz fibre rising at an angle of 45°, was set in motion at 12h. 11m. Potsdam time, which is

[1] This time was communicated to me by Dr. Früh of Zurich. In Symons' Monthly Magazine, XXXII, 92 (1897) the time is given, in a note by Prof. J. Milne, F.R.S., as 11h. 28m. 0s. According to Dr. Früh's communication the time is Paris mean time and requires a correction of 9 m. 21s. This also brings the time more into accordance with that recorded elsewhere. The time is given as 12h. 19m 5s. T. E. C., equivalent to 11h. 19m. 5s. G. M. T. by Dr. Agamennone, Boll. Soc. Sismol. Ital, III, pt. ii, 292.

52m. 15s. in advance of Greenwich. The G. M. T. of commencement is, therefore, 11h. 18m. 45s. The times can be relied on to half a minute. At 11h. 37m. G. M. T. the horizontal pendulum was thrown out of gear and the record ceased.

Newport, I. W.—At Shide, near Newport, in the Isle of Wight, Prof. J. Milne, F.R.S., has established a seismograph of his own design. The record is photographic, and unfortunately a change of paper was being made when the disturbance commenced; the record of the commencement of this earthquake was consequently lost, but the end of the disturbance was determined as 14h. 32m. 51s. The largest angular tilt recorded was 5″ of arc, but it may have been greater in the part of the record which was lost. A horizontal pendulum with a boom 4 ft. long gave the period of the large oscillation as 15s.

Edinburgh.—At the Royal Observatory, Edinburgh, is a bifilar pendulum, an instrument consisting of a mirror hung from two threads of unequal length whose upper ends are fastened nearly vertically above each other. As long as the two points of suspension and the two points of attachment remain in the same vertical plane, the mirror remains at rest, but as soon as it is tilted in the slightest degree in any direction, except that of this plane, the mirror swings round till the four points once more lie in the same vertical plane. The mirror is immersed in petroleum to prevent its swinging too freely, and the tilting to which the instrument is subjected is registered by means of a ray of light reflected off the mirror on to a piece of sensitive paper.

A description of the effect of the earthquake on this instrument has been published by Mr. T. Heath[1], along with a reproduction of the photographic record. The first indication of disturbance is at 11h. 18m., when very slight preliminary tremors are noticable: at 11h. 28m. more violent oscillations set in and lasted till 12h. 33m. After this, there is a slight but distinct disturbance at

[1] Proc. Roy. Soc., Edin., 1897, pp. 481—488.

14h. 6m.[1] The amplitude of the recorded oscillations of the mirror when at its maximum was equivalent to a tilting of the whole instrument through 20″ of arc; but in the gap, where the oscillations were too great to be photographically recorded, it must have been greater.

In discussing these observations the first point to be noticed is that there are three distinct phases and seven epochs, which can be recognised in the records. The phases are (1) the first phase, consisting of nearly horizontal rapid displacements of the instruments unaccompanied by undulating movement of the ground, (2) the second phase, during which there were distinct undulations, apparently accompanied by angular tilting of the instruments, and (3) the great oscillations commencing at about 11-45. The epochs which can be recognised more or less distinctly on the records are—

(1) The first commencement of disturbances.
(2) The maximum of the movement of the first phase.
(3) The commencement of the undulatory movement of the second phase.
(4) The maximum of the same.
(5) The commencement of the larger undulations.
(6) The maximum of these larger undulations.
(7) The cessation of the disturbance.

One or all of the epochs can be determined on all the traces, and the respective times are given in the tabular statement on the following page, the time being minutes and seconds after 11h. Greenwich mean time:—

[1] In the published account 13h. 12m. I am indebted to Prof. R. Copeland, Astronomer Royal, for the information that a reexamination of the record showed that the disturbance could be traced for a longer period than was originally supposed.

	1	2	3	4	4	5	6
	FIRST PHASE.		SECOND PHASE.		LARGE UNDULATIONS.		End of disturbance.
	Comm.	Max.	Comm.	Max.	Comm.	Max.	
	m. s.	m. s.	m. s.	m s.	m. s.	m. s.	
Ischia . .	17 13	19 19	26 0	27 40	42 33	47 0	13h.
Rome, Rocca di Papa.	17 40	...	25 50	...	41 45	46 50	13h.
„ Ufficio centrale.	17 5	20 20	25 20	28 0	43 8	47 0	...
Padua . .	16 47	22 0	25 45	28 15	42 30	47 10	15h.
Catania . .	17 23	...	25 55	26 25	45 0	48 0	14h.
Siena . .	17 0	19 30	26 0	27 0	46 0	48 0	...
Pavia . .	18 17	20 0	...	27 0	45 43	48 0	12h.
Grenoble . .	19 5	...	...	...	...	...	...
Potsdam . .	18 45	...	...	...	...	...	...
Strassburg .	18 32	...	...	...	...	...	14·5h.
Edinburgh .	18 0	...	28 0	...	...	...	14·5h.

In connection with this table and the apparent imperfection of the records at all but the Italian observatories, the difference in type of the instruments used must be borne in mind. In Italy, heavily weighted pendula are favoured, whether vertical or horizontal, and the record is made by a pen, or a pointer travelling over a moving strip of smoked paper. This type of instrument has some disadvantages, but it enables the recording surface to move sufficiently rapidly to give an open and detailed record of the displacements of the pendulum, and the heavy weight on the pendulum enables it, in virtue of its inertia, to record horizontal displacements of the instrument which are unaccompanied by tilting.

At Potsdam, Strassburg, and apparently Grenoble, weighted horizontal pendula were in use. At Potsdam, the instrument was thrown out of working order shortly after the commencement of the shock. At Strassburg, the displacement of the pendulum was so great that no impression was made on the sensitised paper, and from Grenoble I have no details.

The bifilar pendulum is not intended to respond to anything but a tilt of the instrument as a whole, but it is evident, from the time of commencement of the preliminary tremors, that the movement of the first phase was sufficiently great to affect the instrument, while the commencement of the larger displacements indicates the commencement of the second phase. The time of maximum movement cannot be decided, as at that period the displacements were beyond the range of recording power of the instrument.

Turning to the magnetic instruments, I have been able to collect the following information.

Bombay.—A description of the effect of the earthquake on the traces of the self-recording instruments at the Colaba Observatory has been given in Chapter XI. The main results may be epitomised here and the times converted into G. M. T.:—

Declination, commencement 11h. 12·75m. end 11h. 41·75m. the trace is lost between 11h. 14·75m. and 11h. 16·75m.

Horizontal force, commencement of disturbance 11h. 11·25m. end 11h. 44·75m. trace lost between 11h. 14·25m. and 11h. 28·25m.

Vertical force, commencement disturbance 11h. 15·25m. end 11h. 22·75m. maximum at 11h. 16·75m. and a second minor one at 11h. 20·75m.

Barograph, commencement of disturbance, 11h. 14·25m. end 11h. 21·25m. maximum at 11h. 18·25 h.

Batavia.—At Batavia the magnetic and electric instruments were affected by the shock. The times taken from the original records, for which I am indebted to Dr. S. Figee, are as follows:—

Declination, Shocks, almost imperceptible, at 11h. 22m., G. M. T., and others afterwards until 11h. 32m.

Horizontal Force, First, small, shock at 11h. 24m., G. M. T., last at 12h. 55m.

Vertical force, First shock at 11h. 23m., others until 11h. 43m.

Electrometer, (Mascart's type) commencement 11h. 17m., end at about 11h. 53m.

The disturbances are of the same type as those of the Bombay instruments, but less extensive.

Potsdam—The instruments are similar to the Kew instruments but smaller in size. All three were affected by the earthquake. The times of commencement were—

Declination . . .	11h. 18·75m. G. M. T.
Vertical force . . .	11h. 18·25m. ,,

The exact time of commencement cannot be determined on the trace of the horizontal force instrument, but there is a perceptible widening of the line commencing at about 11h. 10m., though the first definite disturbance is not for some 6 or 7 minutes later. The termination of the disturbance is at about 12h. 40m. G. M. T. on the trace of the declination instrument, and about 12h. 28m. on that of the vertical force instrument. On the horizontal force instrument there are a number of small oscillations lasting till about 13h. 42m. G. M. T.

The times of commencement were measured at Potsdam on the original records and are accurate within a limit of ·5m. The others are taken from photographs of the traces, for which I am indebted to Dr. Eschenhagen, and cannot be trusted within, say, 2 minutes of time. I am also indebted to Dr. Eschenhagen for the information that the maximum displacement recorded by the horizontal force instrument was at 11h. 48·75m. G. M. T., but, as the time for changing the recording papers fell just as the instruments were being affected by the earthquake, there may have been a greater movement subsequent to this.

Wilhelmshaven.—The magnetic instruments at Wilhelmshaven were all affected by the shock, and I am indebted to Dr. C. Börgen for the following particulars, obtained by measurement from the original traces. The times are reduced to Greenwich Mean Time and correct to about half a minute :—

Declination.—

11h. 19·5m. first indication.
26m. first distinctly visible wave followed by several small waves.
44·5m. first strong wave.
50·5m. maximum.
56·0 m. to 12h. 0·5m. } many shocks, succeeding each other quickly.
13h. 28m. cessation of disturbance.

Horizontal force.—

11h. 19m. first indication.
42·5 strong disturbance ; after this the record ceases till 11h. 57·5m., after which it is again visible.
12h. 40m. cessation.

Vertical force.—

11h. 26·5m. commencement.
11h. 29m. small wave.
11h. 31m. larger wave.
11h. 40m. to 12h. 0m. } a violent movement of the magnet causing a blurred trace.

Copenhagen.—The magnetographs in the observatory of the Meteorological Institute at Copenhagen were affected by the shock. I am indebted to Dr. A. Paulsen, the Director of the Institute, for the following particulars, obtained by direct measurement on the original records :—

Declination, commencement of disturbance 11h. 25·5m., end 11h. 56·5m.; maximum 11h. 36m. ; maximum angular displacement 0·75m.

Horizontal force, commencement of disturbance 11h. 16·5m. end 11h. 51·5m, maximum displacement 0·6m. at 11h. 36m.

Vertical force.—A disturbance of the trace was noticed at 11h. 47m., the angular displacement is too small to be measured.

Pawlowsk (St. Petersburg).—According to Dr. Agamennone[1] the horizontal force instrument at this observatory was disturbed at 11h. 17m. the disturbance reaching its maximum at 11h. 22m., and ending at 11h. 25m., but the trace is again disturbed from 11h. 39m., to 11h. 42m. though in a less degree. The declination instrument trace was affected at the same time, but not so distinctly.

Paris, Parc, St. Maur.—According to the Bulletin du Bureau central there was a slight disturbance of the curves of the horizontal force and declination instruments at 11h. 27m. 40s.[2]

Utrecht.—The disturbance of the declination instrument commenced at 11h. 18·5m., and ended at 12h. 38m.

The horizontal force instrument was not disturbed till about 11h. 36·5m., the disturbance lasted till 13h. 47m.

Tabulating the times given, for convenience of comparison, we have the following :—

	Horizontal force.			Declination.			Vertical force.		
	Comm.	Max.	End.	Comm.	Max.	End.	Comm.	Max.	End.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Bombay	11 11	?	11 45	11 13	11 16	11 42	11 15	11 17	11 23
Batavia	11 24	?	11 55	11 22	?	11 32	11 23	?	11 43
Potsdam	?	11 49	13 42	11 19	?	12 40	11 18	?	12 28
Wilhelmshaven.	11 19	?	12 40	11 19·5	11 50·5	13 28	11 26·5	?	?
Utrecht	11 36·5	...	13 47	11 18·5	...	12 38	...	...	...
Copenhagen	11 16·5	11 36	11 51·5	11 25·5	11 36	11 56·5	...	11 47	...
Paris	...	...	...	...	11 27·5	...	...	...	...
Pawlowsk	11 17	11 22	11 42	...	...	...	...	...	...

From this table it is easily seen that the magnetographs cannot be depended on for accurate or concordant times of arrival of the

[1] Boll. Soc. Sismol. Ital. III, pt. ii, p. 290 (1897).
[2] Quoted in Cosmos, XLVI, 652 (1897).

disturbance, or of its different phases. There is a tolerably close agreement between the time of the first disturbance of the horizontal force instrument and the times recorded in Italy, as those of the arrival of the waves of the first phase, and when we consider that this instrument is by its construction especially sensitive to mechanical, as well as magnetic, disturbances this agreement is not to be wondered at.

When dealing with the records of the Bombay magnetic observatory the question of whether the disturbances were mechanical or magnetic was discussed, and it was shown that though they might in part be explained by the purely mechanical effect of the earthquake yet they could not be wholly so explained, and must be attributed in part at least to locally induced magnetic disturbances. An examination of the irregularities and discrepancies among the records of the European observatories points to a similar conclusion, and it seems as if here the mechanical effect of the earth waves was completely masked by the induced magnetic disturbances; a conclusion which is borne out by the limited number of observatories at which any effect was noticed, as compared with the much larger number at which nothing was recorded, though the instruments in use were of the same type and in some cases identical in construction.

Whatever may be the cause of the disturbances of magnetic instruments which are due to distant earthquakes it is evident, from the details given above, that the records are useless for comparison with those of instruments specially constructed to record the mechanical displacements of the earth's surface due to distant earthquakes or other causes. They will consequently be omitted in the discussion of the distant records of this earthquake.

We have, then, records which can be utilised from 11 distinct stations, situated at from 4,300 to 4,900 miles from the centre, as shown in the following tabular statement :—

1	2	3	4	5	6	7
	Latitude.	Longitude.	Angle.	Arc.	Chord.	Versin.
Potsdam	52°25′ N	13° 2′ E	62°36′	4,322	4,111	576
Ischia	40°45′ N	13°58′ E	63°28′	4,382	4,162	591
Catania	37°28′ N	13°28′ E	63°53′	4,411	4,185	599
Rome	41°54′ N	11°28′ E	64° 5′	4,425	4,198	603
Padua	45°24′ N	11°50′ E	64°29′	4,452	4,221	610
Siena	43°19′ N	11°19′ E	65°18′	4,509	4,269	625
Pavia	45°11′ N	9°10′ E	66°22′	4,582	4,331	645
Strassburg . . .	48°35′ N	7°43′ E	66°32′	4,594	4,340	648
Grenoble . . .	45°10′ N	5°40′ E	68°14′	4,711	4,438	681
Edinburgh . . .	55°57′ N	3° 1′ W	70°51′	4,891	4,586	732
Snide	50°41′ N	1°19′ W	71°34′	4,942	4,626	747

In this table the first three columns require no explanation. The fourth column represents the angle subtended, at the centre of the earth by the place mentioned in the first column, and an assumed centre in N. Lat. 25°45′, E. Long. 91°0′. The fifth column is the length of the corresponding arc in miles, calculated to a mean radius of 3,956 statute miles; or, in other words, the distance in a direct line, measured along the surface of the earth. Column 6 gives the distance in a direct line measured through the earth, and column 7 the greatest depth, in miles, of this line from the surface. In calculating 6 and 7, the focus was assumed to be at the surface, and they are consequently subject to an inaccuracy on this account, which would tend to increase the value of 6 and diminish that of 7. In other words, the true distance in a direct line would be rather less than that tabulated, and the true depth rather greater. The error is, however, proportionately so small that it may be neglected.

Taking these distances, we may calculate the rates of travel, represented by the principal epochs in the records. In doing so, we may assume that all the waves started at the same time from the centre, and as a matter of fact they certainly did so within a minute of time.

Taking the time of arrival of the first tremors, we have the following result:—

	Interval in minutes.	APPARENT RATE OF TRAVEL ALONG			
		SURFACE.		DIRECT LINE.	
		Miles per min.	Kilometres per sec.	Miles per min.	Kilometres per sec.
Ischia	12·25	366	9·68	340	8·99
Catania	12·5	353	9·33	335	8·86
Rome, Rocca di Papa .	12·75	347	9·18	329	8·71
„ Ufficio centrale .	10·0	369	9·75	350	9·25
Padua	11·75	379	10·02	359	9·50
Siena	12·0	376	9·94	356	9·41
Pavia	13·25	355	9·19	347	8·64
Arithmetical mean .	12·36	364	9·58	345	9·05
Potsdam	13·75	314	8·32	299	7·91
Strassburg	13·5	340	9·00	321	8·50
Grenoble.	14·0	336	8·90	317	8·39
Edinburgh	13·0	353	9·33	361	9·95

That is to say, these tremors travelled between India and Europe at a rate of about 345 miles a minute, or 9·0 kilometres a second, if they travelled in a straight line from point to point, and at a greater rate if they followed a curved line.

Turning to the time of commencement of the second phase we have the following results:—

	Interval in minutes.	APPARENT RATE OF TRAVEL ALONG			
		SURFACE.		DIRECT LINE.	
		Miles per minute.	Kilometres per second.	Miles per minute.	Kilometres per second.
Ischia	21·0	209	5·52	198	5·24
Catania	21·0	210	5·56	199	5·27
Rome, Rocca di Papa .	20·75	213	5·64	202	5·35
,, Ufficio centrale .	20·25	214	5·78	207	5·48
Padua	20·75	215	5·68	203	5·38
Siena	21·0	215	5·69	203	5·38
Arithmetical mean .	20·7	213	5·64	202	5·35
Edinburgh . . .	23·0	213	5·63	200	5·29

Here we have a rate of propagation of about 200 miles a minute, or 5·3 kilometres a second, lower than that of the preliminary vibration, but still much greater than that of the sensible earthquake in the region where it could be recognised without instrumental aid.

There remains only the group of large undulations, lasting for about 10 minutes. It is only in the Italian records that these can be recognised, as the oscillations at this period were too extensive to allow an impression being made on the sensitive paper where photographic registration was employed.

For the commencement of these oscillations, we have the following result:—

	Interval in minutes.	APPARENT RATE OF TRAVEL ALONG			
		SURFACE.		DIRECT LINE.	
		Miles per minute.	Kilometres per second.	Miles per minute.	Kilometres per second.
Ischia	37·5	117	3·09	111	2·94
Catania	40	110	2·92	105	2·77
Rome, Rocca di Papa .	36·75	120	3·19	114	3·02
,, Ufficio centrale .	38·0	116	3·08	110	2·92

	Interval in minutes.	APPARENT RATE OF TRAVEL ALONG			
		SURFACE.		DIRECT LINE.	
		Miles per minute.	Kilometres per second.	Miles per minute.	Kilometres per second.
Padua	37·5	119	3·14	113	2·98
Siena	41	108	2·84	104	2·75
Pavia	40·75	112	2·97	106	2·81
Arithmetical mean .	38·8	115	3·03	109	2·88

The important and striking fact in this table is that we obtain a rate of propagation which is almost identical with that deduced in Chapter III as the probable rate of travel of the sensible earthquake.

If instead of the time of commencement we take that of maximum movement, and take, as we may well do, the origin of these cases to be one minute later than the earlier ones, we get very slightly a slower rate of propogation as shown in the following table :—

	Interval in minutes.	APPARENT RATE OF TRAVEL ALONG			
		SURFACE.		DIRECT LINE.	
		Miles per minute.	Kilometres per second.	Miles per minute.	Kilometres per second.
Ischia	41·0	107	2·83	101	2·69
Catania	42·0	105	2·78	100	2·64
Rome, Rocca di Papa .	40·75	109	2·88	103	2·72
,, Ufficio centrale .	41·0	108	2·85	102	2·71
Padua	41·25	108	2·86	102	2·71
Siena	42·0	107	2·84	102	2·69
Pavia	42·0	109	2·89	103	2·73
Arithmetical mean .	41·5	107	2·84	102	2·70

Before considering the meaning of these results, a short digression concerning the nature of the movements which would be propagated from the earthquake centre will be necessary. They are:—

(1) Waves of elastic compression, or condensational waves.

(2) Waves of elastic distortion or distortional waves.

(3) Undulatory waves, whether purely gravitational, elastic or elastic-gravitational, set up at the surface in and near the epicentral region and propagated along the surface.

The existence of waves of the first two classes has long been recognised; they are propagated through the body of the earth and it is to them that all earthquake effects are commonly ascribed, as was done by Prof. Grablowitz in his discussion of the records in Ischia.[1] The existence of undulations of the third class, first suggested by Professor Milne in 1888,[2] has not yet been fully accepted.

The rate at which these waves travel is governed by the density of the medium and its elasticity. The rate of travel of the wave of elastic comparison is always greatest, that of the distortional waves less, while the only form of elastic surface undulation which has yet been investigated has, according to Lord Rayleigh, a still slower rate of transmission.

Now, as pointed out by Dr. A. Schmidt of Stuttgart in 1888,[3] not only it is inconceivable that the elasticity of the materials of which the earth is composed should be unaffected by the very different conditions of pressure and temperature existing in the deeper-seated as compared with the superficial portions; but it is also not in accordance with observed facts, for were such the case, the rate of travel of the waves would inevitably be the same for the same rock and the same region in the case of every earthquake,—a conclusion which is in utter want of accordance with observed facts. We must, accordingly, allow that the depth below the surface at which an elastic wave is propagated has an important influence on its rate of

[1] See p. 232.

[2] Trans. Seismol. Soc. Japan, XII, p. 112.

[3] Wellenbewegurng und Erdbeben: Jahresheft. Ver. f. Vaterland. Naturkunde in Wurttemberg, 1888, pp. 248—270; noticed in Nature; LII, 631—633 (1895).

travel, whether this be in the direction of diminishing or, as observations show, of increasing the speed.

The study, by means of special instruments, of the earth movements due to earthquakes at a distance from their place of origin, shows that the preliminary tremors begin before the greater undulations, and that the period through which they last is longer as the place of observation is more remote from the centre. It is found too that the time by which the tremors precede the greater undulations is greater than that which is due to the difference between the distance in a straight line and along the surface of the earth; in other words, the rate of propagation of the tremors, which travel through the earth, is more rapid the greater the depth of the wave path from the surface.

In this the records of the great earthquake present no peculiarities, but the marked three-fold character of the disturbance is peculiar. The only published instance of a similar record, with which I am acquainted, is that of the Japanese earthquake of 1894,[1] and the meaning of these three phases may now be investigated.

The first phase consisted of comparatively rapid waves, whose period is estimated by Dr. Agamennone[2] as not more than about ·5s. to ·8s. Prof. Grablowitz' investigation of the records of his instruments has already been referred to, and his conclusion that the motion in this phase was mainly of a to and fro nature, unaccompanied by any considerable tilting of the ground. He expressly refers to the wave motion in this phase as condensational, and the most reasonable explanation is that the commencement of the disturbance was due to the arrival of waves of elastic compression. If these travelled in a straight line from the centre, the angle of emergence would be about 30°, if the wave path was a curved one, convex to the centre of the earth, it would be higher. That is to say, the

[1] E. von. Rebeur Paschwitz: Europäische Beobachtungen des grossen japanischen Erdbebens vom. 22 März 1894, und des venezolanischen Erdbebens vom. 28th April 1894, nebst Untersuchungen über die Fortplanzungsgeschwindigkeit dieser Erdbeben; Peterman. Mittheilungen, 1895, pp. 13-21 and 39-42.

[2] Boll. Soc. Sismol., Ital. IV, pt. i, p. 48 (1898).

ground was moved bodily backwards and forwards in a direction inclined more than 30° to the horizon.

A movement of this kind need not be accompanied by any marked surface tilting, and any way the tilts would be too rapid for the slowly moving pendula to respond largely to them; consequently the effect of the backward and forward movement on the pendula would be much greater than that of the up and down movement, as deduced by Prof. Grablowitz from a comparison of the records of his instruments.

In the second phase the wave period was longer than in the first, and there are indications of tilting of the surface of the ground. This phase appears to be due to the waves of elastic distortion, in which the movement of the wave particle is at right angles to the direction of travel of the wave. As demanded by theory these waves travelled at a slower rate than the waves of elastic compression.

An important point to note is that the rate of propagation of the wave motion of the second phase, 5·3 kilometres per second, is in close agreement with what is regarded as the normal rate of propagation of the preliminary tremors, corresponding to the distance between Italy and the epicentre. That of the first phase, 9 km., per second is, on the other hand very much in excess. Reference has already been made to the fact that the only published instance of a three-fold division of the record, similar to that of this earthquake, appears to be the Japanese earthquake of 1894, but too much importance must not be atached to this. From the nature of the case, these waves would only be recorded, or at any rate only separable, in the records of heavy pendula of the Italian type, and would ordinarily be unrecorded by Darwin's bifilar pendulum, or if recorded, not distinctly separable from those of the second phase on account of the slowness of travel of the recording surface and consequent compression of the record. It is therefore possible that the waves of elastic compression have been more frequenty recorded, and that records showing a three-phase character of the trace are commoner than the published references suggest; on the other hand, the fact that the rate of transmission of the second phase, in the case of this earthquake, accords with what, according to the text-books, should be regarded as a normal rate of transmission of the preliminary tremors,[1] seems to show that the more rapid rate of transit shown by the disturbance of the first phase is exceptional, or at least unusual.

This is not the place to go further into the subject. To treat it satisfactorily the original records of distant earthquakes preserved in the observatories of Europe require a careful reexamination, but if the explanation of the two phases of preliminary tremors offered is accepted, it follows that the waves of elastic compression die out sooner than those of elastic distortion, and are only transmitted to great distances in the case of exceptionally severe earthquakes; in ordinary cases they have died out while the waves of elastic distortion remain and are recorded as the preliminary tremors. From this it is obvious that in making any deduction from the duration of these preliminary tremors, it is necessary to be certain which phase they begin with, whether that of the condensational or the distortional waves.

In the case of both these first two phases of the records we have a rate of travel much greater than that of the earthquake which was felt, an increase which must be mainly attributed to their having travelled through the earth at depths where pressure and temperature produced profound modifications in the elasticity of the rocks they travelled through.

If we now turn to the large undulations which are estimated by Dr. Agamennone[2] to have had a complete period of 22 seconds, a length of 34 miles, and a rise and fall of 20 inches, we get the

[1] Prof. Milne gives the following as the average rate of transmission of the preliminary tremors for varying distances (Seismology, 8° London, 1898, p. 113).

Distance from origin	20°	rate of travel 2 to 3 km. per sec.
,, ,, ,,	50°	,, 5 ,, ,, ,,
,, ,, ,,	80°	,, 8 ,, ,, ,,
,, ,, ,,	100°	,, 10 ,, ,, ,,

[2] Boll. Soc. Sismol, Ital. IV, pt. i, 49 (1898).

result that the rate of travel, as between the centre and Italy, was about 113 miles per minute, or 2·98 kilometres per second, which is practically the same as the apparent rate of travel of the sensible shock along the surface between Calcutta and Bombay. There is only one conclusion possible from this, that these undulations, which are quite characteristic and distinct on the records, were not due to waves of elastic distortion, as has been assumed by some observers, and did not travel through the substance of the earth, but along its surface. Had they travelled through the earth, instead of along its surface, it is impossible to conceive that their rate of travel would not have been affected by the depth, as was the case with the two other kinds of wave.

We have here a very strong confirmation of Professor Milne's suggestion that an earthquake sets up a wave motion at the surface which travels outwards along the surface at a practically uniform speed, the individual waves becoming longer and slower in the movement of the wave particle, just as the ripples caused by a stone falling into a pond become longer and less pronounced as they travel outwards from the centre.

One thing only is needed to complete the demonstration, and that is to find the undulations which came the long way round the earth, as well as those which came direct. If we consider what happens to the surface undulations, we will see them spreading outwards in continually widening circles till they pass round the earth and converge on the antipodes of the epicentre. Here we would expect to find an instrument, had there been one set up, giving a very confused record, but after the waves cross each other they diverge once more, in widening circles as they travel on their way, and in due time we should find the trace of the undulations which have travelled past the antipodes of the centre and are on their return journey round the other side of the world.

A simple calculation will show that if the rate of travel of these surface undulations remained constant, the return wave should be expected about 10 minutes past 2 P.M. by Greenwich time.

At Edinburgh, as has already been noticed, I am indebted to the Astronomer Royal for the information that there is a small but distinct disturbance of the trace at 14h. 6m.

From the observatory at the Rocca de Papa, Dr. Cancani most obligingly sent a tracing, nearly 8 ft. long, of the record of the horizontal pendula at that observatory, and on this I notice at 14h. 4m., two distinct though minute undulations and again between 14h. 7m. and 14h. 8m. some more. Though small these undulations are distinct, and like the great ones of the principal disturbance, have a complete period of about 20 seconds.

A photograph of the record at Shide shows a decided enlargement of the trace from 14h. 5m., to 14h. 7m., which is doubtless due to the same disturbance.

Besides these I find in the detailed account published in the Bulletin of the Italian Seismological Society, the following:—

At Leghoru oscillations of the *Tromometro Egidi*, are recorded at 14h. 10m.[1] The extent is only 1mm. as against 3·2mm. of the great undulations, but no other disturbance is recorded between 13h. 42m. and 15h. 45m.

At Catania a slight disturbance of the *grande sismometografo* of 25m. length of pendulum, at 14h. 12m. 41s. on the NE-SW component.[2]

At Ischia the horizontal pendula, which are evidently extremely sensitive instruments, were repeatedly disturbed between 2h. and 3h. p.m. and it is impossible, without access to the original records, to identify the undulations referred to here.

Tabulating these records, as is done below, we obtain a rate of travel practically identical with that of the direct passage of the great undulations from the centre.

[1] Boll. Soc. Sismol, Ital. III, pt. ii, p. 251.
[2] Loc. cit. pp. 283, 284.

	Rate of travel.				
	Interval. h.	m.	Distance miles.	Miles per minute.	Kilometres per second.
Edinburgh	3	1	19,968	110	2·93
Shide	3	0	20,233	112	2·96
Leghorn	3	5	20,408	110	2·93
Rocca di Papa	2	59	20,434	114	3·02
Ditto	3	2	20,434	113	2·98
Catania	3	8	20,448	109	2·88
Arithmetical mean	3	2	20,321	111	2·95

From this table we see that the time of arrival and the rate of travel of these undulations is so close to what should be expected if they were surface undulations travelling round the world, that we may consider their character as such to be established, as well as is possible in the absence of observations from intermediate stations.

The recognition of surface undulations which have travelled round the world, may be regarded as one of the most interesting results of this investigation. It is the first occasion, since suitable instruments have been set up, on which the surface waves of an earthquake have been of sufficient size to maintain their character, and leave a recognisable record, after traversing five-sixths of the circumference of the globe, and the announcement of this may well bring the report of the great earthquake of 1897 to its close.

Appendix A.

Reports of officers of the Geological Survey of India despatched to investigate the effects of the earthquake.

This appendix contains, with unimportant omissions, all those parts of the reports, referred to on p. 2, which have not been incorporated in the body of the text. They were drawn up under specific instructions to report only the facts observed, and to refrain from any expression of opinion as to the conclusions to be drawn, as this could only be profitably done after a review of the whole of the facts, of which only part could become known to each individually.

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1. Report by Mr. T. D. LaTouche, *Superintendent, Geological Survey of India.*

Calcutta, Assam, Sylhet.

Monument to Sir William Jones, Old Cemetery, Park Street, south side.

Calcutta.—The monument consists of a massive oblong pedestal built of brick, measuring 16 feet 2 inches from east to west, and 13 feet from north to south, 10 feet 3 inches in height, surmounted by a tapering obelisk, also of brick, the original height of which from the ground was 50 feet. The upper 6 feet or so of this has been broken off, and the fragments, including a conical stone cap which formed the summit of the obelisk, are now lying at the foot of the pedestal on its south-west side. The longer sides of the monument run E 20° S and W 20° N.

The brickwork in falling from the top has struck and broken off the edge of the cornice running round the top of the pedestal over the south-west side, rather to the west of the centre, the mean direction of the break, measured from the centre of the obelisk, being S 20° W. The stone cap struck the cornice still further to the west, and made a separate fracture, the direction of this from the centre being S 53° W. As the stone cap was, however, fixed to the monument by an iron pin, it is likely that the latter, striking against the sides of the monument, caused the cap to be deflected in its descent, and the fracture caused by the brickwork probably represents more nearly the actual direction of the shock.

Monument to Mrs. Mary Ann Wiltshire, Old Cemetery, Park Street, north side.

This monument consists of a square brick pedestal about six feet in height, with an ornamental cornice and frieze running round the top, which is conical. This was surmounted by a brick and plaster urn, fixed to the pedestal by an iron pin. The urn has been shattered into fragments and fell to the south-west, striking the cornices in three places in a direct line, the direction of which is S 27° W from the iron pin, which still remains fixed in the top of the pedestal.

St. Paul's Cathedral, Calcutta.

The iron framework forming the top of the spire was thrown off, and a number of bricks were dislodged from the portion of the spire immediately beneath it. Some of these fell to the north side of the tower, crashing through the corrugated iron roof, but the larger portion fell to the southern side, and, penetrating the roof, struck the tiled ceiling of the Church and dislodged some plaster from the inside. A large number of bricks also fell down the sides of the spire on all sides and lodged on the gallery running round the base of it. The iron framework was projected in a direction S 31½° W from the centre of the tower, to a mean distance, horizontally, of about 40 feet, and struck the corrugated iron roof, but only partially broke through it. The top is described by eye-witnesses as having oscillated for some time, a rain of bricks falling at the same time from the base of it, and then pitched over, coming down head foremost. The iron stays fixing it to the brickwork of the spire have been broken through.

Cracks have appeared at each of the angles where the body of the Church joins the tower, but the crowns of the arches supporting the tower are intact.

Town Hall, Calcutta.

At the south-east corner a large portion of the cornice, which projected four feet from the top of the wall, has fallen, as well as the heavy balustrade above it at the edge of the roof. The corner pillar of the balustrade, a large mass of brick masonry, has fallen almost intact, and is now lying 21 feet from the base of the building, in a direct line with the eastern wall. The height from the ground to the centre of the pillar, as it stood originally, was approximately 54 feet. In falling it is possible that the pillar struck the cornice and was thus projected further from the building than would otherwise have been the case, but it is quite likely that the cornice fell as soon as the balustrade, and did not affect the fall of the latter. The direction of projection is S 20° W. A large portion of the balustrade adjoining this pillar on the southern side of the roof was thrown down with it, and is lying at the same distance from, and parallel to, the foot of the wall.

Fissuring of river banks.

1. **Brahmaputra above Goalundo.** Proceeding up the river from Goalundo, I first noticed fissuring of the banks about Sirajganj, the first place the steamer stopped at. From about this point the banks are fissured on either side to a greater or less distance from the edge of the bank, usually about 20 or 30 yards, to the neighbourhood of Mangaldai in Assam, a distance of some 260 miles, and fissures extend of course along the banks of all the minor branches of the river and its tributaries within this area. As a rule, the fissures run parallel to the bank of the river, and where this is not the case, some peculiarity in the contour of the ground, a drop for instance from a higher to a lower level, can usually be found to account for the change in direction.

Rowmari.

2. At Rowmari, for instance, besides the fissures parallel to the bank of the river, which here runs nearly north-east and south-west, a large fissure runs to the south-east at right angles to the river bank for a distance of at least 500 yards, when it becomes lost in a jheel. (It is

said to run to a distance of nine miles from the river, and very likely extends much further than I traced it.) This fissure runs along the edge of a tract of ground, on which the village stands, rather higher than the level of the river bank, probably marking the line of an old river channel. Sand and mud have been ejected from the fissure to a depth of at least four feet. Other fissures branch off from this through the higher ground to the north, one of them passing beneath the huts of the villages. Subsequent to the ejection of the sand, the surface sank down to a depth proportional to the amount of material ejected, and several crater-like hollows were formed as the water drained back into the fissure (Plates X and XI). Where the principal fissure crosses those parallel to the river bank, the surface of the ground is broken up into a number of square blocks.

Jatrapur.

3. At Jatrapur the narrow gauge railway from Kaunia to Dhubri joins the river. The railway bund[1] is much fissured, the fissures running parallel to the bank of a jheel along which the railway is carried. In places the bund has subsided vertically by settlement and spreading out on either side of the earth composing it, and the rails are bent and twisted.

Time of shock.

4. **Dhubri.** No accurate record of the time was taken at the Telegraph Office, as the pendulum of the clock was broken by the shock. It is estimated to have occurred at about 5-20 P.M. local time, which is 39 minutes in advance of Madras time.[2]

Gate pillar at Telegraph Office.

5. The gateway faces south-east. The pillars are of square section 1 foot 8 inches square by 4 feet 10 inches high, built of brick. That on the north-east side has fallen towards N 40° E and struck the bank alongside the gateway, rolling off into the ditch. The capping has turned round in its fall and is lying with its point facing the pillar. The other post is standing, but cracked through at the base.

Treasury.

6. This is a strongly brick-built structure, measuring outside 80 feet by 41 feet 4 inches, standing nearly cardinal, the longer side facing N 5° E. It is divided in the centre of its length by a passage eight feet wide, on either side of which are two large rooms.[3] The flat roof is supported as usual by strong beams, on which small battens are laid, which in turn support the tiles of the ceiling. In the passage way the beams run east and west, the battens north and south, while in the rooms the position of the beams and battens is the reverse of this. In the passage way the battens have been dislodged some of them having fallen out and all having moved more or less out of their places. In the side rooms, on the contrary, the battens have not moved at all, but the beams can be seen to have moved backwards and forwards on the walls. The upper part of each corner of the building has fallen, in the most symmetrical manner, for about eight or ten feet from the roof.

Observatory.

7. This is a hexagonal brick structure, two storied, measuring 9 feet 6 inches on each side (outside measurement). The door faces S 15° E. From the top of the door-way, 7 feet 6 inches

[1] Embankment.
[2] The Cutcherry and Treasury clocks both stopped at 5½ minutes past 5 P.M.
[3] *i.e.*, four rooms in all.

above the plinth, a crack runs diagonally up to the roof on the east side, passing through the small hexagonal window on that side. A portion of the cornice has fallen from the east-south-east and north-east sides.

Thermometer shed.

7(*a*). The thermometer shed is in front of the observatory building. A plan of this is given in fig. 24. It consists of a thatched roof up po rted by eight brick pillars, each of which is cracked through near the base and twisted in the direction of the hands of a watch from 5 to 12 degrees.

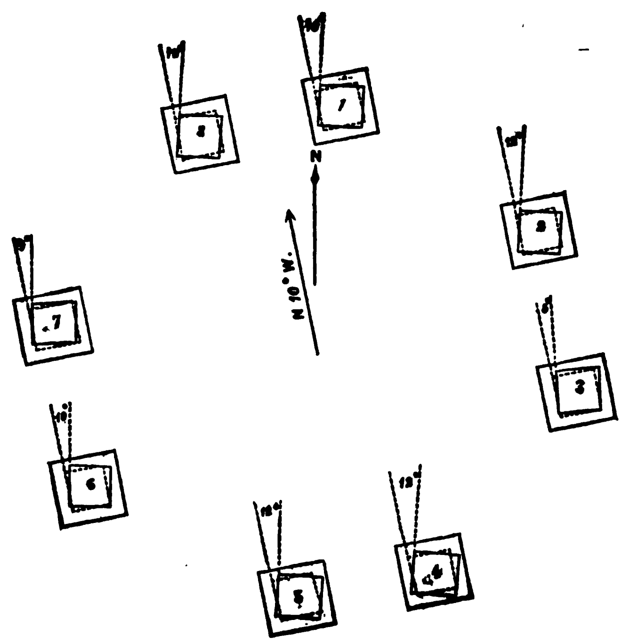

Fig. 24. Plan of pillars of thermometer shed at Dhubri.

The anemometer, which was fixed to the top of a wooden structure 14 feet high, was thrown down, but had been removed at the time of my visit.

Gate pillars at Zamindar's house.

8. Of these two gate pillars one has fallen due north, having broken off at 20 inches from ground level. The other pillar has not fallen, but is leaning over at an angle of 5° from the perpendicular towards S 15° E.

Jubilee well.

9. This was an octagonal structure, well built of brick masonry, with alternate walls about 14 feet high supporting an ornamental roof. Between these on three sides were low walls supporting an iron tank above the well, the fourth side on the west being left open to allow access to the well. Of the four walls supporting the roof three, *viz.*, those on the south-west, north-west and north-east sides, have each fallen flat

on the ground away from the well, while the fourth on the south-east side is still partly standing, but cracked through. The well was originally about 30 feet deep and held about 20 feet of water. It is now filled up with sand to nearly one foot below the surface of the water.

Fissures along river bank, etc.

10. The greater part of the station of Dhubri is built on a low eminence of gneiss, bounded on the north, east and south by the river, and to the west by alluvium, on which the bazar is built. This portion of the station has suffered severely from fissuring, especially near the banks of the river. Several high bunds which run due north from the bazar to the road connecting Dhubri with Kuch Bihar have been fissured transversely at intervals of a few feet, and settled down considerably.

Effects of earthquake in district.

11. From a letter written after the earthquake by the Deputy Commissioner, Mr. Hallifax, to the Commissioner, Assam Valley Districts, dated 24th June 1897, I obtained the following particulars:—

At Gauripur, 5½ miles to north of Dhubri, pucca buildings and bridges were all destroyed and low-lying places filled with sand. The time is given as 4-30 P.M.

At Sukhchar, a khal, 300 × 78 × 5 feet, was entirely filled with sand ejected from fissures, which is said to have spouted up to a height of 10 cubits.

At Mankachar (Lat. 25° 32, Long. 89° 55′), the thana is said to have sunk 4 cubits. The river, which was 30 feet deep before the earthquake, was choked with sand to within 8 feet from the surface, and heavy floods occurred in consequence.

At Bijni (Lat. 26° 30′, Long. 90° 45′), sand and water were forced up to a height of 4 or 5 cubits. The time of shock is given as 4-55 P. M.

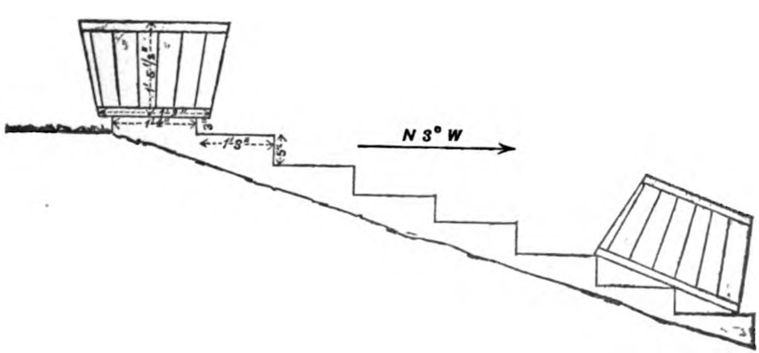

Fig. 25. Overthrow of plant-tubs at the Assistant Commissioner's bungalow, Goalpara.

12. **Goalpara.** The Assistant Commissioner's bungalow is situated on the crest of a ridge of gneiss overlooking the river, running from south-east to north-west.

Assistant Commissioner's bungalow.

The bungalow itself has entirely fallen, the general direction of fall being towards north. In front of it is a flight of steps eight in number (see fig. 25), on the topmost of which stood two tubs, one at each side, filled with earth. Both of these have toppled over and rolled down the steps, both falling in exactly the same direction, to N 3° W. They seem to have struck the third step from the top in falling and then turned completely over. It is possible that the tubs were jerked forward to the edge of the steps by the shock and then tilted over. If they were first tilted up, it would, I found by trial, require an angle of tilt of 35° to cause the tub to slip off the edge of the step.[1]

Cemetery. Tomb of Mrs. Ann Simons.

The cemetery is situated on the south-south-east slope of the ridge, the average angle of slope being 15°. The monuments are mostly of the oblong box form, common some 50 years ago, with their longer axes lying east to west, or transverse to the slope of the hill. Mrs. Simons' tomb has fallen over to S 5° E without breaking, and now stands at an angle of 24° from the vertical.

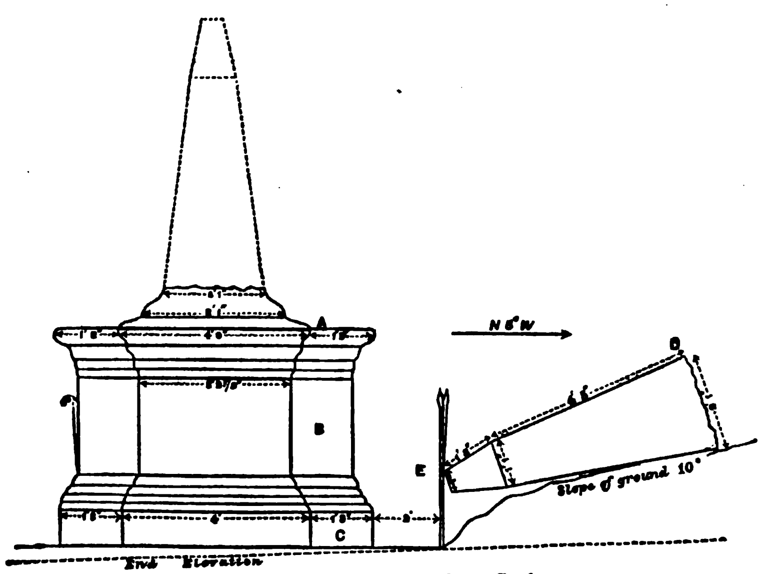

Fig. 26. Tomb of Ensign Law, Goalpara.

Tomb of Ensign Law.

Ensign Law's tomb is of the same shapegenerally, but was surmounted by an obelisk 5 feet 8 inches high, which broke off at its plane of junction with the top of the tomb and was thrown to N 5° W. As it fell, it must have

[1] It seems more probable to suppose that they were projected, like the tomb of Ensign Law.—R. D. O.

turned over, since the apex is now lying at the foot of the railings surrounding the tomb. It just touched the top of one of the spikes of the railings in falling and bent it slightly outwards.

A square column at the lower end of the Cemetery has fallen over to E 30° S. This measures 3 feet 5 inches high by 1 foot 10 inches square, with a conical cap 2 feet 4 inches square by 1 foot 6 inches high.

Two other tombs similar to that of Mrs. Simons' have slipped off their foundations and heeled over to south without breaking.

All these tombs are built of brick masonry.

14. The Treasury was a massive brick building standing at the foot of the hill near the river bank, and facing N 17° E. A portion of the front of the building has fallen out, and the west end is also destroyed; the remainder is greatly cracked.

Treasury.

15. A large fissure opened beneath the houses along one side of the bazar, running roughly parallel to the river bank, in a westerly direction. From this a large quantity of sand was ejected, filling the interior of the houses up to the eaves. The surface of the ground then subsided, carrying the houses with it, so that the roofs are now resting on the sand (Plate XXII, fig. 1). A view of the fissure at the eastern end of the bazar is given in Plate XXII, fig. 2. A well, seen at the left hand side of the picture, was entirely filled with sand, which was ejected with such violence that the wooden cover of the well is said to have been hurled through the air to a distance of several yards.[1]

Bazars.

16. The Telegraph Office was destroyed entirely at the beginning of the shock and the time was not noted.

Time of shock.

17. At the time of my visit slight shocks of earthquake were very frequent. As a rule each shock was accompanied by a more or less distinct booming sound, apparently proceeding from the south-south-east, and generally heard slightly in advance of the shock. Frequently the sounds were heard without any shock following, and they then resembled very closely the well known "Barisal Guns," though they were not so sharp and well defined as I have heard them in the south-western portion of the Garo Hills.

Subsequent shocks.

18. **Gauhati.** The clock at the Telegraph Office stopped at 5-15 P.M., local time, which is 46 minutes in advance of Madras time. The clock is said to have been correct within one or two minutes. The pendulum was broken by the shock.

Time of shock.

19. At the head of the steps leading from the bungalow to the river bank, two low brick pillars, supporting a wooden railing, have fallen to S 30° E and S 40° E, respectively. These were 3 feet 6 inches high by 1 foot 7 inches by 1 foot 1 inch on sides, the longer sides facing south.

Deputy Commissioner's bungalow.

20. At the entrance were two large gate pillars, on either side of the gateway facing west-south-west, 10 feet high and 2 feet 5 inches square. One of these has broken through at 2 feet

Commissioner's bungalow gate pillars.

[1] See p. 104.

9 inches from the ground and twisted 6°, from N 24° W to N 30° W. The other pillar is broken through at the same level but is not twisted.

Old Dák bungalow gate pillars, Pl. XXI, fig. 2.

21. Of the four gate pillars at the two entrances to this bungalow,[1] three are broken off and twisted in the same direction as that mentioned above. The fourth pillar has fallen to S 20° W. These pillars are all built of brick masonry.

Civil Surgeon's bungalow gate pillar.

22. The coping of a small gate pillar in the compound wall of this bungalow was shot off and is now lying on the ground at a distance of 4 feet 4 inches from the centre of the pillar. The direction in which it was thrown was S 35° E.

Commissioner's and Deputy Commissioner's cutcherries.

23. Both the cutcherries were wrecked, but a great portion of the roof of each is standing, merely the walls having fallen. The Commissioner's cutcherry is shown in Plate XX, fig. 2. The roof of this was partly supported by strong wooden posts. The Deputy Commissioner's cutcherry (Plate XX, fig. 1) is in the form of a cross with equal arms facing the four points of the compass. The roof was partially supported by round brick pillars, which, though cracked through, have not fallen. The weathercock, seen in the photograph, was an effigy of a peacock and has tilted over to the north, so that its tail is hanging down beside the rod supporting the letter N.

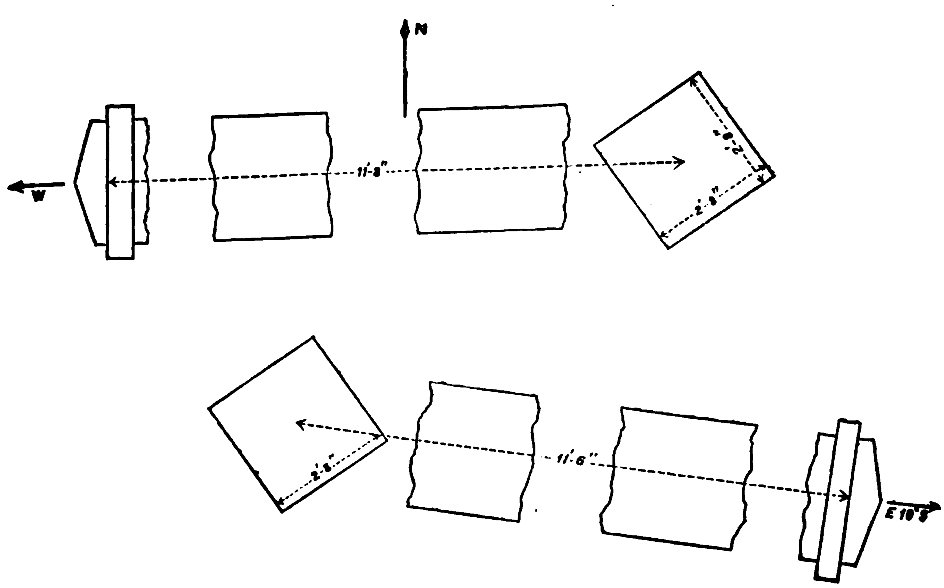

Fig. 27. Plan of overthrown gate pillars at Gauhati.

[1] This is the same building as the Telegraph signallers' quarters mentioned in Chapter XIV.

24. On the west side of the Deputy Commissioner's compound a low wall runs along the road, on which stood a balustrade of clay pilasters supported by pillars at intervals of about 11 feet. Nine of these have fallen, most of them to about S 20° E, one to N 70° W and another to N 35° W. The wall runs E 32° N, W 32° S. One of the pillars has broken off at the top of the wall and twisted, without falling, 10°, from N 25° W to N 15° W.

Compound wall.

At the gateway at the east end of this wall both pillars have fallen, one due west, the other to E 10° S (see fig. 27). At the western gateway there were similar pillars which have broken off at the height of the top of the wall, three feet from the ground, and fallen, one due N, the other to N 20° W.

25. Most of the tombs here are of the common square or oblong box shape built of brick masonry and plastered. That of G. T. Bayfield, died September 1840, was surmounted by an obelisk, the greater portion of which has fallen to S 20° E. A similar obelisk close by (F. Gomes, died September 1848), has fallen to S 25° E. The monument shown in Plate XXI, fig. 1, is of precisely similar construction, but in this case the obelisk is broken across at about half of its height, and the upper part has twisted 48°, from N 18° W to N 30° E. Close to this are two tombs standing on a common plinth and precisely similar in all respects, but instead of conical obelisks they were surmounted by cylindrical brick pillars 1 foot 6 inches in diameter and about 4 feet high. Of these one has fallen to N 45° W while the other has gone exactly at right angles to this, *viz.*, to S 45° W. Both pillars have been entirely broken up by the fall, but in the first case the base of the pillar is lying at a greater distance from the base of the tomb than the rest of the pillar. The tomb measures 3 feet square by 4 feet 6 inches high, and the base of the pillar is lying at a distance of 12 feet from the corner of the tomb nearest to it. The top of another obelisk (Samuel Fleming, died May 1853) has fallen to N 45° W. The lower part of the tomb on which this stands is also cracked through, at a height 1 foot 7 inches from the plinth. This tomb measures 4 feet 9 inches high by 2 feet 9 inches square.

Old cemetery.

Only one of the more recent tombs has been affected by the shock (Miss Lamb, died April 1875). This is a small marble pedestal standing on a brick plinth and surmounted by a cylindrical marble pillar 3 feet 5 inches high by 11½ inches diameter. The pillar was thrown off to the south and fell, without striking the low railing surrounding the tomb, and is now lying pointing east and west at a distance of 8 feet 6 inches from the centre of the pedestal. It may have rolled somewhat after touching the ground.

This cemetery is situated on the alluvial ground to the south of the station.

26. The new cemetery is situated on the flanks of a low hill of gneiss to the east of the station, and has suffered little or no damage from the earthquake, except that the wall surrounding it has fallen at the north-west and north-east corners and near the south-west corners. A marble slab on the tomb of R. J. Eades, died 1884, is cracked across the middle, the crack running N 10° E.

New cemetery.

Railway station.

27. This is a perfectly new brick building, but is greatly damaged by the shock. It faces S 10° E. The centre gable has fallen out on both sides of the building to south and north respectively, the brickwork having broken up into large masses. The end walls east and west are cracked but standing, the cracks running diagonally in both directions, north and south, at an angle of about 45°, from the corners of the windows in centre of walls.

Old temple near steamer ghat.

28. This Temple is an octagonal building with a domed roof, built of tiles, 9 inches × 7 inches × 1½ inches in size. The sides facing E 15° S and W 15° N have fallen outwards altogether, and those facing north and south are partly fallen.

Pucka ghat at the steamer landing.

29. This is a brick structure with a flat roof supported by numerous arches with minarets at each corner and on either side of the large central arches. The larger side, towards the river, faces west. Only one of the minarets has fallen, that on the north side of the central arch towards the river. This has fallen due west. The two side arches at each side of the central arch, and those at each end of the building, are cracked at the crown.

Bridge on Grand Trunk Road west of Gauhati.

30. At the western end of the Gauhati Bazar is a bridge of three girders carrying the Grand Trunk Road over a small stream, which here joins the Brahmaputra. The original length of the bridge, as measured along the hand rail, was 99 feet 4 inches, while the present length, between the same points is 97 feet 10 inches. The bridge has therefore been shortened 18 inches. This has been caused by fissuring of the banks on both sides of the stream, the abutments having been carried forward. One of the piers has been tilted over, probably by the thrust of the girder. There are no cracks in the abutments.

Temples at Gauhati north.

31. On the north bank of the Brahmaputra, opposite Gauhati, are some old temples standing on a rocky promontory immediately over the river. These were built of tiles similar to those in the temple above mentioned. All except one, which is at the base of the promontory close to the water, have fallen, the tiles having slid off each other in all directions. The dome of the one which is standing is split through the middle, the crack running N 15° E and vertical.

A small structure consisting of a corrugated iron roof supported by four low brick pillars, erected over a lingam near the temples, has fallen over bodily towards E 10° S.

Effect of earthquake in districts.

32. The accounts of the earthquake received from the surrounding country all speak of fissures opening along the banks of rivers and consequent subsidence of the surface, also of quantities of sand being ejected, filling up the beds of rivers and jheels and causing floods. The Sub-Deputy Collector of the Borpeta Circle says that, while he was proceeding by boat down the Singur river towards Borpeta, which lies to the west-north-west of Gauhati, he heard, when near Kahi Kuchi, a low rumbling noise occasionally, apparently coming from the direction of the

Garo Hills, to the south-west. The shock was immediately preceded by a noise of the same kind. The river became filled with sand, and the water flowed over the surrounding country. At Borpeta the water continued rising till the 19th June and the station was flooded.

At Patti Darrang, 10 miles to the north of Gauhati, an old stone bridge, said to have been built by the Mohamedans, has fallen.

At Hazu, 16 miles west-south-west from Gauhati, the Mahdub or Madhava temple,[1] said to have been the oldest in Assam, has also been destroyed.

33. **Tezpur.** The time at which the shock occurred was not observed in the Telegraph Office here.

Church.

34. The east wall of the Church has fallen outwards. The north and south walls are considerably cracked. The cracks run vertically upward from the crowns of the arches over the windows. At the western end of the Church is a small belfry supported by tall wooden posts let into a brick-and-cement plinth, raised 2 feet 9 inches above the ground. The posts have rocked from east to west, forcing out the bricks and cement at the edge of the plinth opposite to each post.

Cemetery.

35. In the Cemetery very little damage has been done and no good measurements could be obtained. An inverted *ghurra* on the top of a square pillar 8 feet high, has fallen over to south, and an obelisk on another tomb has been cracked through at about one-third of its height from the top, the plane of the crack dipping slightly to south-west.

A large pillar on one side of the gateway, measuring four feet square, has fallen to pieces, the greater portion having gone to the west. The corresponding pillar is badly cracked but standing. These were built of very loose masonry.

General remarks.

36. Beyond the cases above mentioned I could find no overthrown gate pillars or anything of the kind which would enable one to determine the direction of the shock at Tezpur. The banks of the river here were not fissured, and I did not notice any fissures to the east of Mangaldai. Numerous large fissures are, however, said to have occurred at Nowgong.

37. **Assam-Bengal Railway.** I went out along this line as far as the bridge over the Kopili river, about 41 miles from Gauhati. The rock cuttings, in gneiss, have not been affected in the slightest degree by the shock, but where the line passes over alluvium, the embankment has settled down carrying the rails with it. Many of the culverts are badly cracked, apparently from the same cause as has affected the bridge mentioned above at Gauhati, *viz.*, the fissuring of the banks of the streams and the consequent sliding forward of the abutments and wing walls. The piers of the large bridge over the Kopili are cracked through horizontally at about 2 feet above the ground level, and the girders have shifted lengthways on top of the piers. This bridge runs east to west.

Telegraph Office.

38. **Shillong.** The time of the shock on the 12th June was not observed accurately, but it is said to have occurred at 5-15 P.M., local-time. Since the first shocks occurred the signallers have amused themselves by telegraphing a certain signal to Gauhati or Sylhet, whenever

[1] This temple was built in 1672 Saka, under orders of the King Pramatta Singha.

they happened to be at the instrument and felt a shock, at the same time receiving a signal from either of those places, if the shock was felt there. The Telegraph Master assures me that in all cases the shocks are felt absolutely simultaneously at these places. I asked him to note the exact second at which a shock was felt in Shillong, and to ask the signallers at Gauhati and Sylhet to do the same, but he assured me afterwards that no difference could be detected.

He also informed me that an Assistant was sent down to Nongpoh, on the Gauhati road, as soon as possible after the shock of the 12th June, to restore communication with Gauhati. On attempting to signal through a single wire, with return circuit through the ground, it was found that as each earthquake shock occurred the current was interrupted, or even reversed. What is called a "closed circuit" was being used, that is, the current was kept continuously flowing through the wire, and interrupted by the key only at the moment of sending a signal. Apparently the earthquake shocks set up currents in the earth, for, when a second wire was used instead of the earth as a return circuit, no effect of the kind was observed.

Cemetery.

39. A large number of the monuments in the cemetery were affected by the shock. The cemetery lies on a spur at the west end of the station, the ground sloping at an average angle of about 7° to south and south-west. The greater number of the monuments, of which plans are given, lie close together on the more level ground on the crest of the spur.

Major Willans, d. July 1886.

This is a marble slab, 4½ inches thick, resting on a plinth of quartzite.[1] The slab has been jerked towards E and at the west end, slightly to S.

G. R. Nicholls, d. May 1889.

A marble slab, carved into a cross, resting on a quartzite plinth. The movement of this has been towards S-E.

Mrs. Maxwell, d. February 1889.

This is a granite cross standing on a base of the same rock forming three steps, the lowest of which is tilted to E at an angle of 2° 50", while the upper two have fallen over with the cross and are still attached to it.

Mrs. Spring, d. December 1885.

This is a similar cross but built of marble. The lowest step has tilted over at an angle of 8° 30', the next has slid off and is resting against it, while the cross with the topmost step attached has fallen to E.

Mrs. Rossenrode, d. July 1885.
Pl. XXXVIII, fig. 2.

This is a small marble pedestal, resting on a plinth of quartzite slabs covering the grave, and supporting a small marble cross. The pedestal has twisted round 26°, the eastern side now facing E 26° S. The cross has fallen and is lying in the position shown at the foot of the pedestal.

Mrs. Walker, d. July 1885.

This consists of two marble slabs, the upper one carved into a cross. The lower slab has tilted over to S, at an angle of 10°, and the upper one slid off in the same direction.

[1] The quartzite, of which all the plinths and some of the tombs are built, is quarried from the quartzites of the Shillong series in the neighbourhood.

Mrs. Sherriff, d. August 1881. Pl. XXXVIII, fig. 3.

This is a similar tomb to the last, but in this case both slabs have been jerked to the north-east. The upper one then slid off and is lying beside the lower.

Captain Maitland, d. April 1873.

This is a marble cross standing on a marble pedestal, supported by four narrow strips of marble. One of these strips on the southern side has been jerked to S-W and the pedestal has slid off to S. The cross then fell over to S 15° W, the top of it catching on the railings of the adjoining tomb.

Douglas Gray, d. June 1879.

This is a small dome-shaped marble slab supported on a quartzite plinth. The slab has been jerked to S E.

Captain Cookesley, d. April 1872.

This is a freestone slab carved into a cross, resting on a thinner slab of similar material, the whole supported on plinth of quartzite blocks. The lower slab has moved two inches to E, while the upper has moved three inches further in the same direction, and has been jerked off to S, the edge of it resting on edge of the plinth.

Mrs. McCulloch. Pl. XXXVIII, fig. 4.

A marble slab with cross carved upon it, resting on a quartzite plinth. The western end of the stone has been jerked round to S, while the eastern end has hardly moved.

C. A. Eglinton, d. June 1892.

This is also a marble slab, similar to the last but supported on four oblong strips of marble. The slab has been jerked to N E, while the strips at the W and S sides of the grave have gone in the opposite direction.

Small tomb without date.

A small marble cross three inches thick lying on a quartzite plinth. The cross has been jerked its own width due S.

Alfred Goldney, d. July 1881.

This is a small freestone slab carved into a cross resting on a quartzite plinth. The slab has been jerked towards S E.

R. D. Prazer, d. June 1884. Pl. XXXVIII, fig. 1.

In this case the marble slab carries a small marble cross, supported on three steps near the west end. The cross has not fallen, but the west end of the slab supporting it has been jerked to the south, being twisted through an argle of 15°.

Miss F. Fitzpatrick, d. October 1888.

This is a large marble slab resting on a quartzite plinth. It has been jerked about two inches to E, and the eastern end has moved slightly to south. This tomb lies on the slope of the spur near the south-east corner of the cemetery.

Rose Skene.

This is a small tomb consisting of two oblong blocks of quartzite with a small marble cross let into the centre of the top. The blocks have been jerked towards S rather more at the western end than at the other.

Cecil Skene.

This is a similiar tomb to the last, but in this case there are four blocks of quartzite covering the slab supporting the cross. The whole have been jerked in the same direction as the other, but the block on the south has separated from the others and fallen over the edge of the plinth.

At the top of the cemetery near the north-east corner three crosses have fallen due W and broken up. The headstone of another grave near these has broken off a few inches above the ground and fallen to E.

Fenton's Hotel gate pillars. Pl. XXXIV.

40. The pillars on either side of the gateway are built of cubical blocks of stone with a heavy stone coping, facing the four cardinal points very nearly. That on the south side of the gateway has fallen due N. The other is standing, but has twisted about 5°, from N8° E to N3° E. The cubes have each an iron pin let into the centre, which fits into a hole in the cube above.

Inglisby gate pillars.

41. These pillars are similar to the last, but the blocks measure 16″ × 16″ × 10″ and the coping 21″ × 21″ × 3″. One of them has fallen to N10°E. The other has not fallen in any particular direction, but the stones are lying scattered round the base. These pillars were not able, however, to fall freely, as the wire fencing surrounding the compound was attached to them.

Two pillars on the opposite side of the road from this house, built of oblong blocks of stone, have both fallen due S.

Ashley Hall gate pillars.

42. These were two pillars built of rubble stone masonry, the longer sides of each facing north and south. Both have fallen, the one due N and the other due S.

Beauchamp Lodge gate pillars. Pl. XXXIV.

43. These are two strongly built pillars of cut stone. neither of which has fallen. They are both a good deal shattered near the base, and the one on the western side of the gateway has shifted bodily above the second course from the base to the north-west, twisting slightly, from N15°E to N18°E, at the same time. The other pillar has also twisted, the greatest amount of twist having taken place between the 4th and 5th courses from the base, from N15°E to N19°E. The lower seven courses of this pillar are more or less shattered. Each pillar supports a heavy iron gate, which was standing open at the time of the shock.

Col. Macgregor's house gate pillar.

44. One of the pillars of the gateway of this house, built of squared stone blocks, has fallen to N 10° W, the pillar faced N 40° W, and was 5 ft. 2 in. high by 2 ft. square. The corresponding pillar to which the gate is attached is much shaken but has not fallen.

Other gate pillars.

45. Of other pillars of which I was not able to get the dimensions, as they have broken up entirely, the directions of fall were—

(1) S 5° E.

(2) S 25° W ? stones probably moved since fall.

(3) S.

Willans memorial. Pl. XXXIII.

46. The Willans memorial stood in the club grounds, and consisted of a square pedestal supported on two steps, and surmounted by an obelisk. The whole was built of blocks of Shillong quartzite. The apex of the obelisk, which was a square

pyramidal stone measuring about 1 foot on sides, had been carried from the position in which it fell before I saw it, but I was able to identify four of the blocks immediately beneath this, and the positions in which they fell are shown in the plan. The three blocks seen in the sketch on the top of the portion of the pedestal still standing are twisted slightly towards the east.

Bridges on Gauhati Road.

47. The large bridge on the Gauhati Road about 1½ miles from Shillong, over the Umkra river, has suffered severely. The abutment on the south-east side fell entirely, carrying the girders with it. The two piers and the abutment on the north-west side, which are of more recent construction, remained standing, though somewhat cracked. It appears that the piers were recently widened and that the vertical cracks near the lower sides of them occurred at the junction of the newer and older masonry.

Landslips, Pl. III.

48. Numerous landslips have occurred along the steep hill sides between Shillong and the crossing of the Umiam river, 8 miles from the station. At the Bishop's Fall, about 2 miles from Shillong, the precipitous cliff on the right of the fall, down which the path was carried, slipped down entirely into the basin at the foot of the fall. The crest of the fall was not affected, as it is formed by a strong dyke of diorite. The nearly vertical quartzites have been shaken away from this dyke. Some fine slips are seen on the hillside facing the fall. A view of these is given in Pl. III.

Khasia monoliths.

49. At the Khasia Bazar at Maokhar, just outside Shillong on the Gauhati road, was a collection of the large monoliths of quartzite set up in former times by the Khasias as ancestral memorials. Several of these have fallen, the majority between W and S W, but one or two have fallen due N. Some of them are broken through at ground level or a foot or so above it.

Khasia monoliths.

50. **Maophlang**. At the Dâk bungalow at Maophlang, 14 miles to the south-west of Shillong, there were four large monoliths in a line running W. 30° S to E 30° N. Two of these have fallen, both to S 30° W. One of these was 20 feet high by 4 feet 3 inches broad and 9 inches thick at the base, slightly tapering towards the top. This has broken off at 2 feet from the ground. The other was 14 feet high and has broken off at ground level.

Reported change of level in hills.

51. Mr. Evans, the Missionary at Maophlang, informed me that soon after the earthquake his attention was called by one of his converts, a Khasia, to the aspect of the hill immediately to the west of the village. These hills are separated from that on which Maophlang stands by a deep valley, through which one of the tributaries of the Bogapani runs. It appeared to them that beyond the hill on the west side of this valley they could see more of the distant hills than before, and they came to the conclusion that the intermediate range of hills had subsided. The furthest peaks they can see from Maophlang are some four or five miles distant. Of course an elevation of the more distant hills, or of that on which they were standing, would produce the same apparent effect as a subsidence of the intermediate hills

and if any change of level has taken place, I should think it more likely that it would be elevation than subsidence. The hills to the west of Maophlang, judging from the number of landslips visible, have evidently been very severely shaken.

Road to Cherrapunji.

52. The Khasia path from Maophlang to Cherrapunji, which is part of the old main road across the hills from Tharia Ghat to Gauhati, has not suffered much, as it usually avoids the side slopes of the hills. The cart road, however, from Shillong to Cherra has entirely disappeared in places, wherever it was carried along the edge of the scarps above the stream, which runs in a deep gorge to the east of Cherra, and is everywhere badly fissured.

David Scott's monument.

53. **Cherapunji.** The monument erected by the Supreme Government to the memory of David Scott is a very massive structure, built of large squared blocks of sandstone, bound to each other with iron clamps. The upper portion of the obelisk has fallen, mainly towards the S W, but some portion has also fallen towards N N E. One of the loosened stones is still lying on the top, overhanging the southern side by about $\frac{1}{8}$ of its length. The whole monument above the two steps at the base has moved bodily towards S W. The stones of the lowest course of the pedestal have been shaken apart from each other, the one on the west side having been jerked out to the edge of the step below.

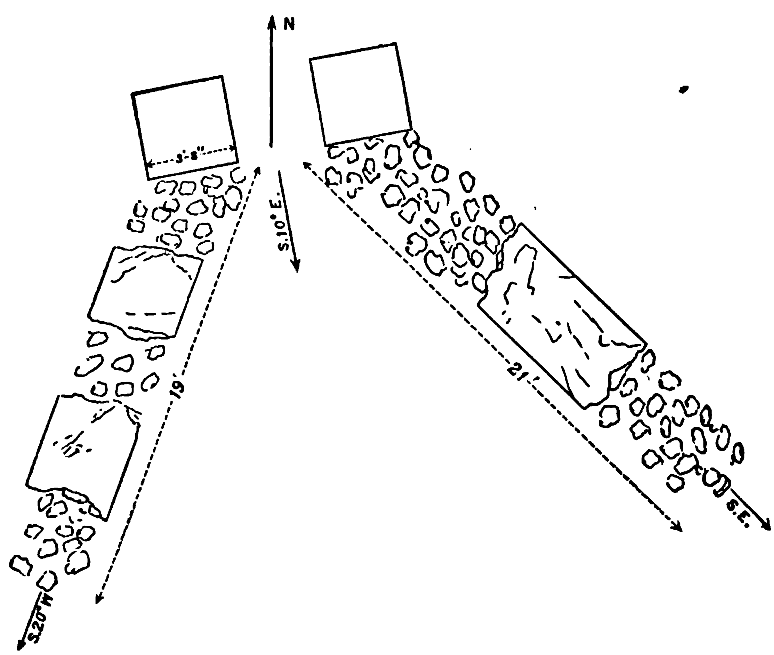

Fig. 28. Plan of overturned gate pillars at entrance to Inglis' house, Cherrapunji.

54. At the entrance to the avenue leading to Mr. Inglis' house stood two lofty gate pillars, which formed a conspicuous object in the land scape. No gates were attached to them. They were built of rubble stone masonry. Both have fallen, but in different directions, as shown in the plan, fig. 28. The material of one lies scattered to a distance of 19 feet from the base of the pillar, and the other to 21 feet.

Mr. Inglis' house gate pillars.

Close to the gateway of the house a small stream crosses the road, over which, when the house was inhabited, a small aqueduct was carried on a series of brick pillars. One of these on the edge of the stream has fallen, and the corresponding one on the other side has cracked across at the base and twisted through 5° from N 25° E to N 30° E. The pillars are built of brick.

At the gateway leading into the compound of the house an ornamental pillar standing on the wall surrounding the compound has broken across at the top of the wall and twisted through 5° from N 54° E to N 58° E. The height of the fracture from the ground is 4 feet 6 inches. The two gate pillars have fallen in a heap in the gateway, that on the east side having fallen to south-west. These pillars are built of rubble stone masonry.[1]

55. On the road from Cherra to Maosmai, there are two gate pillars, one of which has fallen to N 50° E, while the other is not even cracked. These are cylindrical, 2 feet in diameter and 7 feet high, built of rubble stone masonry.

56. All the tombs are of the oblong form with sloping tops common 50 years ago, and are all built of rubble stone masonry. Very few are broken up, but nearly all have sunk down into the loose sand beneath them, and are leaning over at various angles to the north. The cemetery is situated on the top of one of the small knolls of sandstone which are scattered over the Cherra plateau. This sandstone originally rested upon the limestone of the plateau, which has been dissolved away from beneath it, and is accordingly much broken. The earthquake seems to have shaken the surface down into a perfect quicksand, into which the tombs sank.

Cemetery. Plate V.

57. **Maosmai.** At the village of Maosmai, on the edge of the cliffs about 3 miles south of Cherra, there are two well known groups of Khasia monoliths of unknown antiquity, from which the village takes its name (the stones of the oath of allegiance). In each group there are five stones ranging from about 12 to 18 or 20 feet high. They stand in a line facing due east on the edge of the stream running through the village. I found that one stone in each group had fallen, in each case due W.

Khasia monoliths.

In the larger group the fallen stone measures 14 ft. × 3 ft. × 1 ft. In the smaller 12 ft. × 3 ft. × 1 ft. They were let into the ground to between a foot and 18 inches.

58. I asked the missionaries both at Cherra and Maophlang, whether it was likely that, in case any of these monoliths, which are found all over the hills, had been overthrown by a former earthquake, the Khasias would have set them up again. They said that it might be done in the case of well known and venerated stones like those at Maosmai, but in ordinary cases, where they were put up by the members of a family in memory of an ancestor, no one after a generation or two

[1] For plans of these two pillars see plate XXXV.

would take any care of them. It seems then that as the erection of the monoliths must date back to a remote antiquity, and as the Khasias have for generations neglected the custom of putting them up, no shock at all comparable to that of the 12th June last can have visited the country for very many years.

59. Sylhet. The Telegraph Master can give no accurate information as to the time the shock occurred, but says that it was between 5-15 and 5-20 P.M., local time, which is 47 minutes in advance of Madras time.[1]

Time of shock.

60. All the public buildings in Sylhet suffered more or less, but many of them are still standing. Several are built on a narrow strip of land between the bank of the river and a large tank, the Nawab Talao, and it is likely that they were affected quite as much by settlement of the ground as by the shaking they received. Since the earthquake occurred many of the cracks in these buildings running parallel to the edge of the river or tank have opened out, more than at first, which fact certainly points to a gradual settlement of the soil.

Public buildings.

61. This pillar stood at the head of a flight of steps leading down to the water at the north-east corner of the Nawab Talao. The corresponding pillar at the other side of the steps has not fallen and is not even cracked. The fallen one broke off at ground level, and apparently fell in a northerly direction, but struck the wall on that side and rolled off to the west.

Pillar at side of Nawab Talao.

A gate pillar at the side of the road near the Government School fell towards N40°E and broke to pieces in the fall. Another near the Deputy Commissioner's bungalow fell due N.

62. The cemetery is situated on a low knoll near cantonments, and about 3 miles north of the river bank. Very few of the tombs have been damaged by the shock. They are nearly all fairly old and built of brick masonry.

Cemetery.

A tomb near the east wall, without any inscription. It was surmounted by a plaster urn fastened to the top of the tomb by an iron wire. The urn has fallen over to S 25° E and is now lying on top of the tomb.

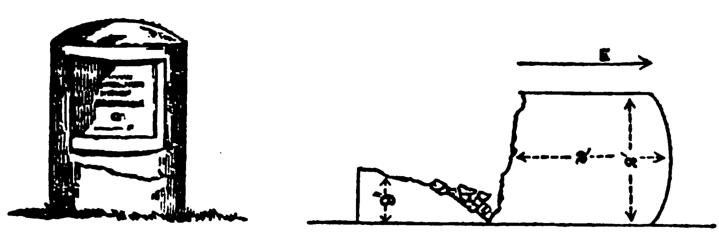

Fig. 29. Overturned tomb in Cemetery, Sylhet.

[1] A clock in a small tower near the river fell with the tower and stopped at 5-15 P.M.

A low brick pillar, fig. 29, built of bricks rather loosely put together. The pillar broke across at about 9 inches from the ground and fell due east.

A small brick pillar 2 feet 7 inches high by 1 foot 2 inches in diameter to the north of the last has fallen due south. The top has turned over in its fall and is lying 3 feet from the centre of the pillar. A portion of the side is lying further away in the same direction at a distance of 5 feet from the pillar.

A square column at the south side of the Cemetery has fallen due south-west and broken up almost entirely. The pillar was probably about 4 feet high and has broken off at 18 inches from the ground.

Cantonment.
Hindu temple.

63. The cantonment was situated on some rising ground to the north-west of the Civil station and nearly a mile from the river bank. A Hindu temple near the hospital, the four sides facing the cardinal points, has been cracked in a curious way as shown in fig. 30, the cracks running diagonally from corner to corner of the base. On the sides facing north and south a horizontal crack runs along at the top of the base beneath the dome. On the west side there is an arched door-

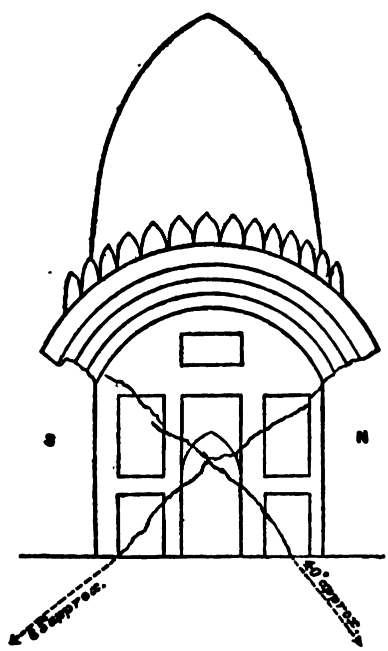

Fig. 30. Hindu Temple in cantonments, Sylhet.

way and two cracks run diagonally upwards from the crown of the arch to the base of the dome. The wall surrounding the temple has fallen in the north and south sides, in each case to south, but is standing on the east and west.

A gate pillar at the foot of the hill on which the hospital stands has broken off at ground level and fallen to W 18° N. It stood at the end of a culvert, the wall of which may have interfered with its fall. The corresponding pillar on the other side of the culvert is not cracked. Both are built of brick masonry, 1 foot 10 inches square. The broken piece is 5 feet long.

Vertical boiler overturned.

64. At the entrance to the bungalow occupied by the Executive Engineer, on the main road leading north and about a mile from the station, was a well from which water was pumped by an engine with a vertical boiler. The boiler has fallen over to W 30° S. Its dimensions are, height 7 feet 9 inches, diameter 3 feet 6 inches; chimney of sheet iron, height 4 feet, diameter 10 inches.

Church gateway.

65. The Church has fallen entirely. At the gateway in the east wall were two large pillars of brick, both of which have partially fallen. The one on the north side of the gateway apparently fell due north, struck the churchyard wall and rolled off to east. The other fell towards W 20° S.

The churchyard was surrounded by a low wall on which stood a balustrade of clay pilasters, supported by brick pillars at intervals. On the walls facing north and south these have nearly all fallen to the south, but on the east and west walls they are standing.

Fissures in banks of rivers and jheels.

66. **Sonamganj.** Everywhere in Sylhet, so far as I saw, the banks of the rivers are fissured for some distance from the edge, in the same way as those on the Brahmaputra. At Sonamganj, where the river runs nearly due west, I noticed a considerable difference in the way in which the shock had affected either bank of the river. On the north side a large slice, some 50 or 60 yards broad, had been detached and slipped forward and downward, the portion furthest from the river sinking more deeply than the edge of the bank, so that there is now over 30 feet of water over the inner edge of the slipped portion, while over the former edge of the bank the depth is only 8 or 10 feet. As the houses are built close to the edge of the bank, this being the only ground in the country that is above the usual flood level, they were carried down, and the inhabitants, to the number of about 40 were drowned. On the southern bank, however, there was no subsidence of this kind, but the ground was fissured to a distance of 30 or 40 yards from the edge of the bank by a number of cracks running parallel to each other and to the bank. It seems that on the north side the bank was not sufficiently supported by the water and so slid forward, but at the moment of the shock the water was violently driven over to the south side of the river and supported that bank.

Probable results of the fissuring of the banks.

67. At the time of my visit to the country round Sylhet, the rivers were in high flood, the water over large areas overflowing the banks. So long as they remain full it is probable that the banks will not slip down, since they are supported by the water. But as the rivers fall it is almost certain that the fissured portions of the banks will slip down, at any rate until they attain their former slope. A large amount of silt will thus be thrown into the bed of the river, far more than the water, with its diminished velocity during the cold weather, and its very slight fall, will be

able to carry away at once. It is extremely likely therefore that when the rivers rise again next rainy season, if the rainfall should be normal or at all above the normal, unprecedented floods will occur, and it is possible that considerable changes may take place in the course of the rivers. Moreover, as a consequence of the enormous landslips that have occurred in the hills to the north of the Surma valley, the hill rivers are bringing down an enormous quantity of silt, and this will tend to raise further still the beds of the rivers in the plains. I have already called the attention of the Chief Commissioner of Assam to the possibility of there being very high floods in Sylhet next year.

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2. Report by MR. H. H. HAYDEN, *Assistant Superintendent, Geological Survey of India.*

CALCUTTA, NORTHERN BENGAL.

Calcutta.—The area dealt with in the following notes includes the parts of Calcutta lying in the neighbourhood of Theatre Road, Park Street Cemetery, Lower Circular Road, Harrington Street, and a portion of Alipur Lane. The notes refer almost entirely to the effects of earthquake on the houses comprised in the above areas; many of the places to be referred to were visited by me in company with Mr. LaTouche, who has, no doubt, already handed in the chief observations of scientific value.

As regards the direction of the shock as shown by fallen objects; observations were taken of the direction of fall of the Cathedral spire and portions of two tombs in Park Street old cemeteries, with a few of minor importance, chiefly relating to the fall of portions of walls. Measurements, etc., were made by Mr. La Touche, relating to the Cathedral spire and certainly to one of the monuments in Park Street Cemetery, *viz.*, that of Sir Wm. Jones. The other tomb was also examined by me in company with him, but having noted down the results myself, I shall give them here in case he has not already done so. The monument is in the northern part of the Old Park Street Cemetery, and is that of Mrs. Mary Ann Wiltshire (1822). It is a massive cuboidal structure, built of brick and mortar, and having a somewhat pyramidal upper portion, which was surmounted by an urn. This urn, which was merely made of plaster built upon a cylindrical iron rod, was thrown down to S $24\frac{1}{2}°$ W. Another monument in Park Street old cemetery is of interest owing to the fact that, although probably broken previously to the earthquake, yet it did not fall owing to the shock. Although it was carefully examined by Mr. LaTouche and myself, we could find no indications of the fracture being a recent one; in fact, it had every appearance of having been in the same condition for some years.

Among buildings, the worst falls in this neighbourhood took place at No. 8, Circular Road, and No. 44, Circular Road.

At No. 8, Circular Road, much of the northern side of the house fell out to the north, while very bad cracks also ran through the house from north to south.

The Baptist Chapel, No. 44, Circular Road, was badly damaged, and the roof of the porch fell in. The building faces E 7° N.

The porch, which, according to the Baptist Minister, was a subsequent addition made about the year 1850, was in reality little more than a "lean-to," that is to say, it was not bonded into the main portion of the chapel, but was merely built against it, the beams only being built into the main wall. Consequently after the shock took place, the periods of vibration of the main building and of the porch being different, these two structures must at some particular moment have been vibrating in opposite directions; the result of this was that while these two elements were travelling away from one another, some of the wooden beams supporting the roof of the porch and running nearly east to west drew out and fell down, but when the two vibrating bodies were approaching one another the beams were thrown into a state of compression. Some of the beams of the porch were of wood, while a few consisted of iron girders put in at different times to replace unsafe wooden ones. One of these iron girders furnishes ample proof of the existence of the above strain, for it has remained fixed at both ends but has been bent in the middle owing to horizontal thrusts from the ends.

The remaining observations are of no great value, referring chiefly to the fall of parapets and to the directions of cracks through the houses.

The cracks may be divided into two sets, those running north and south and those running east and west; the former would be due to the fact that the structures vibrated east to west, and the latter to vibrations at right angles to that direction: and during the earthquake the existence of these vibrations was clearly seen. A good example is found in No. 13, Theatre Road, which house I was carefully watching throughout almost the whole duration of the earthquake. When I reached the compound (a few seconds after the first tremor), I found that the house was violently vibrating east to west, and soon a crack opened through the house from north to south, and the western third of the house could be seen vibrating outwards, the large cracks opening as much as four inches and then closing again. This was observed from the southern side of the house. Suddenly, however, the motion appeared to change, the crack in the south wall ceased to open and on passing round to the western end of the house, the building appeared now to be swinging from north to south and vertical cracks began to open over windows and along lines of weakness in the west wall, but they did not gape to nearly the same extent as the large crack in the south wall. Nevertheless, judging by the fallen portions of other houses, the greatest damage was due to this second series of vibrations, for at No. 3, Theatre Road, parts of the parapet fell from the north wall. At No. 9, Harrington Street (Plate XXIII, fig. I) the parapet on the south wall (over the porch) fell, while the fall of the north wall of No. 8, Circular Road, has already been mentioned. Other examples of this are No. 6, Badeapara Lane, Bhowanipur, where an old two-storeyed house in the bazar has partly fallen, chiefly to the north[1] and the building occupied by the Asiatic Society, a skylight on the roof having been tilted through an angle of 5° to the north. At No. 6, Alipur Lane, belonging to the Raja of Burdwan, the porch, which is on the north side of the house, has come away from the body

[1] About 80 yards further to the south, however, the house at the corner of Badeapara Lane and Shambhu Nath Pandit Road has lost the south-west corner which fell out to the south-west.

of the building, and the massive brick pillars supporting it have bulged out near the base.

Examples of falls to east and west, however, are not wanting, the best being seen in the Baptist Chapel, No. 44, Circular Road, already mentioned, and the house No. 38, Chowringhee, from which much of the western parapet and a verandah on the west side of the house fell.

There is little doubt that the fact that greater damage was done to north and south walls is due to the peculiar construction of Calcutta houses; for the majority are so oriented as to obtain as much of the south breeze as possible, and consequently they are in most cases considerably longer from east to west than from north to south, and are therefore more stable in the former direction.

Calcutta to Darjiling.—Eastern Bengal State Railway, and Darjiling and Himalayan Railway.

No damage has been done at *Bagula* beyond cracks in the houses, but at *Krishnagar* many houses in the bazar were badly injured, though few actually fell. In the European quarter, the Collector's house and the house of the District Superintendent of Police were badly damaged, while a considerable part of the Joint Magistrate's house fell down. The east gable also fell out of the *kacheri*, but the Circuit House, which stands only about 50 yards away, was scarcely even cracked; this was due to the fact that it was a low building and fairly new.

Krishnagar.

The church of the London Missionary Society suffered severely and the steeple fell. This steeple, which was over the porch at the west end of the church, did not fall *en bloc*; portions appear to have been shaken off at various times, falling in ten different directions, *viz.*—

S. 27½° W.	S. 38° W.	S. 48° W.
S. 17½° E.	N. 17½° W.	N. 13½° E.
N. 38° E.	E. 22½° N.	E. 27½° S.
E. 38° S.		

The two largest masses fell to E. 27½° S. and E. 22½° N. respectively.

It would thus seem that the steeple had vibrated in almost every direction; but it is more probable that these directions are merely modifications of two principal vibrations at right angles to one another, the one being about NE to SW and the other SE to NW: and that partly owing to a resultant elliptical motion and partly to unequal resistance at different points in the masonry, apparent irregularities in the direction of overthrow were introduced.

At *Chapra*, a village 11 miles north of Krishnagar, the church steeple also fell: the main portion fell to S. 42½° E., while smaller portions fell in various directions. Pinnacles also from the corners of the church fell E. 52° N. and E. 32° N.

Chapra.

After leaving Bagula no striking effects of the earthquake are seen till reaching the *Baral* river. Here the railway bridge has been much damaged; the massive hexagonal brick piers in the middle of the river have sunk and lean over to the south-west. In one case the sinking amounted to 11½ inches and in another to 7 inches. The rails on the bridge were displaced to the west; when seen by me, they had been to some extent

Baral Bridge.

straightened, but the engineer in charge informed me that the displacement had amounted to 3 feet 10 inches, while the sinking of the piers had converted the line into a switch-back[1].

From this point onwards damage had been considerable and was noticeable everywhere, and on reaching the *Atrai* river fissures were seen for the first time; here they run almost due east and west, parallel to the banks of the river, and continue for several hundred yards, with a breadth of (on an average) 6 to 8 inches.

Atrai.

At *Atrai* railway station the buildings were badly cracked, and portions of the houses had fallen.

At *Raninagar* the ground was much fissured ; the fissures were often three hundred yards long and ran parallel to the railway, and the rails were frequently displaced.

Raninagar.

In this neighbourhood numerous huts collapsed, chiefly towards the east They were built of bamboo and thatch, and the bamboo posts had in most instances broken near the centre.

At *Sultanpur* the railway station and other brick buildings have suffered, gable walls and corners having fallen. The south western corner of the railway station fell to the south.

Sultanpur.

At *Tilakpur* several bamboo huts collapsed, but the railway station, which was a low, squat building, and apparently new, was uninjured.

Tilakpur.

At *Akhalpur* the north-west corner of the railway station fell to east-south-east, carrying with it part of the roof of the verandah.

Akhalpur.

At *Saidpur* buildings suffered badly : several houses were badly cracked and portions of walls fell, but no good indications as to the direction of the wave were obtained.

Saidpur.

Three miles beyond Saidpur the fissures were very marked. They were seen crossing the railway transversely, running north and south for many hundred yards, and often having a width of over 2 feet.

About two miles beyond *Darwani* the ground is much fissured, and the gate-house at telegraph post No. 129/22 is completely wrecked, having fallen to the east.

At *Nilphamari* railway station the fissures run north and south, and are often as much as 10 feet wide, while areas of from 40 to 50 feet long by 10 feet in width have subsided to a depth of 3 feet, and in some cases nearly 4 feet. The goods shed on the eastern side of the line was badly injured, the southern half of the floor having subsided. In places the ground beneath the rails has sunk, and rails and sleepers remain suspended.

Nilphamari.

Similarly at *Haldibari* railway station the permanent way and platform are cut up by fissures running north and south and a large portion of platform has subsided. Between the railway station and the dâk bungalow there are fissures and more or less circular holes from which, it is said, sand and water were ejected during the earthquake.

Haldibari.

[1] The bridge runs north and south.

After leaving Haldibari the line is very badly damaged: at telegraph post 161/8 the gate-house is cracked and the south wall leans outward, gaping 7 inches at the top and about 1 inch at the foot, being displaced 5° from the vertical. The fissures here run from S. 18° W. to N. 18° E. Beyond this, deep fissures, varying from 3 to 7 feet in depth, run along each side of the rails: as a rule they are from 6 inches to 1 foot in width, but in places wider, in which case the rails and sleepers are supported only by a narrow column of earth running along the centre of the permanent way.

The rails also are often displaced, the displacement being usually towards the west. In some cases the displacing force has been sufficient to break the solid steel rails, but, more frequently, fracture has taken place at the junction of the rails, the fish-plates being broken and bolts torn out.

At about half way between Haldibari and Mandalghat four telegraph posts have fallen, and point in the direction W 10° S: this observation is, however, of no great value, as the direction of fall must have been largely modified by the pull of the wires. Here fissures run transversely to the railway (S. 10° E, N 10° W), but gradually draw away from the neighbourhood of the line and strike across the open country in a direction S 9° W, N 9° E.

Mandalghat.

At about 3 miles to the south of Mandalghat the fissures gradually begin to disappear, and at *Mandalghat* railway station they are no longer seen. Between this station and Jalpaiguri small overhanging banks of drains and ditches have collapsed, but no true fissures are seen.

Jalpaiguri.

At *Jalpaiguri* some little damage was done: the post office, a two storied brick building, was rather badly cracked, while some of the inner walls of the new club, which is in process of construction, were damaged, large cracks having opened in directions at right angles to one another and at 47° to the horizon.

The only actual falls, however, took place at the District Board Office. This is a rectangular building, 24 feet high, and with a flat roof, round which runs a parapet 4′ 5″ in height; at each corner the parapet was surmounted by a solid cupola; two of these cupolas fell.

One fell in a direction S 18° E and stands upright on the ground exactly as it originally stood on the parapet.

Original height of base above ground =24 feet.

Horizontal distance through which it was projected=8ft. 6in. from base of wall.

The other cupola fell N 2½° W and lies on the roof at an horizontal distance of 9 feet from its original position; the height through which it fell — *i.e.*, height of parapet from roof=4ft. 5in. It is probable, however, that it rolled over after it fell.

Belakoba.

At *Belakoba* railway station the eastern wall of the station house is cracked at its north-east corner, while other small brick buildings in the neighbourhood have been cracked, but no serious damage appears to have been done.

Between Belakoba and Siliguri fissures again appear at telegraph-post 192/12; here they run parallel to a small river and cross the railway at right angles.

They are apparently only 3 to 4 inches wide, and are purely local, disappearing again immediately, nor are fissures again seen till some miles beyond Siliguri.

This absence of fissures between Mandalghat and Siliguri is no doubt due in great part to local peculiarities in the soil, which, from being of a light sandy nature in the fissured region, gradually assumes a dark loamy character, and it would appear highly probable that the greater tenacity of this latter enabled it to withstand strains under which the porous and ill-compacted sands gave way. A similar absence of fissures for a considerable distance along the railway to the south of Kuch Bihar will be noticed further on (p. 286).

Siliguri.

At *Siliguri* no damage appears to have been done, in fact all signs of a violent earthquake are strikingly absent: the railway station is slightly cracked, but does not appear to have suffered any damage beyond the loss of a few loose bricks; and it is not till the Mahanadi river has been crossed that we come on any marked effects of the shock. Between that river and Sukna Railway Station, however, the ground is fissured in several places, the cart road which runs beside the railway line being much cut up.

Darjiling and Himalayan Railway.—Very little damage was done at any part of this line, though many of the bungalows and tea factories on the neighbouring spurs suffered considerably. As already stated, fissures opened between Siliguri and Sukna.

Tindharia.

At *Tindharia* railway station the station building was cracked and some stones fell from the gables, while two small landslips occurred on southern hill slopes. A larger landslip occurred subsequently (June 24th) at this station, and much of the hillside below the station master's house was carried away.

Darjiling.

Darjiling.—Here the most striking effects of the earthquake are seen in the large numbers of chimneys which have fallen. Many houses, which were otherwise uninjured, have been badly damaged by the falling in of the great heavy chimney stacks which crashed through the roof, breaking everything before them. As a rule, however, they are not of much service in determining the direction in which the wave travelled.

A chimney on Collington fell to the N 8° E while the western chimney on Dr. Anderson's house on Jalapahar fell E 8° S.

At Snowy View, the front of the house fell out to the north, while most of the inner walls also fell, and a small window in the east wall fell inwards in the direction W 28° N. A small cottage a few yards below Snowy View was completely wrecked: the walls collapsed and the roof fell to the W 38° N while a window in the east wall fell out E 38° S.

Singamari was a new house built of stone and mortar. The upper part of the western gable wall fell out and several inner walls suffered badly. Cracks ran through the house from N 32° W to S 32° E.

In the old Bhutia Cemetery, on the eastern side of the Ridge and just below the Calcutta Road, several old tombs were partially thrown down. These were built chiefly of loose stones, uncemented by mortar, and having on their summits small pyramidal heaps of smaller stones, or single ovoid or conical stones propped up on end. Here one tomb fell over to the E 38° S, while the top-stones of several others are tilted to E 38° S and E 28° S.

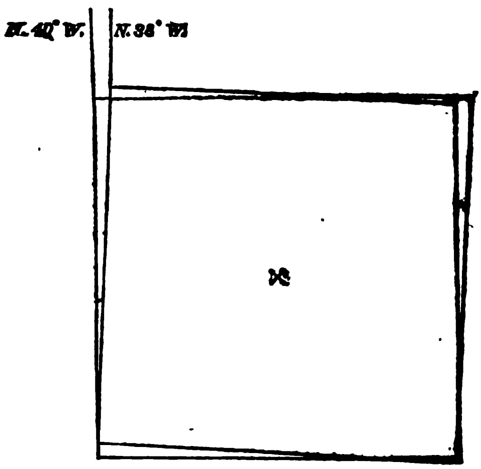

Fig. 31. Plan of twisting of obelisk in the Cemetery at Darjiling.

In the European Cemetery on the western side of the hill, below the Shrubbery an obelisk has been affected in a very interesting manner. At the plane of junction between two of the stones, the plaster has given way, and the upper portion of the obelisk has been disturbed in such a manner that it has apparently been twisted through an angle of about 2°: as shown in plan in figure 31. The monument is built of sandstone, of which a small chip gave a specific gravity of 2·485; this gives a weight of 12½ cwt. for the upper part of the monument.

As will be seen from plate XXXII, fig. 1, the chief displacement occurred at the third joint from the apex, a slight displacement also occurred at the next higher joint, but was too small to be measurable.

[In any calculations based on the displacement of this monument the factor of the adhesion of the plaster may be neglected, as the layer between the stones was not more than $\frac{1}{16}$ inch in thickness, and has now crumbled almost into dust.]

Besides the above monument a few tombstones have been affected; the ground appears to have been shaken loose, and the tombstones have sunk on one side and are now thrown out of the vertical, but this is not very marked.

The most useful observations as to the direction of wave were obtained from the old chimneys at *Senchal*, near Darjiling. These chimneys are all that now remain of the old barracks; the intervening walls have completely disappeared, and the chimneys remain as isolated towers. One of these fell completely to E 28° S: the mass of the chimney (which was originally 20 feet high) now lies along the ground up to a horizontal distance of 35 feet from the base of the chimney, but smaller stones and mortar are found scattered about in some quantity up to 51 feet, while one piece weighing 9lbs. was found at a distance of 78 feet. The piece appeared to have fallen where it lay, for the ground under it was dented and the grass killed, while the moss, with which the chimney was thickly covered was still found adhering to the stone which would make it seem highly improbable that it could have rolled.

Senchal.

A few small stones fell to W 28° N at the foot of the chimney. None of the remaining chimneys collapsed completely, but portions fell from several of them and all agree in indicating the same direction of wave, *viz*., E 28° S, to W. 28° N.

Kuch Bihar Railway.—Turning now to the railway from Parbatipur to Kuch Bihar, the effects of the earthquake are everywhere striking. At *Shampur*, the ground is much fissured and the station platform has sunk, while along the side of the railway the stone posts used in wire fencing have in many cases been snapped off at various heights above the ground : some almost at the ground, but the majority have been broken off within a foot or so of their summit.

Shampur.

These posts are made of sandstone and are usually about 3 feet high, 4 to 6 inches wide and 2 inches thick : the wire passes through holes in the stone. As a rule, the posts have not broken at the holes. The fracture is probably due to jerks and pulls of the wires as the waves passed, for it would seem impossible for such short and substantial posts to have vibrated sufficiently to produce fracture.[1]

Near Shampur also, the hexagonal brick piers of one of the bridges have been broken through horizontally, and the upper portion has shifted slightly ; this form of fracture appears to have been rather common, and though at first supposed to be of no great moment, was subsequently found to render the bridges unsafe for either rapid or heavy traffic.

Of all the places visited by me, *Rangpur* was undoubtedly that which had suffered the most damage. The railway station was not very seriously injured, but in the town itself, which is situated some 3 miles west of the railway station, almost every brick building was irretrievably damaged, while several were almost completely overthrown. A few, however, escaped with only the loss of the upper story, the lower portion being badly cracked, but possible to repair.

Rangpur.

The damage was not due so much to the actual shock as to the secondary effects of the earthquake : for the whole town being built on a loose and porous sand, overlying, at a depth of only a few feet, a substratum of waterlogged sand, the surface is everywhere cut up by fissures, which run parallel to main lines of weakness such as canals, sides of tanks, etc. These fissures have frequently opened under houses, in which case there has been differential subsidence and consequent rupture of the walls. The directions of the fissures are chiefly from E 4°—10° S to W 4°—10° N and N 4°—10° E to S 4°—10° W though some run in other directions. The first direction, however, is the more noticeable owing to the fact that it is roughly parallel to the canal, which runs through the town, and is, of course, a line of weakness.

Near all tanks the fissures run parallel to the banks, and consequently intersect at right angles, and it is owing to their proximity to a large tank that the most important buildings have suffered so severely : in fact, some of them stand between a large tank and the canal, and are completely undermined by a network of fissures, resulting in a differential movement of adjacent parts of the buildings and consequent destruction. This effect is well seen in the Judge's house and in the courts. (Pl. XXV, fig. 1.) In the case of these two buildings the chief destruction has been caused by the same fissure, which has also undermined

[1] On comparison with the effect of the earthquake in the epicentral tract of the Khasi and Garo Hills it would seem that the explanation, here rejected, might be accepted.—R.D.O.

numerous other houses in its line. Houses, however, which have not been thus built near lines of weakness have in several cases escaped with a comparatively small amount of injury, while the Raja of Dimla's house, about 4 miles to the east of Rangpur, was almost completely surrounded by tanks and consequently suffered very badly, so much so, indeed, that the Raja appeared to have given up all idea of attempting to repair or rebuild it. Indications of the direction from which the shock came were obtained from two plaster sowars[1] which fell from the gate-posts at the entrance to this Raja's palace : both fell E 6½° S.

In the cemetery at Rangpur two similar monuments were partially overthrown, but unfortunately they were close together and both fell inwards, the space between the two being filled with a confused mass of bricks and mortar, it being impossible to decide from which monument any particular portion fell; consequently no observations as to velocity could be obtained; the directions in which the monuments were overthrown were, however, E. 7° S. and W. 7° N. Other monuments were much tilted owing to sinking of the ground in some parts more than in others : this effect was seen to a greater or less degree in every cemetery visited by me.

The following is a list of the observations which give indication as to the direction of the shock :—

Plaster sowars at entrance to Raja of Dimla's palace	E. 6½° S.
Monuments ir cemetery	E. 7° S. and W. 7° N.
Pillars on east side of library verandah .	E. 4½° S.
Gate-post at entrance to Collector's house .	E. 4½° S.

This pillar fell mainly into two blocks and many loose bricks. The upper portion weighing about 7 cwt. (calculated) was completely overturned and dropped down almost vertically at the base of the wall; it lies W 4½° S of the base of the gate-post. The next piece, though it actually lies to E 4½° S of its original position, nevertheless fell, together with the top, towards W 4½° N. In fact, the pillar was broken off at 2ft. 10in. from the summit : the lower part of this fell to E 4½° S, while the upper part was split into two, of which the topmost was overturned completely and the next portion only partially so. That is to say, the pillar broke while vibrating towards E 4½° S, but owing to its inertia the upper portion was left behind and at the same time overturned, and points towards W 4½° N.

The canal being, as already stated, a line of weakness, it is not surprising to find that the banks on each side are cut up by fissures, while its bed has risen, in some cases through several feet, the central portion being now above the water : this is well shown by the bamboo bridges which have been shot up in the centre. (Plate XXVI, fig. 1.) The same effect is seen in numerous places between Rangpur and Kuch Bihar, where bridges of small span cross canals, small water channels or swamps. If the bridge has a central pier, then this pier has been thrust up and, the bridge broken. This is, however, in some cases due partly to a sinking of the abutments as well.

Similar to this effect is the silting up of wells which took place throughout Rangpur district. These wells were of no great depth, water being obtainable at

[1] Horsemen.

a few feet below the surface. After the earthquake they were found to be filled with sand. The sand is the same as that which was thrown out of the fissures, and is a rather coarse variety containing much muscovite. At Haripur, in Rangpur district, rolled pieces of lignite were said to have been ejected in large quantities with the sand: it is therefore highly probable that the sand was originally derived from the disintegration of the coarse tertiary sandstones which are seen in large quantity on the lower slopes of the nearest range of the Himalayas.

Sand was thus ejected in every part of Northern Bengal visited by me; and the quantity thrown up must have been enormous; for lines of sand, four or five yards in width, are often seen running almost uninterruptedly for miles parallel to the railway. In this sand occur numerous vents, either in the form of conical hollows or of small cones built up of sand to a height of several inches. These vary in width from a few inches to about 10 feet: the latter size is rare, the more usual width being from 1 to 3 feet. These are well seen on the Kuch Bihar branch between Teesta and Dewan Hat. The amount of sand ejected is variable but in some places it covers the ground to a depth of over a foot, as on the chur between Moghal Hat and Gitaldaha, where the railway has been buried for about 200 yards under some 8 inches of sand.

Between Rangpur and Kaunia the railway line was much damaged; the permanent way was fissured and, in places, completely undermined. Bridges are broken, that over the Monas river having been rendered unfit for traffic. This bridge consists of three steel girders supported on hollow cylindrical iron piers, and resting at each bank on brick abutments. The fissures which opened along the river bank completely destroyed the abutments, while the piers have been tilted as much as 15° from the vertical, and the ends of the girders no longer rest on them.

Monas Bridge.

All along this line, the distortion of the rails is very marked: they have been displaced and bent in an east and west direction: this distortion has usually been to the west, but in a good many cases it has taken place in the opposite direction. In a north and south direction, the ground has been thrown into a series of folds and undulations; the whole effect being that of an enormous "switch-back." Places formerly level have risen or fallen, and differences of level, often amounting to several feet, are found in the space of a few hundred yards. The effect of the motion producing these undulations has been to develop pulls and thrusts in the rails. Where they have been in tension, adjacent rails have drawn away from one another at the ends, breaking bolts and fish-plates, and where they have undergone compression, the rails have been distorted, usually in the centre, and often with such force that the rail has broken.

Returning now to the places of interest between Rangpur and Kuch Bihar, we find that at *Kaunia* much damage has been done: the transhipment-inspector's bungalow was completely wrecked, while the land in front of it was much fissured and sand and water rushed out. An interesting fact as regards the difference of period of consecutive waves is well exemplified at Kaunia: if we take a line running north and south through the bungalow just mentioned, we find that much damage has been done along that

Kaunia.

line, but on a line at about 100 yards to the west a somewhat similar bungalow has remained standing, and the other buildings along this second line have come off without much damage: further west again, we find a line of greater destruction and it is probable that, if this were followed up, we should find an alternating series of lines of destruction and of comparative immunity. Even allowing for the variable factor necessarily introduced by the difference in construction and age of the various buildings, the series of lines above mentioned is sufficiently marked to make it a matter of great probability that the destruction or escape was to a large extent due to interference.

Chaarha Hat.

Passing on from Kaunia towards Kuch Bihar, much damage has been done all along the line up to *Chaarha Hat.* For some 5 or 6 miles beyond this station, however, the effects of the earthquake are hardly perceptible, the absence of fissures being as marked in this area at it was between Mandalghat and Siliguri. The soil, too, bears some resemblance to that of the latter area, but is rather more sandy. It is, however, not improbable that the absence of fissures may in some part be due also to the large numbers of bamboo clumps throughout the surrounding country: as far as one can see on either side of the railway, the country is covered with these clumps, which, by their thickly mátted roots, bind the earth together and thereby prevent the formation of fissures: but as the railway itself is barely damaged, it is more probable that the soil is chiefly accountable for this immunity.

Dewan Hat.

In the neighbourhood of *Dewan Hat,* however, the line has suffered severely and the bridges, particularly that over the Manshai river, have been broken. At about 7 miles south of Kuch Bihar a small bridge passing over a water channel in swampy land has been damaged by the thrusting up of the central pier. At this spot also the surface of the surrounding country has been covered with sand and water, from which in many places bubbles of gas are seen rising: this gas has an unpleasant odour somewhat resembling both H_2S and SO_2, but though it was asserted by many people that the opening of the fissures during the earthquake was accompanied by a "smell of sulphur" which was popularly accredited to volcanic phenomena, it is probable that these gases are merely derived from the decaying vegetation which has in so many places been covered by the sand and water. This is the more probable as the same ebullition of gas may be seen taking place in small puddles in the fields in districts such as Krishnagar where no fissures were formed.

At *Torsa* Railway Station the station-house has not suffered, but the banks of the river have been much cut up by fissures on both sides, and have in many places caved in.

Kuch Bihar.

At *Kuch Bihar* most brick buildings have been severely damaged. With the exception of the Palace and the Superintendent's house, the principal buildings surround a large tank, and have consequently been injured by the fissures which have opened in their neighbourhood. Curiously enough, however, the building which in the whole town has suffered least is built on the western bank of the same tank. This building is the Dewan's house, but it owes its escape to the fact that it is built on a raised mound of earth which apparently acted as a cushion and enabled the house to escape with only a few cracks and with the loss of one small cupola from the parapet.

The Palace was rather badly injured, but chiefly by the fall of numerous immense turrets which carried with them parts of the adjacent walls, and often crashed through the roof carrying all before them.

The Superintendent's house was seriously injured, in fact ruined, by a fissure opening beneath it, with the result that the building was broken into two. It was, however, like many of the other buildings, built on sand, which in its turn lies on another bed of soft water-bearing sand (almost a quicksand).

The chief directions of overthrow at Kuch Bihar are:—

Palace turrets fell	S 42° E.[1]
	W 28° N.
	E 28° S.
	E 23½° S.
	E 20° S.
A marble vase in front of the palace fell .	E 20° S.
Lansdowne Hall.—Clock tower fell . .	E 18° S.
Superintendent's house.—Urn from turret fell	E 20° S.
Brick gate post	S 12½° E.
A tall brick watch-tower in the town fell .	N 8° E.
Minaret of a mosque	W 28° N.

Between Kuch Bihar and Alipur Duars the road is fissured and bridges broken, while at Alipur the western wall of the gaol fell. Between Alipur and the foot of the hills not much damage has been done, as the country is mostly protected by forest, but at Baxa (about 2,000 feet) all stone buildings were damaged, while many collapsed completely. The hill sides are everywhere scarred by landslips, and much of the road between Santrabari and Baxa was carried away. Owing to reflection of the waves, objects fell in every direction, but the prevailing direction at Baxa and the neighbouring picquets was E 48° S. Near the foot of the hills, however, a tree fell to W 38° N.

Baxa Duars.

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3. Report by the late Mr. G. E. Grimes, *Assistant Superintendent, Geological Survey of India.*

Calcutta, Eastern Bengal, Cachar.

Calcutta.—At the time of the commencement of the earthquake I was lying down reading on a sofa in a room on the top storey of No. 11, Middleton Row and the first indication of the shock which I perceived was a loud rumbling noise and a shaking of the wooden partition, as if something very heavy, much heavier

[1] The weight of this turret was calculated to be 12 tons 11 cwt. 20 lbs. It fell from a height of 38 feet, and was found lying at a horizontal distance of 26 feet from the base of the wall.

than the floor would have supported, was being rolled along the corridor just outside the room. I started up, but could not at first make out what was the matter, and it was only when I got on my feet that I felt the ground rocking underneath me. After rushing out of the house I stood in the compound on the west side, and viewed from that direction, the house appeared to be rocking in a north and south direction. A few minutes after the earthquake was over, I went into the house to see what damage had been done, and I then saw that the north-east and south-west corners of the house had suffered more severely than the other parts, and that there the walls were leaning out more than in the other corners. Besides this, the verandah on the south side of the house, which was built at a later time than the main building, was separated from the rest by an east and west crack.

On the following days I went round parts of Calcutta, chiefly in the area between Park Street and Bow Bazar Street, and also to Howrah, to examine the nature of the damage done. Within this part of Calcutta there are a large number of native bastis, the cutcha huts of which show practically no signs of being shaken by the earthquake, but scattered amongst them there are a large number of pucca houses, many of a considerable height, and most of them showing signs of age and dilapidation, but despite this the damage done was not so severe and prominent as immediately to the south of Park Street, where the houses are almost all detached and lofty; many of these are old and show signs of very frequent patching up. I made the following notes on the chief buildings affected by the earthquake :—

At St. Thomas' Church, Free School Street, there are two large cracks and several smaller ones in a north and south direction; by one of these larger cracks the chancel was separated from the main body of the church, and by the other crack the porch was separated from the church. In the Boys' Free School, which is close by the church, the cracks were at right angles to those in the church, the façade with Doric pillars of the School, which faces to the south, being damaged by east and west cracks. From the top of the spire of the Free Church of Scotland, Wellesley Street, a considerable piece had fallen, and the next day I saw it on the ground, considerably broken, near the base of the tower, and taking the position of the largest and main block of the fallen top of the spire as the position where the top had struck the ground, and there was no evidence of its having rolled to that position. I found that it must have fallen in a direction W 10° S. The tower on which the steeple is built was separated from the main building by an east and west crack. St. James' Church, Lower Circular Road, had three small minarets fallen from its steeple, but as the fragments had been cleared away, there was no evidence of the direction in which they were thrown. The other damage to the church consisted of several east and west cracks running along the length of the building. From a house just off Wellesley Square, near St. Saviour's Church, the south parapet wall had fallen into the yard below towards the south. A large pucca house at the Circular Road end of Dhurumtollah Street was very badly damaged, and the front (south) quarter of the house was separated from the rest by a large east and west crack, but the south-west corner of the house was much more damaged than the south-east corner. No. 114, Lower Circular Road (Plate XXIV, fig. 1), was very badly damaged, and the south bay of the top story had fallen out towards the south.

At Messrs. Traill & Co.'s business premises, at the back of the Great Eastern Hotel, the front portico and balcony which face to the west were completely destroyed, and at the back the eastern parapet wall had fallen over towards the east, and, after carrying away the bathroom below, had crashed through the roof of the godowns. The front part of the house in Bentinck Street, opposite the entrance to Mangoe Lane, had fallen forwards into the road (Plate XXIV, fig. 2); this side of the house faced the east, the front wall being built in a direction N 10° E—S 10° W.

After crossing the river to Howrah we see that here, as in Calcutta, a few houses have suffered very severely, whereas others quite close to them have escaped with little or no damage. The north-west corner of one of the houses facing the Howrah Green has fallen out, and the direction of the slope of the rubbish is to N 25° W. The eastern parapet wall of the next house has fallen down. The only other badly damaged house I was able to examine was that of the Deputy Magistrate of Howrah in the Grand Trunk Road. This was very badly cracked everywhere, but the south-east corner had suffered most and fallen outwards. At the time of the earthquake the Chaplain of Howrah was watching the water in the tank near his house, which was swaying violently to and fro, and the direction of this movement, which he pointed out to me, was almost exactly north and south.

Looking over the notes above, we see that there is very little definite evidence with regard to the direction of the earthquake waves, and nothing from which one can calculate its intensity. In Calcutta the fallen walls have mostly gone over towards the south or west, and the corners of the houses in Calcutta which have suffered the most are the north-east and south-west corners, and this would seem to point to a NE and SW direction for the earthquake wave, with variations from a direction N and S to one E and W. In Howrah, however, the evidence rather points to a NW and SE direction.

Dacca.—At Dacca the earthquake was felt much more severely than in Calcutta, and the relative damage is much greater; almost all the pucca buildings in the place being badly damaged, some have entirely collapsed and very many were uninhabitable.

For the direction of the earthquake wave the following are the chief pieces of evidence. In almost all the buildings the greatest damage is that done to the north-west and south-east corners; and in some houses as the club, dâk bungalow, etc., the south-east corner has fallen out. The top half of one of the low pillars round the race-course has been broken off and thrown from the base, and is now lying on the ground at the side, the direction in which it has moved being S 25° E. The top ornament of another pillar is broken off, but part of it is left hanging on its centre rod, which is bent, and the direction in which it has fallen is W 15° S. Also on one of the gate pillars the top is bent in a direction N 10° E. In the centre of the race-course there is a Hindu temple with a lofty narrow spire; the top of this is broken off, shifted to one side, and bent over, but it was prevented from falling, I am told, by a strong iron rod through its centre; the direction of movement of the top I determined to be as near as possible S 20° E. The Nazir's mutt, a Muhammadan shrine on the banks of the river, has been completely overturned in a direction which, as near as

I could make out, was N 25° W. In the Armenian churchyard there is a lofty square tower, the walls of which are set almost exactly north and south, east and west (N 6° E, and at right angles): the whole of the northern half of this tower has fallen over towards the north. From the European cemetery but little evidence is obtainable, as only two or three tombs showed any signs of damage. From the tomb of John Charles, infant son of T. Richardson, Judge of the Civil Court of Dacca, the top is broken off, but most of it is still held on to the central rod, which is bent over to one side, and the direction in which it is bent, and the fragments have fallen, is E 10° S. The only other tomb which shows any indication of the direction of the earthquake is the very large and lofty one which is ascribed to '*Columbus saheb, kampani ka naukar*'; this had on its sides, at three different heights, small minarets, some of which have fallen; little, however, could be ascertained from these, as there was evidence to show that in almost every case the top ones in falling had struck those lower down: besides this, the fallen pieces had, previous to my visit to Dacca, been shifted from their original position, and although the marks where they had struck the ground were visible, it was impossible to tell which fallen minaret had made them; one, however, of these minarets had apparently fallen free in a direction W 10° S. The Engineer Babu at the water-works told me that at the time of the earthquake he was standing close by the tank there, and that the water in it was swaying to and fro in a direction which I measured, when pointed out to me, as S 15°—20° E.

Putting the above in a tabular form, we see that—

Club and Dâk Bungalow .	indicate	NW	and	S E.
Low Pillar, near Racecourse .	. ,,	N 25° W,	,,	S 25° E.
Second ,, ,, ,, .	. ,,	E 15° N,	,,	W 15° S.
Gate ,, ,, ,, .	. ,,	N 10° E,	,,	S 10° W.
Hindu Temple on Racecourse	. ,,	N 20° W,	,,	S 20° E.
Nazir's mutt	. ,,	N 25° W,	,,	S 25° E.
John Charles Richardson's Tomb	. ,,	W 10° N,	,,	E 10° S.
Columbus Saheb's Tomb .	. ,,	E 10° N,	,,	W 10° S.
Tank at Water-works . .	. ,,	W 15°—20° N	,,	S 15°—20° E.

Looking at this evidence, and also considering that the impression of the inhabitants of Dacca was that the direction of the earthquake-wave was along a line north-west and south-east, we see that the most reliable observations point to a direction N 20°—25° W.

Of the velocity of motion of the wave-particle the pillar near the racecourse is the only thing which gives any evidence.

Before the earthquake this pillar, of which the horizontal section is square, was 2 feet 9 inches high, and the length of one of its sides 1 foot 8½ inches. From this the top part, 1 foot high, had been thrown off in a direction S 25° E, and so the height from which its centre of gravity had fallen was 1 foot 9 inches; this piece was standing upright and perfectly square with the bottom part, the distance of its centre, from the centre of the basal piece, being 3 feet 2 inches. At first I felt doubtful if this had been thrown off by the earthquake, but an examination of the grass underneath showed that it had not been long in its present position. The pillar was old and considerably weathered, and along the surface of the course, where the parting occurred, the weathering had almost entirely loosened the top part from the bottom, so that there was very little cohesion between them.

For the time and duration of the shock the only evidence at all reliable was that obtained at Dacca by the Traffic Superintendent of the Dacca-Mymensing Railway, who looked at his watch directly he felt the earthquake. He tells me that the shock started at 5.11 P.M. local time, and lasted almost exactly 90 seconds.

Dacca-Mymensing Railway.—Of the damage done to the railway line between Dacca and Maimansingh I was not able to see much, as the line had been largely repaired and the trains were running again when I travelled over it. I could, however, see that the most serious damage to the line had been at its northern end; for the first two-thirds at least of the journey I saw practically no damage, and a great part of this was through dense jungle growing on the reddish lateritic beds of the older alluvium at the east side of the Madhupur jungle. During the latter part of the journey, however, the railway was running on the newer alluvium, and it was here that damage was done and the lines curved and bent by the earthquake; this curving and bending had been entirely removed before I got there, and the only evidence of it was some bent rails lying at the side, and these showed that the shock must have been very severe. Across the line and running through the fields on each side, there were very many fissures in the ground from which sand and water had been forced up and spread over the ground on both sides of the fissure. This sand, when I saw it, was of a light bluish-white colour, but I was told that, when it first came to the surface, it was of a blackish colour, and had a strong sulphurous smell. To these fissures and the sand from them I shall refer later on. This portion of the line was saved from more serious damage by its running along the surface of the ground; if it had been on raised embankments, like a great part of the Assam-Bengal Railway, these would have been most probably fissured and overturned, the bridges over the streams been broken and buckled, and the damage to the line much greater than it was.

Maimansingh.—At this place the earthquake was very severe, and the damage done was enormous. Almost all the pucca buildings were at least partially wrecked and many were complete ruins. Of the church, only a small part of the wall at one end was left standing; one of the Hindu temples has fallen completely down; the upper part of the Rajah's, Palace had all fallen, and the lower story was very severely damaged; the upper part of the Judge's cutcherry had likewise gone, the Judge's house also; one end of the Collector's cutcherry was in ruins, and, besides these, many other places too numerous to mention, including the bazar, which was a complete wreck.

In Maimansingh the collapse of a structure is usually so complete and the different parts interfere with one another so much that indications of the direction of the earthquake-wave are rare, and then are mostly somewhat vitiated. The best indication of the direction is the following. The top of one of the Hindu temples (Deota Din Siwala) in the bazar has fallen in a direction N 48° E and was lying at the side; it had not, however, fallen free, for there was a mark on the side of the tower where it had struck it, but one could see that the direction of the horizontal component of the movement of the fallen top was not much altered. Besides this, none of the other buildings show any accurate evidence of the earthquake; one of the gate pillars of the Rajah's palace compound was twisted and shifted slightly in a direction N 15° E, but as there is a heavy iron gate attached to the pillar, the latter could not have moved freely. Corroborating evidence of the direction deduced from the Deota Din Siwala is, however, obtainable from the cracks in the open country; these, of course, vary very greatly in direction, but the ones which I chose are those which were most out in the open country, and which would have been least interfered with by irregularities in the surface; these were running in a NW to SE direction, and so the direction at right angles to them, which would in this case be presumably the direction of the earthquake-wave, was NE to SW. At the time of the earthquake the north-east corner and part of the outer walls of the jail fell down, the measurements of which from the corner were 105 feet 8 inches of the wall built in a direction E 30° S and 46 feet of the wall at right angles; if we join the ends of the broken part by a straight line and take a direction at right angles to this line, we find it works out N 54° E, which is not far from the N 48° E, which I obtained from the Deota Din Siwala; this may be only a coincidence, as in such a case as this it is not safe to assume that the line of limit of the breaking of the wall was parallel to the crest of a wave. Beyond the above case I was unable to obtain any evidence of the direction of the earthquake wave, but I think I may safely assume that it was, approximately, N E. to S W.

For obtaining the velocity of the wave particle, the only thing we have to rely on is the overturning of the jail walls, which are 10 feet 8 inches high, and 18 inches thick, the overturned portion being 105 feet 8 inches of the wall in a direction E 30° S, W 30° N, and 46 feet of wall in a direction N 30° E, S 30° W.

For the time and duration of the shock the best information I have was obtained through the Traffic Superintendent of the Dacca-Mymensing Railway. He told me that one of his guards, a Sibpur boy, who was at Maimansingh at the time, took out his watch directly he felt the shock, and it was 5·10 P.M., local time, and the shock lasted almost exactly 90 seconds.

In the station of Maimansingh, and in the country around, the ground is fissured in very numerous places, the cracks near the river being mostly parallel to it, but not in all cases; in the surrounding country, however, they are in all directions, following the lines of weakness. From most of these cracks sand and water, like that seen near the northern part of the Dacca-Mymensing Railway, has been forced out and has flowed over the fields, damaging the crops to a certain extent.

The fissuring of the country is accompanied, too, by sinking of the ground often over large areas. More prominent cases of this may be seen in two or three places on the road from Maimansingh to Muktagachha, where the cracks are nearly at right angles to the direction of the road. In these cases the road is faulted, the ground having sunk so that the road on one side of the crack is about 4 feet higher than it is on the other. Wherever the direction of the earthquake-wave is normal or subnormal to the length of the road, and where the road is raised on an embankment above the general level of the country, the cracks run parallel to the road, and in this case the action of the second semiphase of the wave on the side from which the earthquake-wave is travelling, and the first semiphase of the wave on the farther side, tend to throw the cracked sides of the embankment outward and if these outward movements proceed to the centre of the embankment, the whole of it is lowered and there is a sinking in the road at that place.

Muktagachha.—The town of Muktagachha was, I am told, largely built on made ground, and here the fissuring and sinking of the ground was very severe, and in consequence the Rajbari (Rajah's Palace) and the pucca houses near it were completely wrecked. I have taken two photographs (Plate XXVIII, figs. 1 and 2) from amongst these houses. The first is Moish Babu's house, under which are two large cracks along which the ground has sunk, and so the plinth of the house is faulted by the two cracks in two steps, and one portion of the plinth has sunk 4 feet 6 inches below the higher portion; the crack under this house has a direction W 15° S. The second photograph shows a more complete ruin, where only a part of one of the walls of the house is left standing and this is leaning over to the south owing to a large crack in the ground just on that side.

Maimansingh to Silchar.—From Maimansingh I went to Silchar, and on the way from Narainganj to Silchar by steamer, I was not able to observe much, owing to the rate at which we were travelling, a great part of the journey being by night or in the early dawn. The state of the river, too, was not very favourable for my observations, as it was in flood, so that the banks were covered up and it was often difficult to tell if the flooding of the surrounding country was due entirely to the rise of the water in the river or partly to sinking of the ground. At many places, however, on both sides of the Barak, especially in its upper reaches, the sinking of the land was quite evident, and roofs of houses just out of the water were to be seen at several places, a prominent instance of it being at Karimganj where a great part of the bazar was under water.

Silchar.—In Silchar station itself very little damage has been done, and from the buildings there one can hardly tell that there has been an earthquake at all. The bank of the river has cracked and slipped in places, but not badly, except perhaps at the bend just above the station.

Practically the only evidence of the direction of the earthquake was obtained from a cylinder seismometer like that described in Memoirs of the Geological Survey of India, Vol. XIX. This was kept locked up in a separate galvanised iron shed close to the meteorological observatory, and was in proper working order at the time of the earthquake. The cylinders were made of metal outside, filled with cement; they were 12 inches high, were numbered 0 to 7 and were of the following diameters :—

Diameter of	0	was	1 inch.
,,	1	,,	1½ inches.
,,	2	,,	2½ ,,
,,	3	,,	3¾ ,,
,,	4	,,	5 ,,
,,	5	,,	6 ,,
,,	6	,,	7 ,,
,,	7	,,	8 ,,

Of these, Nos. 0 and 1 had fallen over towards the north in directions which were measured by the protractor as 4° E of N and 4° 30′ W of N. The only other piece of evidence I could obtain of the direction of the earthquake was a statement made by the telegraph master that the water in the tank at the back of the telegraph office was, at the time of the earthquake, swaying from north to south.

Assam-Bengal Railway.—At Badarpur I started the examination of the Assam-Bengal Railway. In the section, at present unopened, north of the Barak, between Badarpur and the hills to the north, there was very little damage, although for part of the way it runs over recent alluvium. In the first tunnel, however, of the hill sections some rather big slips had occurred, and along the southern scarp of the Khasi Hills, facing the Surma Valley, large bare patches may be seen where landslips caused by the earthquake have torn away the jungle from the slopes and laid bare the rock beneath.

On the unopened section of the railway between Badarpur and Silchar the damage is very severe, especially to the bridges. For a short distance from Badarpur this line runs through a number of cuttings in hills formed of tertiary beds, and here it is but little disturbed, the chief damage being the slipping in of the sides of the cutting. A little further on, where the line has left the hills and is on the flat open country, mostly *bhil* land and all covered by a new alluvium, the damage is much more considerable, and for some way the bridges are all badly damaged, especially those over the Dalasar Nadi, the Gangru Gong near Polaspar, and the Bara Khal. In the case of the first two bridges the piers are leaning over to the west; probably they are not broken, but, owing to the stirring up of the silt in which the foundations are sunk, the masonry has, with the shock, tilted bodily over to one side in its then partially liquid bed. The embankments close to these piers are badly damaged and sunk in places, the damage being caused in the same way as I have described for the road at Muktagachha.

In the case of the bridge over the Bara Khal the piers have fallen right over into the river and disappeared entirely; before the earthquake this bridge had eleven piers standing, each with 9,000 cubic feet of masonry, there being three spans of 60 feet and six spans of 40 feet, but after the shock only two piers on each bank were left standing and the intermediate space is quite blank. At the time of the shock the two embankments are said by those who were present to have first moved towards one another and then apart, when the telegraph wires were snapped across and some of the insulators were hurled violently for a considerable distance backwards from the river.

In the neighbourhood of the railway line the country is in places seen to have sunk considerably, and near the bridge of the Gangru Gong only the tops of several huts are now above water. The chief case of sinking in this part of the country is that of an area a little east of Polarpar, which extends for some distance to the south, and of which the sinking near the Gangru Gong bridge is a part. Where the boundary of this sunken area crosses the Government road, it is almost at right angles to the road, the cracks being roughly north and south, and the embankment is not broken down, but the crack across the road has faulted it about 4 feet.

From Badarpur to Akhaura I went along the line by trolly and ballast train with an inspection party, the following being the chief points I noticed during our rapid journey, when we travelled over 128 miles of line in three days. The damage is almost entirely confined to where the railway runs over the flat *bhil* country, and where the deposits are quite recent, but wherever the line runs through the low hills of harder and more consolidated tertiary beds, there is little or no damage, and especially in these places we were able to travel by ballast-train for several miles at a time. When crossing the flat alluvial country, the embankment was in very numerous places broken down, and although it was nearly all repaired at the time I went over it, there were still many very bad places where the line had sunk several feet, this sinking being, as a rule, caused by longitudinal cracking due to transverse, or obliquely transverse, waves and outward movement as in the case of the road from Maimansingh to Muktagachha. In two or three places where the surrounding country is very marshy, as at mile 213 between Dakshinbagh and Kalaura, where the direction of the alignment is S 30° W, and also at a place just south of Daragaon, the embankment has sunk into the disturbed ground below, and has caused a rising of the ground, or has come up itself at some little distance from the lines at the sides, forming long, low ridges in the first case and filing up the borrow pits in the other.

The bridges are nearly all in the flat alluvial country, and most of them are more or less damaged. The following is usually the nature of the damage done to a bridge :—

The abutment walls are cracked or broken and have come to, shortening the span. This is the case when any of the shock acts longitudinally to the embankment, and it is caused in a similar manner to the cracking of river banks, as described by Dr. Oldham in Memoirs of the Geological Survey of India, Volume XIX, the first semiphase of the wave on the side from which the earthquake is advancing and the second semiphase on the other side tending to throw the two abutment walls together; this coming to of the abutment walls is often quite considerable, and in spans of 20 feet it is sometimes as much as a foot. Accompanying this movement, we in almost every case see that, on one or both sides of the bridge, the embankment has sunk several feet. Where the bridges have wing-walls to the abutment, this forward movement has cracked and considerably damaged them, but where, as in the case of many of the smaller bridges, there are straight return walls, the pressure has acted along the length of the walls and not across them, and so the bridges have mostly escaped with little or no damage. The coming to of the abutments and consequent shortening of the span has either resulted in the buckling up of the girders in the centre, or the girders have pushed back on and broken off the balance walls of the abutments. In a few cases the piers of the bridges have been tilted over to the side, but in most cases only inwards.

The following are a few notes on some of the bridges which were damaged :—

Madhob Cherra Bridge, mile 217.—The end abutment walls have sunk into the ground and have been tilted inwards and twisted so that the face of one has a bearing of E 33° S and of the other E 16° S the direction of the line over the bridge being N 20° E. The balance walls of the abutments have been broken and forced back, and this, with the sinking of the abutments, has caused the line over the bridge to be arched and the girders to be torn apart at their junction on the centre pier, which centre pier was not affected by the earthquake. The embankment on the north side of the bridge was badly broken down.

Juri Bridge, mile 212.—The two centre piers have moved 18 inches bodily towards one another and are not tilted.

Markal Bridge.—The piers on the east side of the bridge are leaning towards the west, and the piers on the west side towards the east.

Manho River Bridge.—The line over this is in a direction of N. 15° E, and the piers are little, if at all, damaged. The north abutment wall and the adjoining embankment are broken down and the banks of the river on this side are badly cracked.

Dhulai Bridge, mile 188.—The centre pier is leaning to one side and the line on the top is curved, and the end piers are leaning inwards. The original direction of the bridge was N 42° E; the embankment and river bank on the south-west side are both very badly broken down.

Khwai Bridge, mile 162, near Shaistaganj.—The direction of the line over the bridge is nearly east and west. The abutment wall on the eastern side is leaning over to the east; it has sunk about 2 feet and its balance wall is broken off. The next pier is, however, leaning towards the west, and the girder between the abutment and this pier has slipped off and is now supported on a pile of sleepers. The face of the abutment has a dip of 84° to the west and the face of the pier a dip of 81° to the east.

Besides the breaking down the embankment, the railway line is in many cases bent into curves. These had almost all been straightened out again at the time of my visit, but some severe cases were still to be seen. The force required to bend the line into curves must have been very great, as in many places the steel rails are bent and curved, and the nature of the curving of the line sometimes seems to indicate movement of the ground horizontally.

Of the horizontal movement of the ground I was, however, able to obtain a definite piece of evidence. Between Daragaon and Shaistaganj the embankment, which is quite low, was much broken down and the line twisted into curves for a considerable distance, and as I was going over it on a trolley, Mr. F. P. Anderson, the Executive Engineer, Shaistaganj Section, Assam-Bengal Railway, pointed out to me that the line was shifted several feet from its original position. As the alignment here was perfectly straight for a considerable distance and part of it had not suffered in the slightest, this could be tested with certainty, and at my request Mr. R. K. Coxe, Assistant Engineer, Shaistaganj Section, set up his theodolite and took sights along the line. The place we chose to test was a small bridge of three 20 feet spans in mile 164, which was in the centre of the disturbed portion: this bridge was somewhat cracked and broken, but it was absolutely certain that it had not moved relatively to the surrounding country and trees, yet the theodolite showed that the centre of the bridge was 6 feet 9 inches out of the straight line. At the time it was built it was 6 inches out and so now it is 6 feet

3 inches from its original position, and as it has not moved relatively to the surrounding country, it proves that the ground around, which is composed of newer (recent) alluvium, must have shifted bodily towards the north.[1]

At this place and many others along the line where the railway runs over beds of newer alluvium there are numerous cases of cracking of the ground and outpourings of sand and water, the sand having the same characters as that ejected at the other places I visited. At one place near Shaistaganj a native said that petroleum came up with the sand, but I was unable to verify that statement. Traces of sand craters very much washed down were seen in one or two places.

Comillah.—Just before the earthquake at this place a noise was heard, which the Collector described as the noise of trains coming from the north-east (others say north-west), but after the shock he heard nothing. The District Engineer, however, told me that the noise continued during the shock and for about 3 minutes after, and then there were two reports like gunshots in the distance, and after the first report the earthquake rumbling ceased; the direction from which these sounds came was the north-east. The information that the rumbling continued after the shock was confirmed by the reports of other people, but it seems then to have been less loud than before. The reports were heard by several people, both European and native, and by some they are said to resemble the Barisal guns. These latter reports are heard faintly at other times in Comillah, chiefly in the night between 2-0 A.M. and 3-0 A.M.

In Comillah the damage done by the earthquake is less than in Dacca, and of the pucca houses, which I saw, only two had to be evacuated after the earthquake. Of the direction of the earthquake-wave the evidence is somewhat contradictory, and in the following I will give accounts of the chief cases of damage and evidences of the direction of the shock. The belfry of the church was cracked across by a horizontal crack and the top part was shifted forward in a direction of W 20° N, which is the direction in which the church is set. The top, and three side, minarets of a Hindu shrine in the bazar had fallen, but the pieces had been removed before the time of my visit; the places where they had fallen were, however, pointed out to me by the keepers of the shrine, and from this, and the marks where the falling pieces had struck a side cornice, I put the direction of movement as S 40° W. The District Engineer noticed the direction in which the water in a small tank at Chaumata was swaying at the time of the earthquake, and this was almost exactly east and west. The temple of Jaganath, about a mile outside from the bazar, was very badly cracked and damaged, part of its eastern face having fallen out, and since the earthquake the temple is leaning over in a direction which I measured as near as possible as S 20° E. The *nat mandira* attached to the temple has its walls built exactly north and south and east and west, and the walls on the west and south sides have both fallen completely down outwards.

In the tank at the back of Mr. Delayne's house the water was set swaying by the earthquake in a direction roughly north-west and south-east. From the top of the Sub-Judge's Court the western parapet wall had fallen crashing into the oof of the verandah below.

[1] See p. 94.

In Mr. Smart's bungalow a lamp, hanging on a wire 5 feet 10½ inches long; in the verandah, was set swinging by the shock in a direction which, as pointed out to me, was N 35° W. One of the ladies in the station saw a circular haystack rocking to and fro in a direction approximately N W and S E. About two miles from the station to the west and close to one of the main roads there is a Hindu mutt from which the top has fallen in a direction of N 35° W. This top, before the earthquake, was evidently very shaky, and the pieces which have fallen, and are lying on the ground near the base of the tower, are very much broken up. Near the road which goes from the Dâk Bungalow towards the river and close to the railway embankment there are two mutts which are leaning over to the south-east, the larger one in a direction of S 30° E and the smaller one in a direction approximately of S 25° E. From the Kaliajuri mutt the top had fallen off, and although at the time of my visit most of the debris had been removed, the mark where the falling piece had struck the ground, and a little of the debris, was still to be seen, and from these I deduced a direction of N 10° E for the earthquake-wave. In a brickfield close to the railway station there is a mutt, from the top of which some bricks had fallen, probably separately, and these were lying on the ground close to the base of the tower in a direction of N 20° E from the centre of the tower. Another mutt in a small basti on the other side of the river also has its top fallen off. This shrine is built on the top of the bank of a tank, and its top, which came off bodily, fell on the slopes of the bank, and then slipped down it a little, but the marks in the ground tell where it fell, and the direction is to the N E (N 55° E). From the following table we shall be able to see better the evidence which we have of the direction of the earthquake-wave:—

The belfry of church . . .	indicates	W 20° N	and	S 20° E.
Tank in Chaumata	„	E	„	W.
Hindu shrine in bazar . .	„	N 40° E	„	S 40° W.
Temple of Jaganath . . .	„	N 20° W	„	S 20° E.
Tank back of Mr. Delayne's house	„	N W	„	S W.
Lamp in Mr. Smart's bungalow .	„	N 35° W.	„	S 35° E.
Haystack	„	N W	„	S E.
Hindu temple on road to west .	„	N 35° W	„	S 35° E.
Big mutt, Dâk Bungalow Road .	„	N 30° W	„	S 30° E.
Small „ „ „ . . .	„	N 35° W	„	S 35° E.
Kaliajuri mutt	„	N 10° E	„	S 10° W.
Mutt in brickfield	„	N 70° E	„	S 70° W.
Mutt beyond river	„	N 55' E	„	S 55° W.

Looking down this list we find that the majority of these indications, including some of the best of them, point to a direction about N 35° W and S 35° E, and we may, I think, take this as the general direction for the earthquake, but the cases of the last three mutts point to some waves at least coming from a north-easterly direction.

For the intensity of the earthquake shock and the velocity of motion of the wave particle the only building from which any evidence can be obtained is the mutt on the other side of the river as, in the case of all the other mutts, the top of the fracture is very irregular, and the fallen pieces may possibly have come down separate. This mutt, which, as before described, is built on the top of the sloping side of a tank, is polygonal in its lower part, and on this is built a tapering spire, the top of which has fallen in one piece on to the bank of the tank. After falling the top has slipped a little, but the mark in the ground shows where it first struck it, and also shows that the top was at least partially overturned before it reached the ground, where it is now lying on its side with its base towards the tower. The following necessary dimensions and measurements were made for me by the District Engineer:—

Length of fallen piece	6 feet.
Diameter at base „	2 feet 6 inches.
Do. at top „	8 inches.
Horizontal distance of fallen piece from the centre of the mutt, *i.e.*, horizontal distance of inner edge of mark where top struck the ground from the centre of the mutt	12 feet.
Diameter of tower at its base	12 feet.
Height of base of mutt above where the top first struck ground	3 feet.
Height of mutt as it now stands	43 feet 6 inches.

From these measurements, I think, a minimum value for the velocity of the wave particle may be calculated.

Mogra.—Between Mogra and Akhaura, about 30 miles north of Comillah, I visited a Hindu temple which had fallen completely over, only small pieces of the bottom of the walls being left standing; unfortunately, at the time I saw it, the greater part of the debris had been removed by order of the Maharajah of Hill Tipperah, in order that the idol might be rescued, but there was still sufficient evidence remaining for me to measure the direction in which the temple had fallen over, and my reading was S 30° E, which would indicate a direction of the earthquake-wave very nearly the same as that I obtained for Comillah. One of the natives here told me he heard a noise, like a sharp clap of thunder in the distance, about 15 minutes after the earthquake.

A minaret had fallen freely from one of the Hindu shrines near Mogra station in a direction of N 30° W, and the south-east corner of the pucca wall at Mogra Headquarters House had fallen out.

Chittagong.—The earthquake was not felt so severely at Chittagong as at the other stations I visited, and the damage there was confined to cracks in few houses of which the following are the chief cases. In the Anglican Church there are several cracks both north and south and east and west, but the former are most prominent, one of them running between the chancel and the nave. In the Old Municipal Hospital there are several bad east and west cracks, one of which runs along the verandah floor in a direction W 10° N. Right across the Magazine at the Police Lines there is a big east and west crack, and there are also some north and south cracks, but not nearly so bad as the east and west one; the walls of the Magazine are built in directions only 3° from due north and south or east and west. Right across the Municipal School there were large cracks, the most promiment of which had a direction of E 20° N. The Sudder Ghat Police beat-house was very badly damaged, and cracks parallel to the walls, which are built exactly north and south, have practically divided the house into three parts. These cracks are both of them worse at the southern end of the house than at the northern.

One of the clerks in the District Engineer's office told me that directly he felt the earthquake he rushed out of his house to watch the water in the tank close by. The size of the tank is 80 feet by 85 feet, and, according to him, the direction in which the water was swaying, when he first saw it, measured as W 20° S, and he tells me that this gradually turned in a direction opposite to that of the hands of a watch until the water was moving almost exactly north and south.

Sirajganj.—At Sirajganj the earthquake was very severely felt, the Sirajganj Jute Mill being badly wrecked, and many of the houses in the bazar in complete ruin. Unfortunately, although so much damage has been done, there is nothing to indicate the direction from which the earthquake waves came, and without this information other observations, from which the angle of emergence, velocity of motion of wave particle, etc., might be calculated, are of no avail, and so I will merely give a few notes on some of the most prominent buildings damaged by the earthquake.

The Sirajganj Jute Mill had suffered very severely, so much so that the building has had to be abandoned; all the walls are very badly cracked and some have fallen down, whilst others are leaning outwards, the roof has fallen in places, and the top of the chimney has fallen down. The damage, too, is increased by a number of large cracks in the ground underneath the mill and across its compound, which are nearly all running in a direction about N 55° E, and those I measured varied in direction from N 38° E to N 70° E, but the biggest and most prominent ones are in the direction mentioned above, which is about a mean between these last two; the damage effected by these cracks is increased, too, by the sinking of the ground on one side of them. In the walls of the mill buildings there are not so many windows, doors, and other openings as in private houses, and the following is a list of some of the cracks, whose dip I measured:—

In wall	bearing	N. 26° E,	crack dips	57° to S.
,,	,,	E 17° S,	,,	51° to W.
,,	,,	E 20° S,	,,	46° to W.
,,	,,	E 8° N,	,,	48° to W.

From the mill chimney the top has fallen; before the shock it was 110 feet high, but at present is only 79 feet high, 31 feet of it having fallen. This fallen part did not fall *en masse*, but the upper portion of the stack apparently crumbled with the violent agitation, and the bricks fell separately, or a few at a time, and the upper surface of the part left standing is very irregular. The bricks were lying all round, and an examination of the debris showed that there had been very little cohesion between the bricks and the mortar, as almost all the bricks after the fall were clean, or else the mortar could be separated from them by hand; the mortar was very inferior, with very little lime in it, and at the time the chimney was built the bricks had evidently not been properly steeped in water.

The southern walls of a row of godowns have partly fallen out towards the south (Plate XXIX, fig. 1). The walls bear E 19° S, and are 2 feet 1 inch thick, and the side walls of the building to which they are joined are 15 inches thick. In the worst case the upper portion of the wall has fallen outwards after fracturing the junction with the end walls, and an examination of the debris shows that the upper part of the wall has fallen bodily. The roof is made of galvanised iron, which is supported on girders, the main ones of which rest on cast-iron pillars let into the side walls, and as only the light cross girders rest on the end walls, which have fallen, there was very little pressure from the roof on them.

The manager's house was badly cracked, especially at one end (Plate XXIX, fig. 2); here in a wall bearing N 16° E, there are cracks with dips of 53° and 54°. In the bazar almost all the pucca houses were wrecked, and, after examining a number of them, I came to the conclusion that there was no evidence of the direction of the shock, as, if in one house the N W and S E corners were the worst, in another the N E and S W corners were so. Half the post office has fallen over to the south-west, but this is probably largely due to there being a tank close to the house on this side, the banks of which are very badly cracked. In the jail the upper part of the wall in the south-east corner and part of the south and east walls have fallen outwards. The southern wall bears W 5° N, and the upper part of this for a length of 94 feet had fallen: the height of the wall before the shock was 14 feet 6 inches, and its thickness 20 inches, and the lower part left standing afterwards was 6 feet 6 inches high. The eastern wall was at right angles to the southern, and of the same height and thickness as it, and also the lower part left was of the same height as in the other case; of this wall a length of 71 feet had fallen.

Both in Sirajganj and in the surrounding country the ground is very badly fissured, but the direction of these cracks varies very greatly. Although there is a tendency for the Dan Bandi River banks to be fissured parallel to the stream, these cracks are quite subordinate, and the main fissures run obliquely to the river, and even cross it, still keeping their direction. As at every other place I have visited, which is on the newer alluvium, sand and water was forced up through the fissures, and has spread over the surrounding country, and in appearance the deposited sand is exactly like that seen at other places. I was told by those who watched it that the liquid mud continued to be forced up for about half an hour after the earthquake ceased, probably owing to the weight of the fissured surface beds pressing on the semi-liquid stratum below. Of the depth from which the sand came there is no visible evidence, but I am told that when digging wells at Sirajganj, they find first 25 feet of mud and then sand like that forced up. Tanks and other excavations were points of weakness in the upper bed of mud, and into many of them the sand and water has been forced up, and in some cases the tanks are entirely silted up.

Within half an hour of the earthquake the Dan Bandi River at Sirajganj had risen 4 feet, but this rise went down during the next two days.

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(4) Report by Mr. E. VREDENBURG, *Assistant Superintendent, Geological Survey of India.*

WESTERN BENGAL.

Bhagalpur.—The intensity of the earthquake, so far as can be judged by the damage done to buildings, was about the same at Bhagalpur as it was at Calcutta, possibly a shade less.

The buildings principally damaged are the jail and the church.

In the jail the most serious damage has been done to the factory chimney, a slightly tapering structure built on a square plan and oriented N 62° E, N 28° W.

The sketch, fig. 32, represents the appearance of the side facing S 62° W. The upper part of the chimney is uninjured; the side facing S 28° E also shows no signs of injury, while the opposite side facing N 28° W has four horizontal cracks, in which the lower part has moved outwards away from the upper portions, forming a series of steps and giving rise to the inclined cracks visible on the sketch. They are quite similar on the side facing N 62° E, but slightly wider.

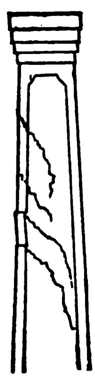

Fig. 32. Chimney in jail at Bhagalpur.

The part of the structure which has been displaced has moved towards a direction N 28° W, or perhaps a few degrees more west, on account of the slightly wider cracks on the north-eastern face. This may not be the exact direction of the shock, since the structure is a square one, and moves more easily along certain directions. Therefore the direction may have been several degrees further north or further west than that along which the masonry has moved. As other evidence points more nearly to an east-to-west direction, we may abandon the supposition of its having been more towards the north than the direction observed. It is, therefore, more probable that the direction of the shock was some degrees more to the west than that in which the masonry has been observed to move, the limit, however, being the S 73° E—N 73° W diagonal, for had the shock followed exactly the direction of the diagonal, there would remain little reason for the difference in the manner in which the several faces have been affected.

The District Engineer in his reports made out the direction to be from N 10° W towards S 10° E. The reasons for this estimate are not given, but taking into consideration the facts above referred to, the direction given appears to be too near north and south; we see also in the case of the chimney that the portion which is displaced has moved towards the west and north, not towards the east and south. The structure must have been swinging as upon a hinge round various layers of bricks of the wall facing S 28° E, the oscillation of the chimney being in a direction S 28° E—N 28° W. This must have loosened the lower part of the structure and allowed it to move to the north-west under the impulse of the shock. As previously observed, however, it is probable that the direction of oscillation was influenced by the shape of the structure, and we may take it as a rough estimate that the direction of the shock may have been about E 30° S towards N 30° W.

There are some slight injuries in the prison wards. These are long red-brick buildings, consisting of a ground floor and upper story with a few transverse partition walls, disposed in a radiating manner round a central tower. This tower is intact. The only injuries in the wards are in the transverse walls on the upper floor, and they are so evidently the result of peculiarities in the construction that they are not very useful for determining the direction of the shock.

One more building is badly injured in the jail; but it is designed in a manner specially liable to suffer from a fatality of this kind. It is a small watch-tower, a polygonal building with arches supporting a dome. The key of each of these arches has become displaced by the shock, and determined at once a gaping crack which could no longer close up. These have given way in the same manner on all sides, the dome itself has remained without support and is cracked. This building, however, affords no clue as to the direction of the shock; it will be seen from the plan of the building that the arches are particularly weak as there is nothing to bear the horizontal pressure resulting from them, and as soon as one of the voussoirs gives way the structure is hopelessly wrecked, for the cracks cannot close up again as they might in a building consisting of horizontal layers.

Fig. 33. Watch tower on Jail wall, Bhagalpur.

The choir of the station church has been ruined by the fall of a pillar and of the roof which it supported. It is difficult to say whether it is the pillar that brought down the roof or the roof that brought down the pillar. It would seem that the damage is to be ascribed rather to peculiarities in the building than to the violence of the shock.

The building consists of a central nave with two aisles. As will be seen on the following diagram, the buttresses give the building an illusory appearance of solidity for they merely strengthen the outer wall, which is quite disconnected from the inner row of pillars and arches which have to bear the weight of the central roof. This roof is supported by beams and by wooden arches, both transverse and diagonal. The beams are all transverse and are placed both upon the pillars and the centre of the longitudinal arches of the masonry wall.

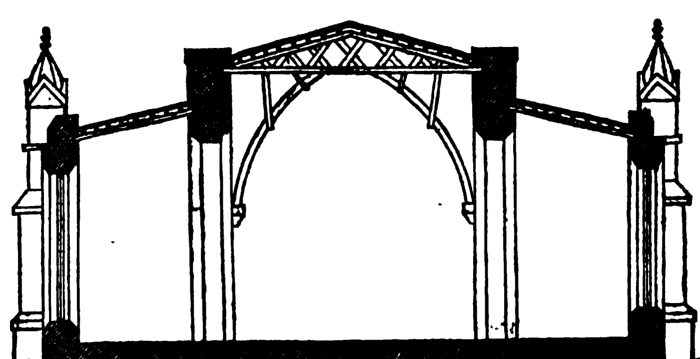

Fig. 34. Cross section of church at Bhagalpur.

The wooden arches can only bear a fraction of the weight of the roof, the effect being quite different from that of a stone roof with ordinary cross-vaulting, which carrie sthe entire weight upon the pillars. The transverse beams carry a considerable proportion of the weight on to the masonry wall at its weakest points, being the points of the lateral arches, each of which carries a beam on either side as shown in the section. The effect differs also from that of an ordinary ceiling which would have many more beams, distributing the weight far more evenly.

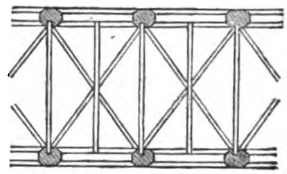

Fig. 35. Plan of roof trusses in church, Bhagalpur.

Another cause of weakness is the small distance to which the beams penetrate into the masonry, which appears out of proportion with their span. The most probable explanation, therefore, is that one of the beams was actually dislodged, and, in falling, carried down the roof, which in turn wrecked the pillar. It is the eastern pillar at the extremity of the northern series of the inner walls. The building is oriented exactly east and west, the choir occupying the eastern end.

I have gone into these details at some length in order to show that the damage to this building is the result of somewhat special circumstances; otherwise it might give an erroneous idea as to the intensity of the shock at Bhagalpur. The remainder of the building is almost without any injury. There is a crack through the window in the east wall, but this might be merely the result of the falling of the adjoining pillar and roof.

The little pinnacles and turrets are all uninjured with the exception of those a the west end which have had the plaster and bricks shaken off their upper part, merely the knob remaining, supported on an iron rod. A small belfry springs from the centre of the pediment; its upper part has broken but has not fallen, owing to the iron rod that runs through it. It is bent in a north-west direction.

According to the station master and the telegraph clerk at the railway station, the earthquake began at 4-25 railway time; the telegraph clerk says it lasted till 4-29 and the station master until 4-30. I have ascertained, however, that these railway clocks are not strictly correct; variations may amount to as much as two minutes.

Jamalpur.—This town is built on a very regular plan. All the houses and all the workshops of the East Indian Railway are oriented in the same manner, about N 20° E—N 70° W.

The effect upon the buildings has been the same in most cases: the walls facing north or south are cracked, while those facing east or west are considerably displaced from the vertical, or have actually given way; the effect remains similar whether the longer axis of the building is in a north-south or an east-west direction.

The violence of the shock appears to have been very great; very few two-storied buildings have remained intact; the corners have often collapsed throughout the entire height of the building. In most cases the upper stories had to be taken down at once and many houses will have to be entirely rebuilt.

The sketch, fig. 36, gives a tolerably typical example of the kind of damage,

Fig. 36. House at Jamalpur, facing S 20° W.

though the degree of injury is here comparatively slight. The side of the house shown in the sketch faces S 20° W.

The chimneys situated upon the roofs of houses have given way without exception, and it will be noticed that whenever the lightning conductor has been bent by the falling structure, it is in a westerly direction. This is all the more remarkable as the chimneys, which are square, have their diagonals corresponding with the axes of the houses.

The next sketch shows a house in which the western front presents no cracks (the north-east corner of the house has totally collapsed); the lightning conductor is seen to be bent in exactly the same direction.

Fig. 37. House at Jamalpur, facing W 20° N.

More remarkable still are the houses situated in a symmetrical position, with their front carrying the chimney facing east instead of west. In that case the chimneys have fallen inward instead of outward, dragging the lightning conductor after them, so that it is still bent in a westward direction.

Taking into account the orientation of the houses, these results agree with the direction as indicated at Bhagalpur, that is, the shock would have proceeded from a direction S 20° to 30° E.

Mr. Rednell, the Locomotive Inspector, happened to be outside his house at the time the earthquake began, and he watched it very carefully from the commencement; he realized the nature of the phenomenon at once owing to the vibration of a large iron roof built over the terrace of the house. The earthquake commenced at 4-27 railway time, and lasted seven minutes. According to Mr. Rednell, the first vibration, which was very moderate, was approximately in a north-south direction, and lasted about two minutes before the shock became more serious and assumed its east-west direction.

It should be noticed that Jamalpur (like Tinpahar and Sahibganj) differs from most of the towns I have visited, in being built at the very foot of the hills, with rock appearing at the surface in many places, while the other towns are built upon a great thickness of alluvium.

One of the chimneys in the workshops, built on a circular plan, was damaged, but it had already been pulled down when I arrived; the crack, as described to me, was vertical and ran through the chimney in an east-west direction; the northern side was bulged out a little more than the southern.

The workshops are oriented just like the houses, but with their longer dimension east and west instead of north and south, the walls facing east and west are torn away from the building or have collapsed.

The church and one large building next to it have escaped without a single injury. This is perhaps largely due to their excellent construction. A very short way east of these two buildings, the ground slopes suddenly towards a large reservoir; if we suppose the shock to have come from the east, this solution of continuity in the surface of the ground may not have been without influence in interrupting the vibration.

Monghyr.—The damage appears to be about the same in degree at Monghyr as at Jamalpur. Many of the one storied houses are injured, but they are of a very inferior style of construction compared to those of Jamalpur.

One of the worst damaged buildings is the Baptist Chapel. The plan is not unlike that of the church at Bhagalpur, as it has an inner room with flat ceiling and an outer portico, these parts being without any connection other than that of the wooden beams which they support. The walls of the inner hall, however, have more consistence than at Bhagalpur; they have no arches, but only a series of doors in their lower part.

The axis of the building runs north and south. Over the porch, which faces north, is a square tower with curious round windows. This tower is cracked right through both from north to south and east to west, the northern and southern faces being the most injured. A great portion of the masonry has fallen southwards, bringing down with it the roof of the church; in other parts of the building the roof has not collapsed, but the walls have been moved out of the vertical, the beams being displaced to a considerable extent. The effect is what might have been produced by a shock travelling in an approximately east-west direction. The porticoes to the east and west are also affected in the same manner; at the corners of the building the arches facing north and south are much more damaged than those facing east and west. A portion of the cornice from the eastern portico fell east.

The E-W direction of the shock is clearly shown in another injured building, the clock-tower. This is a structure in red bricks rising above an arched gateway, facing W 5° N. The eastern and western wall of the tower are supported by flying buttresses; these have acted as a protection to the arched windows placed between them, but as the shock came from the east, and there is no structure of the same kind protecting the north and south walls, the lower part of the tower, as far as the upper part of the flying-buttresses, has moved bodily towards the west, causing the collapse of the arched windows on the north and south walls; the damage is particularly great on the north side.

One of the buildings accompanying the little mosque in the cemetery has had its western extremity injured by a crack inclined at about 85° to the horizon and hading west. It shows equally well on both the northern and southern aspects. The buildings, however, are placed on a small mound, and the outer walls, from their situation, would be predisposed to injury.

In a house not far distant the east-west direction is better shown by a wall facing west, which has become detached, notwithstanding two solid buttresses.

The Collector's house, a one storied structure built on an eminence, has a semicircular verandah facing 5° north of west, which is very badly wrecked; the symmetrical one facing 5° south of east is also damaged, but to a less extent. The rest of the house is not much damaged except for a few arches.

The post office is a one storied building, with a verandah facing west, and a smaller one facing east. These are carried by pillars which are not built on the same plinth as the house. Neither of them has collapsed, but both are damaged and rent apart from the house, the western one especially. The rest of the building has suffered little.

Many one storied houses and the tall houses of the bazar are badly damaged, but, owing probably to their imperfect construction, the cracks follow no spiecal direction, and their ruin merely bears witness to the violence of the shock.

Purniah.—At Purniah the houses are built in such a manner as to give little idea as to the direction of the shock. They are tall buildings made of indifferent bricks jointed with mud or bad mortar, and coated with an enormous thickness of plaster. They have been shattered without the formation of very definite cracks. Comparing them with buildings of the same style at Monghyr, it seems, however, that the violence of the shock was much greater. At the same time one of the Government Offices, a new red-brick building, with an upper floor and a square clock-tower, has remained intact, and the clock was not even stopped.

The ground cracked in every direction wherever it was unsupported, and jets of water escaped from a number of these fissures. Some of them were still open at the time of my visit, for instance, at Harda Bridge, 3 miles south of Purniah. The road at that place is raised some ten to fifteen feet above the level of the surrounding alluvial plain. The fissures ran parallel with the direction of the road along its western portion, and the western slope, as far as the bridge, for a distance of 750 feet; the low ground under the bridge was flooded when I saw it, but at the time of the earthquake it was dry and the cracks extended under the bridge for another 150 feet. The bridge is an iron structure and is not injured. The road at this place runs N 30° E. When I saw it, it was being rapidly repaired, and a gang of coolies were busy filling the fissures with rubble; yet in many places the cracks were still more than ten feet deep; some were over a foot in width.

It is not merely the somewhat unsupported ground of the embankment which has been effected, for some of the fissures are in the plain at the base, so that a permanent displacement of the ground must have taken place at the surface, at least in the immediate neighbourhood of the embankment.

Fissures were opened in many other places at Purniah, particularly on the banks of rivers; they do not exhibit any constant direction, but follow lines of weakness in the ground.

Sahibganj.—At Sahibganj, which is situated at the very foot of the Rajmahal hills, the effects have been still worse than at Purniah. Even the low, one storied houses of the railway officials, which are built of good masonry with iron beams, have been badly damaged, some of them even completely ruined. When they are examined, however, it is seen that they have given way in the weakest portions without reference to any special direction. For instance, many houses oriented S 10° W have had the verandah separated from the house.

The Institute is a large building oriented in the same manner; it has an upper story, and is surrounded by a portico. It is almost completely wrecked, but arches doors, and windows are so numerous that the cracks have merely followed the easiest path offered to them. The building had a tower on the south side that fell south.

The railway station faces the Institute, being similarly oriented; it had also a clock tower, placed on the north façade which fell north, causing the collapse of the stone portico beneath.

The northern wall in a small mosque, a compact building about twenty feet high, three sides of which at least are without large openings or with only blind arches, has one crack hading west, but by referring to the western wall it will be seen that the cracks follow no law, except that they are developed in the weakest part of the building, that is, the corners. The northern crack of the main wall, taken in connection with the crack in the northern wall would represent the shock as proceeding from the south-east; there is a parallel crack at the northern corner of the mihrab, but it is situated exactly in the same manner as regards the masonry. At the southern corner of the building the cracks are in exactly the opposite direction. The southern little turret on the mihrab has fallen partly inwards to the east, partly to the south. The southern face of the building is intact; the eastern face is the most injured, but it consists of arches to which the damage is restricted.

In the bazar, where there are many rows of two storied houses, almost every building is wrecked.

Two clocks were stopped in the railway station; one of them stopped at 4-28 railway time; the other one, in the railway telegraph office, stopped at 4-30. Possibly they did not stop exactly at the same time; but differences amounting to that extent do exist between the different clocks at one station, as they are wound only once a week. The station master's appreciation of the duration of the earthquake was that it lasted three minutes.

Fissures opened out in the ground in many places in the immediate neighbourhood of Sahibganj. This is interesting, taken in connection with the absence of cracks at Jamalpur and Monghyr; the thickness of alluvium and loose ground cannot be less at Jamalpur than at Sahibganj, for both are situated at the very limit of the alluvial area, while at Monghyr the thickness must be much greater. This confirms the conclusion arrived at from the state of the buildings, that the shock was much more intense at Sahibganj than at the two abovementioned localities.

Tinpahar.—At Tinpahar the railway station and smaller buildings surrounding it are much shattered. As at Sahibganj they are in the immediate vicinity of the hills. The railway station is a long building facing N 70° E, with an upper story occupying only the middle part of the building, as shown in fig. 38. The shaded portions of the upper floor have entirely collapsed.

At the northern extremity, on the ground floor, is a waiting room, which shows somewhat regular cracks; it occupies the entire width of the building. In the eastern and western wall the cracks agree in direction; but they are also similarly situated with regard to the corners of the edifice. In the northern wall, however,

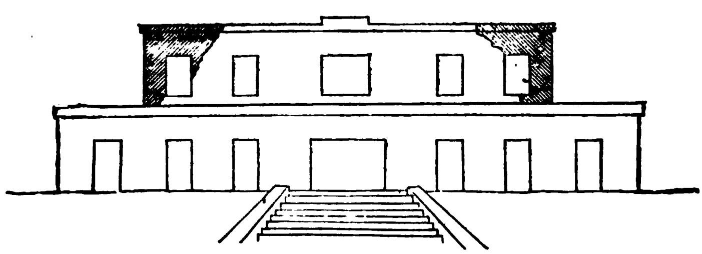

Fig. 38. Railway Station at Tinpahar.

the cracks nearly all hade eastwards; if these cracks are to be depended upon, they would imply that the shock proceeded from a direction a few degrees west of south. It is not possible, however, to place great reliance in these cracks; the cracks in the end wall hade towards the lower ground opposite the eastern façade of the building; and in a small building close by, placed on low ground, and similarly oriented, the northern wall has cracks hading in both directions.

Rajmahal.—The shock appears to have been as intense at Rajmahal; but there are few buildings to bear witness to it; there are a few very squat bungalows which are thatch roofed, and the bazar consists principally of mud huts. As to the older buildings they were greatly ruined before the earthquake.

The injuries observed do not afford much indication as to the point of origin of the shock. The jail has a few cracks in its outer walls.

A large mosque, now transformed into a hospital, has one crack in its northern wall, and one in its southern wall running through the apex of the arches. The rest of the building and the domes are uninjured.

The large railway station, a long building facing SE is almost entirely wrecked owing to the walls having swayed south-east and north-west, which has displaced the iron beams. One of the clocks in the railway station, facing south-east, stopped at 4-30; another facing north-west, did not stop. According to the station master, the shock lasted three minutes.

At the time of the earthquake Mr. McGavin, the Collector and Magistrate, was on the opposite side of the river to that where Rajmahal is situated. The ground cracked in many directions, and water and mud were ejected from the fissures. Some of the indigo fields were entirely flooded with a kind of soft mud. In some places the jets of water and mud formed small conical mounds with a crater, about one foot high. The largest fissure observed was three feet wide.

The earthquake had a curious effect upon the fish in the river near Rajmahal; they rushed into side creeks, several of which communicated with tanks, where they collected in large numbers.

Berhampur.—The four towns of Berhampur, Murshidabad, Baluchar, and Azimganj are the most damaged that I have seen, scarcely a building being left entirely standing, and even those which have not collapsed are badly injured.

At Berhampur the Government Offices are situated in large buildings, of excellent construction, formerly used as barracks. They are double-storied buildings, facing S 20° W. The corners have generally given way; on the upper floor part of the ceiling has fallen down in each of these barracks, also carrying down the ceilings of the lower story. In one of the buildings some bricks from the south-east corner were projected a long distance, over one hundred feet, to the east, but as the corner fell throughout the entire height of the building, which is 50 to 60 feet, they may have been propelled rather by the falling mass than by the shock. The greatest part of the masonry fell outwards at a short distance.

The dâk bungalow, church, post office, etc., are situated in long rows of low buildings with arches on either side. They are very massive buildings, about 20 feet in height. Both the inner walls and outer arches are considerably thrust outwards by the beams they support, which have been displaced as much as one foot in some places. The orientation is the same as that of the barracks, S 20° W.

The southern end of one large double-storied house facing S 70° E has entirely collapsed. In this case, however, it gave way along the cracks of the 1885 earthquake.

The tower of the college is cracked along the four corners; it is oriented N 22° E and N 68° W. The damage appears to be somewhat greater along the north-south diagonal. The clock in this tower has two dials; one of them is stopped at 5-10, the other at 4-45; they may be looked upon as equally unreliable. Mr. Leavinge, the Collector and Magistrate, says that his clocks stopped at 4-55, Calcutta time. Of course, this is only approximate. At the Telegraph Office they were not able to give any definite information.

The ground was fissured in many directions.

Murshidabad.—At Murshidabad most of the buildings are oriented exactly, north-south and east-west. The buildings, whose longer axis runs north and south are generally more injured than those whose principal direction is east-west.

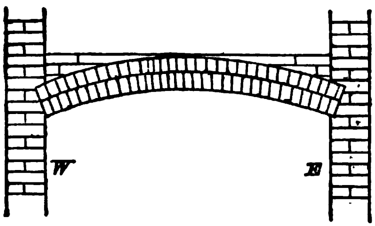

Fig 39. Flooring in Nawab's Palace, Murshidabad.

In the Nawab's new palace nothing has been left standing but the outer walls. This building, which is made of bricks, faces the west, and has an upper story; there were no wooden or iron beams: the ceilings consisted of shallow arches.

As these were held in their place merely by the resistance of the outer vertical walls without any buttresses to oppose this exceptional stress, they must have given way easily.

In another building of this same palace a clock-tower, facing west, fell west by a little south.

In the stables, which were large and well built, most of the ceilings have collapsed. The building was a large quadrangle, the north-east side of which consisted of a double-storied habitation. The outer wall of this habitation facing N 40° E collapsed entirely.

The only building which is comparatively little damaged is the old palace. It is a very large three-storied building with its longest dimension in an east-west direction. It is very massive and well built, largely of Chunar sandstone. The damage is that caused by the rocking to and fro of the walls. The shorter walls, those that run north and south, are not damaged, except for some slight cracks near the upper corners. The longer walls running east and west are not cracked either, but have been more or less displaced out of the vertical; the porticoes and pediments have especially been detached from the building, but none of them have fallen.

In the Durbar hall, a large circular room covered with a dome, the masonry of which has remained quite intact, there are recesses, in which two large candelabra were situated. They were firmly secured in their place by wires. The candelabrum placed in the north-west recess fell south-east, breaking all three wires. The one in the south-east recess vibrated sufficiently to break the south-west wire, but it eventually remained standing. Unfortunately this hall is on the first floor of the building so that little information is given by these directions. In some other rooms on the same floor, marble pillars 3 feet high supporting statuettes or vases have been thrown down; at the time I visited the building they were still in the position in which they fell, and were found lying in all directions.

Opposite the palace there is an isolated clock tower which has not suffered.

Close by is a little Mohammedan shrine, a square building with a dome in the centre and minarets at the corners. Like the other buildings it is oriented exactly north to south and east to west. The dome and the walls are not cracked, but the our minarets have fallen; three of them fell exactly to the west; the one placed on the north-east corner fell due east.

I could not detect any instances giving an exact measure of the intensity of the shock or of its direction; but the general circumstance of greater damage to buildings with a longer north to south axis would show that the shock followed an east and west direction.

Azimganj.—Azimganj is in the same state of ruin as the neighbouring cities. The tall and well built houses have almost entirely collapsed; the very few which have not fallen are much damaged. It is the only place I have visited where temples of the Hindu style of architecture have been damaged. Those of Azimganj are all Jain temples. One of them, a very beautiful building in Jaipur marble, is almost totally wrecked; the others have suffered slight injuries.

The wrecked temple consists of two courts surrounded by porticoes: it is oriented east and west. The inner or western court is on a raised platform connected with the outer court by a flight of steps. In the centre was a group of five towers; the central one fell to the east, causing the ruin of a large portion of the building.

In the three localties described above, just as in Calcutta, the shock was not at all instantaneous, and moderately severe vibrations lasted for a minute or two before the buildings began to fall. This accounts for the comparatively small number of fatalities.

Nalhati.—At Nalhati the shock was not so severe; no fissures were observed in the ground in the neighbourhood.

Bardwan.—At Bardwan it was still less intense. The damage done is much less than in Calcutta. I saw very few houses that were even cracked to any marked extent. At the palace, on the western side of a three storied building, a small portion of the balustrade from the roof fell to the west. Much of the balustrade is missing, but on information I found it was removed since the shock as it was considered unsafe.

Summary of effects on buildings.—The structures which have suffered most of all are imperfectly supported arches; the lower the curvature, the worse they have fared, as in the instance of the new palace at Murshidabad. In the clock tower at Monghyr a very slight displacement of the western wall has caused the complete wreckage of the small arches on the north and south faces; while those on the two other faces which are supported by flying buttresses are intact.

A form of structure still worse calculated to resist this form of casualty is that of the sentry-tower at Bhagalpur, which, being of a polygonal shape, leaves the arches particularly unsupported.

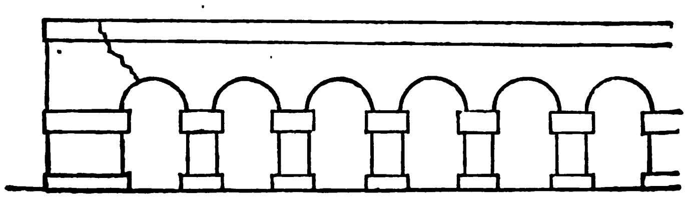

Fig. 40. Elevation of buildings at Berhampur.

On the other hand, rows of arches like those in some of the public buildings at Berhampur (Fig. 40) have stood very well, whatever position they may have occupied with respect to the direction of the shock, and notwithstanding that the transverse beams they support have often displaced them from the vertical to a considerable degree. They have laterally afforded mutual support to one another and only the last one at either end of the series is injured.

The domes of the mosques are generally without a crack, even though the structures supporting them may be somewhat damaged.

Buildings with iron beams have suffered less than those with wooden beams. In one of the barracks at Berhampur, where the upper part of wall has given way, the beams are still resting on one of the lower layers of masonry (Fig. (41). A similar effect is shown in one of the photographs from Jamalpur. Whenever this happens, it may help to save the lower stories and it is more likely to occur with iron than with wooden beams.

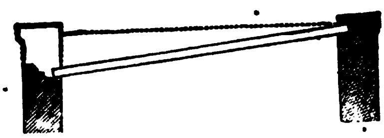

Fig 41. Injury to roofs at Berhampur.

It is not easy to give exactly the relative intensity of the shock at the various places observed. The following list, by order of increasing intensity, is however approximately exact :—

Great damage to buildings, but ground not fissured.	Bardwan. Calcutta Jamalpur	Bhagalpur. Monghyr.
Buildings totally wrecked and ground fissured.	Purniah. Sahibganj Berhampur	Tinpahar, Rajmahal. Murshidabad, Azimganj.

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5. Report by Mr. P. N. Bose, *Deputy Superintendent, Geological Survey of India.*

Eastern Bengal.

My tour lay through a part of the country—Jessor, Khulna, Barisal, Noakhali and Faridpur—which has been but little affected by the earthquake of the 12th of June. The greater portion of the area is composed of deep, soft, recently formed, more or less homogeneous loam, and is intersected by numerous rivers and *Khals*. There are no places which can claim any great antiquity; and some, like Noakhali, have sprung up only within the last century.

Houses are as a rule very lightly built, having mat walls and thatched or corrugated iron roofing. Brick built houses or temples are few and far between, and they have usually escaped with comparatively insignificant cracks (mostly above arches). Only one case of earth-fissure was reported to me; but at the time of my visit it was under water, and could not therefore be seen.*

Calcutta.—Before leaving Calcutta I made a few observations which may be conveniently recorded here.

At No. 5, Bankshall Street (an old two storied house), a portion of the parapet at the north-eastern corner of the house was thrown down in direction N 20° E.

In the next house (No. 6, a very old two storied house), the walls bear N 30° E and E 30° S. The former walls (those bearing N 30° E) were most severely cracked, the cracks being nearly vertical (except those above arches). The walls at the northern and southern ends of the house were slightly fissured off. The house would appear to have swayed not very far from the direction of the walls N 30° E —S 30° W.

At No. 2, Old Court House Street, one set of walls bears NE—SW. A portion of the parapet from the south-western corner of the house was thrown in direction S W.

Gobardanga.—*2nd July.*—In the morning examined the zamindar's house, the largest and most imposing building seen in the course of my tour. It has been badly cracked. The cracks, I noticed, however, were all on arches. The most interesting fact in connnection with this house was the fall of a roundish turret-like structure which surmounted the parapet on its southern side. Unfortunately the débris had been removed before my visit. But from the evidence of eye-witnesses I ascertained the direction in which the turret fell to have been S 25° W.

Reached Jessor in the afternoon. Saw the District Magistrate, the Civil Surgeon, etc. Their impression was that the shock was in a north-south direction.

Ramnagar.—*3rd July.*—Visited Ramnagar, about 5 miles from Jessor. The garden house of the zamindar of that place has been somewhat severely damaged. The cracks were all found to be on arches. The wall of the verandah bearing N 20° E—S 20° W has been shifted northward about 2 inches. The shock here would appear to have been very nearly in that direction.

Jessor.—At Jessor the damage to buildings was slight. The roof of a room in the Collector's Court has been rather badly cracked, the cracks being parallel and running east-west.

4th July.—Left for Khulna in the morning. All the way from Jessor to Khulna did not see a single brick built house, except the railway stations, which are new, small, and have mostly corrugated iron roofing. They have suffered but little.

Khulna.—Reached Khulna at 11-30. Buildings here, belonging mostly to Government, are generally new, low and well built, and have suffered but little damage. The house occupied by the District Magistrate, the oldest in the station, has been damaged to some extent. The parapet on the northern side has got a long crack running nearly E—W. There are other cracks on the roof more or less parallel to it.

Barisal.—*6th July.*—In the Jail some walls bearing N—S have been cracked above arches. So far as I saw, the walls in the opposite direction have not had any cracks.

* The fissure, reported to have been formed at a village called Beliya Bhekutiya some 4 miles west of Jessor. It was said to be about 24 feet deep, and sand and water were affirmed to have issued from it.

In the Reserved Police Barrack the walls bearing N 10° E—S 10° W have been cracked much more seriously than those in the opposite direction.

In the Circuit Houses I noticed numerous cracks on arches in N—S walls; but only one arch on an E—W wall was found to be cracked, and that slightly.

In the office of the District Superintendent of Police arches in N—S walls have been cracked. But in the adjoining Collector's Court, a very old two storied building, the arches cracked are mostly in E—W walls.

Noakhali.—*7th July.*—Reached Noakhali about 6 P.M. Heard the "Barisal guns" in the evening distinctly. They appeared to come from south-eastern direction.

8th July.—The house at present occupied by the Judge and the District Superintendent of Police (a very old two storied house) has got several vertical cracks on N—S walls in the upper story. The arches have been cracked in N—S as well as E—W walls.

The Circuit House (a portion of which is occupied by the District Magistrate) has got a few nearly vertical cracks in N—S walls. The earthquake here travelled very nearly in N—S direction.

The house occupied by the Judge at the time of the earthquake was condemned by the District Engineer three years ago. It is a very rickety old two storied structure. The cracks here are numerous, and are indifferently in N—S and E—W walls, nearly always above arches. Beyond a few pieces of plaster which have come down inside one of the rooms nothing has been overthrown.

Heard the "Barisal guns" again this evening at intervals of 4 to 15 minutes. They appeared to come from a southern direction. In this connection, I may state that at Barisal itself the "guns," as I was informed by the District Magistrate and others, are not heard distinctly or so frequently as they used to be, so I heard them there only once, and that too faintly.

Barisal.—*10th and 11th July.*—A clock in the house of the District Judge, which stood on a bracket and had its pendulum swinging W 34° N—E 34° S, stopped during the shock.

In the house of Mr. N. Gupta (barrister-at-law), a clock standing on a bracket and having its pendulum swinging N 15° E—S 15° W, stopped during the shock. Another clock in the same house fixed to a wall bearing N 15° E—S 15° W. did not stop, showing that the wall could not have moved very far from that direction. A clock in the post office fixed to a N—S wall did not stop, indicating that the shock may have been in that direction.

The clock on the church tower which faces south and has its pendulum swinging E—W, stopped during the earthquake, showing that its motion could not have been in that direction.

The evidence afforded by the last named three clocks—that of the first two not being reliable—combined with that of the cracks in the Jail, the Circuit House, the Reserved Police Barrack, etc., mentioned above shows that the direction of wave-path at Barisal may be taken approximately to be N 15° E.—S 15° W.

Mr. D'Silva, resident of Barisal, saw the water in his tank, which has its length N—S, move lengthwise during the shock and then take a twist and move E—W.

The Telegraph Master of Barisal informed me that the time of commencement of the shock at Barisal was 5-9 P.M. (local time), that is, 5-1 P.M. Calcutta time.

Faridpur.—*14th and 15th July.*—The general impression here is that the houses swayed in N—S direction. The District Magistrate informed me that the District Superintendent of Police had seen the water in a tank move up and down in that direction.

Judge's Courthouse.—Walls bear N 22° W and E 22° N. Arches have been cracked indifferently, but slightly, in both these directions.

Judge's House.—A very old house. A portion of the parapet on the southern side of the house has come down in a SSW direction.

The Judge informed me that some bottles which were standing on a rack fell down. From his evidence, and that of small fragments of the bottles, I made out the direction of fall to have been N 29° E.

The Zilla Schoolhouse.—An arch bearing N 20° W—S 20° W has been seriously cracked at two places.

Sub-Registry Office.—Walls bearing N 10° W have got a large crack at either end of the house. Arches in E 10° N walls have been slightly cracked.

Jail.—Two parallel buildings (wards Nos. $\frac{4}{1}$ and $\frac{4}{2}$) have been rather badly cracked. The walls bear N 15° W and E 15° N. The cracks are worst on the former walls.

The Postmaster informed me that the shock was over at Faridpur at 5-10 P.M. local time (5-4 P.M. Calcutta time). The clock is regulated every day.

Further details from notes by Mr. R. D. OLDHAM, *Superintendent, Geological Survey of India.*

To the foregoing I may add the following details from my own observations:

Dhubri.—The wall of the Gauripur zamindar's compound was overthrown for the most part, but about one-third of its length left standing. Height 3′ 11,″ thickness 2′ 9″.

Two gate pillars of a house were overthrown, one to N 5° W, the other to S 35° E. The original dimensions were about 7′ high × 1′ 6″ square.

Goalpara.—Municipal boundary pillars 1′ 6″ square, 5′ 2″ high, with a truncated pyramid on top 1′ 4″ high and tapering to 4″ at top; total height 6′ 6″. All of these were overthrown, except the one nearest the river bank.

No. 1	to	N 50° E	No. 3	to	N 63° E
No. 2	,,	N 87° W	No. 4	,,	N 65° W
No. 5	to	S 55° W			

Gauhati.—One of the Gate pillars of the Loki Rani's house fell to N 60° E: the other had been removed.

A pair of gate pillars in the compound east of the Telegraph Club were much broken up and overthrown. The west pillar to S 13° E, the east to S 40° E.

In the cemetery a marble cross 2′ 11″ high, 1′ 7″ across arms, 1′ 11″ to bottom of arms, section $4\frac{1}{4}''\times3''$ was broken across at the socket, which was $3\frac{1}{2}''\times1\frac{3}{4}''$.

Another cross 3′ 6″ high, 2′ across arms, section $5\frac{1}{8}''\times3\frac{1}{4}''$ with an oval of 1′ 6″ × 1′ 3″ filling the cross, was broken at the socket, which measured $5''\times2\frac{3}{4}''$.

The monument to Robert Beecher is a stone pillar and vase standing on a pedestal. This had been projected and the base of the pillar struck the steps at the foot of the pedestal in a direction S 15° E, the horizontal distance being 2′ 9″, vertical 3′ 9″.

Tezpur.—A small oblong enclosure, with minarets at the corners, octagonal section, 8" side, about 3' high was not injured. Brickwork evidently poor.

The Dâk Bungalow gate pillars, 8' high × 2' 6" square, were uninjured.

Dacca.—The pillars round the racecourse, 5' high, 1' 7" diameter, circular section, have not been injured.

Chhatak.—The tomb of Lt. H. T. Bird stands in a separate enclosure by itself; the gate pillars at the south side have been overthrown, the east pillar to N the west to S. They were attached to walls which controlled their fall. Height 6' 6", base 2' square.

Cherrapunji.—Gate pillars on eastern road oriented N 25° W, 4' high × 2' 2" square. Northern fell to W 13° S, southern to N 40° E.

Dâk Bungalow western entrance, east pillar fell S 30° W, west pillar S 25° E. They were too much broken up to obtain the original orientation.

A Khasia monument in the compound, a stone slab 4' 6" high and about 2' 6" broad by 6" thick, longer axis N 2° E, has been broken across at ground level and thrown to east.

The tallest pillar of the old aqueduct leading to Inglis' bungalow is 7' 9' high and 2' square. It rises from the bed of a small nala or ravine, and is fractured and twisted, but not overthrown.

The gate pillars of Hudson's bungalow are 9' high × 3' square. Those of east gatewaybear E 13° N; the east pillar has fallen to S 50° W, the west pillar to S 55° W. The western entrance bears N 30° W; the south pillar has fallen to W 11° S, but the masonry is much crumbled at the lower part; the northern pillar is intact.

A small bungalow near by had a number of round pillars in front, evidently old verandah pillars. These fell to N 23° E, N 55° E, S 27° E, N 75° E.

About two miles from Cherrapunji the road to Shillong crosses a saddle, and here an old Khasia monument in the form of an octagon of solid rubble masonry about 9' side has been overthrown and hurled to E 5° S. The debris extends for nearly 50 feet; the original height could not be ascertained.

Shillong.—In the cemetery a headstone over the grave of Major Stewart was fractured. The headstone is of the usual type with vertical sides rounded off in a semicircle at the top. The dimensions are 2' 1½" high, 2' ½" broad at the base and 5" thick. It is broken across near the bottom, the fracture running irregularly from 4½" above ground at one side to ½" above ground at the other. The head stone is made of firm sandstone, a partially weathered form of the Shillong quartzite.

A short way beyond the bridge, five miles out of Shillong, on the road to Cherrapunji, a small Khasia monument was fractured. It is roughly 5' 4" high and broken off 10" above ground, the part broken off being 4' 6" long and the fractured surface about 1' 8" by 8". This is the most striking case of fracture I saw as the rock was a hard glassy quartzite and showed no signs of weathering except for a thin layer on the outside.

Silchar.—According to Dr. Williams, one of the gate pillars of the Mission bungalow was thrown due north. The pillar was 15' high × 2' 4" square and was slightly inclined northwards before the earthquake. Its fellow, which was upright, was unaffected.

Appendix B.

Details of fissures, sand-vents and allied phenomena.

Contains extracts from official reports and replies to letters of enquiry. The extracts given in Chapter II, pp. 14, 15—23, 25—27, should be read in connection with these.

Letter No. 998G., dated Rangpur, the 13th September 1897, from J. D. Cargill, Esqr., Offg. Collector of Rangpur, to the Commissioner of the Rajshahi Division.

In reply to your circular memorandum No. 706 Mcl., dated the 23rd ultimo, calling for a report on the earthquake of 12th June last, giving information as to the extent to which fissures in the earth, outpourings of sands, etc., have been observed, I have the honour to report as follows :—

2. The soil of the District of Rangpur is physically divided into two distinct divisions, locally called *khiar* and *pali*. *Khiar* is hard red clay, and comprises about 10 per cent of the area of the district. *Pali* is alluvial deposit, consisting mostly of fine sand and containing vegetable mould. In the *khiar* section, which extends over the south-western part of the district and comprises parts of the jurisdictions of thanas Govindganj, Pirganj, Mithapukhar and Badarganj, there have been little or no fissures or outpourings of sand and water, and no contraction or filling up of river channels, tanks and wells. It is in the *pali* tract, which comprises an area of about 3,000 square miles, that openings in the earth, outpourings of sand and water obstruction and filling up of river channels, and filling up and breaking of pucka wells have taken place. The openings are of two kinds, *viz.* (1) longitudinal fissures or cracks in the ground, extending in many cases several hundreds of yards in length each, and gaping from a few inches to 4 or 5 feet or more in width, and (2) circular holes, generally 4 to 5 feet in diameter, that burst open, throwing the surface earth several yards away. Both kinds vomited sand and water. Openings of the latter description are more abundant in the Kurigram and Gaibanda subdivisions than elsewhere. The direction of the longitudinal fissures was usually south and west along the sides of tanks or rivers. In Saidpur and some neighbouring villages, forming the south-west corner of the Nilphamari subdivision, and in some scattered villages, such as Domer Bazar, Pochapukhar, etc., there were no fissures or outpourings of sand or water. In some places in Nilphamari subdivision it has happened that while one village was visited with these fissures and natural fountains of sand and water, an adjoining village escaped them. In Kurigram subdivision there is said to be not an acre of land without its fissures and outpourings of sand, more or less, of the description stated above.

3. The fissures running parallel to rivers and tanks, along their sides, have more rarely been accompanied by outpourings of sand and water. They appear to be due to the weakness of the unsupported banks. Owing to them and other causes, nearly all river channels in the *pali* tract have narrowed, some to the extent of 10 to 20 per cent. of their width. In many instances this narrowing process has crumpled up the bridges, or otherwise seriously damaged them. Moreover, the rivers, tanks and wells in the *pali* tract more or less have been filled with sand. Both large and small rivers suffered thus, and most of the small drains have been entirely silted up. Small streams, 100 to 150 feet in width have been filled up 50 to 75 per cent. of their depth. In large rivers the filling up of channels or at least the main channel is not more than 15 to 20 per cent. of the depth. The branch channels, however, in some cases have been considerably filled up. The principal drainage channels of the district that have suffered most injury are the two channels at Rangpur, the river Ghagat, into which they fall and on the banks of which the Civil Station of Gaibanda stands, the Buri Tista nadi passing by the important town of Ulipur, the Bamni nadi between Ulipur and Kurigram, the Jerai nadi, the Kotakhali, the Manash, the Hathalia, the Hatia, the Maroghagat, west of Gaibanda, the Naleya nadi, the Tista and the Mara Akira. Several places in these rivers which were not fordable before the earthquake, but could be crossed only by ferry, became fordable through the earthquake. The bed of the Ghagat referred to above, which passes through the heart of the Gaibanda subdivisional headquarters, rose about 10 to 15 feet from Naldanga in the north to Badiakhali in the south, a distance of nearly 22 miles; the consequence of this has been that while the river is fordable, the ordinary drainage has passed over the country, and a number of the villages on either bank have been under water since the earthquake.

4. Of the 3,000 square miles of *pali* land in the district, the tracts that have suffered most are about Rangpur and in eastern and south-eastern parts of the district, where about 20 per cent. of the area is said to be covered with sand. In the north-western and western tracts there have been fissures and outpourings of sand and water nearly everywhere, but not on such an extensive scale as in the eastern and south-eastern parts. The outpourings of sand have been greatest in the jurisdictions of thanas Sunderganj, eastern part of Gaibanda, parts of thanas Ulipur, Nageswari, Mahiganj and Katwali (Sadar).

Letter No. 1288 J., dated Dinajpur, the 20th October 1897, from N. Bonham-Carter, Esq., Magistrate of Dinajpur, to the Commissioner of the Rajshahi Division.

In reply to your memorandum No. 706 Mcl., dated 23rd August last, forwarding a copy of Government Order No. 4621 J., dated 14th idem, requiring certain information on the subject of fissures in the ground caused by the earthquake of 12th June, I have the honour to say that fissures of a minor nature occurred throughout the district. They occurred usually along the edges of rivers or of low-lying land, and the largest that I have seen were not more than a foot, or perhaps a foot and-a-half, wide. Some are reported to have been a mile long, but I have seen none as long as that, though some are of considerable length. The fissures in most instances ran parallel with the bed of the river, as if the whole bed of the river had sunk, but occasionally transverse fissures seem to have occurred. Outpourings of sand and water also occurred fairly generally, but in no great amount. These outpourings also occurred in the beds of rivers or in low-lying land. I myself observed mud and water bubbling up near the bed of the Purnabhaba river immediately after the earthquake. In this instance, it appeared to me that there must have been, prior to the earthquake, some water under the loose stratum of upper soil. The earthquake had the effect of making this stratum of loose soil subside into the hollow occupied by the water. The water was, consequently, forced up to the surface through the loose stratum of soil. The subsidence of the soil was indicated by the fissures in the ground near where the outpourings occurred. The police have supplied me with a list of places where the fissures occurred, but I place no great reliance on their accuracy or completeness. The list, moreover, conveys little or no information to any one unacquainted with the localities named. I have, therefore, refrained from sending it.

Letter No. 554 G., dated Bogra, the 22nd July 1897, from Umes Chundra Batavyal, Esq., Collector of Bogra, to the Commissioner of the Rajshahi Division.

3. In the *Khiar* or clayey portion of the district, no physical changes on the surface of the ground due to the earthquake are apparent, but in the alluvial tracts the ground is cracked and riven in all directions. Long and large fissures have appeared in many places, and sand and water oozed out of them. The ground has been upheaved in some places, while it has sunk in others. Beds of rivers and tanks have been visibly elevated in some places, while pools have been formed on even ground in others. In the alluvial tracts the water of wells thrown out and the wells themselves in many cases were choked up with sand. Some reporters state that the smell of sulphur was felt coming out of the fissures in the ground at the time of these seismic disturbances.

Letter No. 277 G., dated Bogra, the 13th September 1897, from Umes Chundra Batavyal, Esq., Collector of Bogra, to the Commissioner of the Rajshahi Division.

2. No river channels in this district have been completely filled up, but the beds of some of them have been perceptibly raised here and there. A notable instance of this took place in the bed of the Karatoya river, near the village of Sultanganj, three miles south of Bogra. Here there was a deep pool in the bed of the river, known as the Ramdaha, where in the driest season, the depth of water (the villagers say) used to be about 15 feet. After the earthquake everybody was surprised to find the river bed at the place to be almost dry. The current of the river ceased to flow, and the villagers flocked to catch fish in the mud. After a few days the river cut a small channel for itself over the place, and there was no longer any obstruction to the current. In many other places the people have remarked that the usual depth of water in the Karatoya river has decreased after the earthquake.

3. In the course of my recent tours in thana Sariakandi, I was informed by several intelligent observers that the flood water in this season used to submerge the fields of village Ram Chandrapur before those of village Mathurapara. This year, however, the case is reversed, and the people think that there has been a relative upheaval or subsidence of the ground in one of the two villages.

4. Fissures in the earth and the outpourings of sand and water are confined to the soft *pali* soil between the Karatoya and the Daskoba rivers. They are absent in the hard *khiar* soil to the west of the former river. These fissures were very numerous. The openings in the ground, however, seldom exceed two feet in breadth, but their length varied very much in some cases, the same fissures being observed over a mile or more. Their general direction was from north to south. The width of the fissures increased in those places (very numerous also) whence sand and water were ejected. These outpourings of sand and water are in local language called *bhorka*. From my own house I noticed sand and water oozing out of the ground on the opposite bank of the Karatoya, and a stream of water was flowing down the sloping bank into the river. I, however, did not witness the *bhorkas* (seen and described by many other people) in which the water ejected rose several feet above the ground. Most remarkable is the story told by one Rahaman Ali, Mondal of Bonepara, and I give the substance of it in his own words—" My house is on the bank of the Deakoba river. I was out to see fields when the shock came. I could not stand erect, and I had to sit down. The stream of the river was much agitated as if there was a strong gale. But in a gale the waves move in one direction, on this occasion they moved in all directions. The water seemed to swell, and for a time the surface was covered all over with foam, so that I saw only foam and no water I then observed a large spout of water issue out of the river to the north-east. The column rose, I think, 50 *haths*[1] over the surface. I see the mast of the Magistrate's boat (Note—It is 24 cubits in height). That column of water was much higher than this, and in circumference it was not less than 70 or 80 *haths*. This I saw as the sound resembling cannonade was heard. I ran towards my house in great terror from the *char*.[2] As I looked back, the column of water seemed to diminish. I did not look at it again. A fissure has appeared on the west of my house, which I think is three miles long and about two *haths* in breadth. Sand, charcoal, rotten vegetable matter issued in large quantities out of the fissures."

5. It is very likely that the witness exaggerated the height of the column of water that he saw, and it is doubtful whether the said column of water really rose out of the bed of the river or from a *char* in the river. But the Sub-Manager of the Dighapatia State, Babu Rakhhyakar Moitra of Nowkhila, an intelligent and educated man, and a member of the District Board, who happened to be, at the time, in the *char* of the Deakoba river, saw springs of water rise to the height of several feet above to the ground. He described them to be in appearance like small conical temples rising to the height of five or six *haths*. As he ran towards the village, he was at one place surrounded on all sides with these *bhorkas*. I have visited several places where these *bhorkas* appeared. Indeed

[1] *i.e.*, Cubits. [2] Sandbank.

on the other side of the Karatoya it is scarcely possible to go over a mile of ground without meeting several such places. Small craters were formed out of which sand and water issued with a peculiar sound, which the people described as "hun hun."

Letter No. 900J., dated Pabna, the 20th September 1897, from C. A. Radice, Esq., Offg. Magistrate of Pabna, to the Commissioner of the Rajshahi Division.

With reference to your memorandum No. 706 Mcl., dated 23rd August 1897, forwarding for compliance the Under-Secretary to Government in the Judicial Department, Circular No. 4621 J., dated 14th August 1897, I have the honour to report that, in the Sadar Sub-division of this District, the earthquake of the 12th June only caused the beds of a few of the dry river-beds, close to the big rivers, to sink for a few inches. Cracks were consequently formed along the banks and parallel to the bed. In the beds themselves, sand was, in places, projected to a small extent. These disturbances, showing as they do, subsidence of surfaces, below which the soil is merely lightly deposited sand, are all very slight.

2. In the Sirajganj Sub-division, the seismic effects have been far more marked. I annex copy of the Sub-divisional Officer's letter. This officer has failed to be sufficiently precise, but in order to avoid further delay in the submission of this report, I forward it in its incomplete state, with the suggestion that the Officiating Director of the Geological Survey of India be asked to refer direct to that officer, if he desire to have further particulars. This procedure will save time and labour and is, moreover, to be recommended, as the Subdivisional Officer of Sirajganj is a well informed officer, well acquainted with his sub-division.

Letter No. 350J., dated Sirajganj, the 17th September 1897, from T. Emerson, Esq., Sub-divisional Officer of Sirajganj, to the Magistrate of Pabna.

In reference to your memorandum No. 791J., of 1st September 1897, I have the honour to send the following notes of what I have seen myself of the effects of which information is required by the Director of the Geological Survey. The delay was occasioned by the non-compliance of the Kanungo and Sub-Overseer, Local Board, to report what they had seen.

1. *Fissures* in the town of Sirajganj were generally parallel to the nearest water channel. In the Kutcherry maidan there were several fissures, from 12 to 18 inches wide. The ground invariably subsided on the side of the fissure nearest the Katakhal channel. The subsidence was from 1 to 2 feet. The greatest fissure about 2½ to 3 feet wide and in the form of an arc of a circle was in Messrs. Hannah and Co's. compound. The roads were fissured in several places, always at right angles to their direction. The road from Sirajganj to Pabna was fissured in this way, and sank in many places. The road from Sirajganj to Badraghat was split at various places and also subsided. The chief fissures in this road were near the jute mill at the entrance to the town and at Sealkole village.

At Alukdia and Narnia were fissures from 1 to 2 feet wide parallel to the river.

On the Koijuri road, just beyond the ferry on the opposite side of the river from Koijuri, there was a series of wide fissures parallel to the river for about 200 yards. This is one of the worst series of fissures. The Belkuchi road is fissured about two miles from Sirajganj; holes in parts 2 feet wide, further south no injury.

Along the bank of the river near Nalka and Poraghatle (the south bank of the river) the earth was fissured for about two miles very badly, in a series of parallel fissures extending to from 3 or 4 yards to 40 to 50 from the bank of the river, the fissures varying from 1 to 2 feet width.

At Chanbaria, there were also fissures similar to those at Alukdia, parallel to the river.

2. *Outpouring of sand.*—This has been greatest at Sirajganj. Sand was emitted in great quantities in the Kutcherry maidan, by the side of the Pabna road beyond Messrs. David and Co's house, in Messrs. Hannah and Co's. compound; also at Sealkole and Bhadraghat. I have not noticed it in other places, but have been informed that there were great emissions of sand forming temporary wells near Kamarkhonda.

3. Filling up of channels,—

(*a*) The Katakhal, just by the Barakuti, was considerably disturbed by the earthquake, and sand poured into it from beneath.

(*b*) The Dhanbandi, the river which flows through the town, was being excavated at the time by the Steamer Company. Opposite Messrs. Hannah and Co.'s Ghat two *chars* of emitted sand formed in the river.

(*c*) The Telkupi khal, which runs due west from Sirajganj, was half filled with sand for about four miles. In an ordinary year it would not have been navigable after such a filling up, but this year we have luckily had a record flood.

Letter No. 349J.—G., dated Calcutta, the 19th October 1897, from G. Stevenson, Esq., Offg. Commissioner of the Burdwan Division, to the Chief Secretary to the Government of Bengal.

4. In the Raniganj and Sudder Sub-divisions of the District, no phenomena of the kind, referred to in the extract from the Director of the Geological Survey of India's letter No. 693, dated 26th July 1897, are reported to have occurred.

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6. In the Katwa Subdivision some fissures are said to have been caused in the bed of the Bhagirathi and the Ajai rivers by the earthquake. The greatest width of a fissure was 2 feet, or a little above, and sand, water and dark coloured mud were observed to issue from these openings to a height of 1 to 1½ cubits above water-level.

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7(*a*). In the Kalna Subdivision a small fissure is said to have been formed in the earth near a hill, in village Kobla, in thana Purbasthali, through which a small quantity of sand and water issued. The spot being now under water, the fissure cannot be measured, but its extent was not great. No other fissure or outpouring of sand and water was observed in any other part of the subdivision.

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9. In thana Sakalipur water oozed from a fissure 15 feet long in a field near the village of Tagbora. In the jurisdiction of the Lobpur Police Station there were three cracks observed. One was at Balshanda, about 720 feet in length, and 3 to 9 inches in width at a distance of about 840 feet from the river Majurakha; the second was at Tilpara about 840 feet in length and 3 to 3 inches in width, at a distance of about 360 feet from the said river, and the 3rd at Gopalpur about 75 feet in length and 6 to 12 inches in width, at a distance of about 15 feet from the river Bakreswar. A small quantity of sand and water issued from these three cracks for a short time. In the Moweswar thana one fissure occurred about 24 or 30 feet in length, south of the Kana river, in village Hatina, from which water was seen to issue.

* * * * * * *

11. Four fissures in the earth are reported from the Subdivision of Vishnupur. One was in the sandy bed of the Damudar at Rangamati, 11 miles north of the town of Sonamukhi; a second was in a ploughed field at Dhousimla, 5 miles east of the said town, and a third was at Chowlia, 6 miles west of the said town on the banks of the river Sàli; while the fourth was in the bed of the Darkeswar river about 6 miles north-east of the town of Vishnupur and 15 miles south of Sonamukhi. All the fissures threw up jets of sand and water with considerable force, but it is difficult to give their exact size now. The jets were some 10 to 15 feet in height, it is said.

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15. There were several fissures in the earth in the villages of Bhagabanpur, Bharatpur, and Nandeswar, all within the jurisdiction of the Debra Police Station in the Sadar Sub-division of Midnapur. Sand, water and mud were emitted from these openings, but in no case was any damage done to the river channels or tanks. The average length, breadth and depth of the fissures were 45 feet, 9 incnes and 18 feet, respectively. Most of them have disappeared owing to the rains.

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26. There were no fissure or landslips in the Hooghly District on the occasion of this earthquake.

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33. There were no fissures or landslips in the District of Howrah.

Letter No. 2073J., dated Bhagalpur, the 12th September 1897, from H. J. McIntosh, Esq., Magistrate of Bhagalpur, to the Commissioner of the Bhagalpur Division.

With reference to your endorsement No. 103-P. W., dated the 25th August 1897, forwarding a copy of Government of Bengal's No. 4620-J., dated the 14th idem, regarding the earthquake of the 12th June last, I have the honour, in continuation of this office letter No. 1406-J., dated the 6th July 1897, to state as follows.

2. The Subdivisional Officers of Banka and Madhipura report that no fissure was opened in the earth in their subdivisions by the earthquake, nor have any outpourings of sand or water or filling up of river channels or landslips been observed anywhere.

3. In the Supaul subdivision it is reported that "a very small piece of land on the bank of the river Kosi on the east of the village Guria, was cracked, and only water issued out of it for one day." It is said that no damage was done to any land.

4. In regard to the Sadar subdivision, I beg to submit a statement showing the names of villages and the extent to which fissures in the earth, outpourings of sand and water, etc., were observed.

Statement showing the information called for in connection with earthquake of the 12th June 1897—vide Commissioner's No. 1036, P. W. D.

Name of village and police station.	Extent to which fissures to the earth.	Outpourings of sand and water.
1	2	3
Gopalpur, Police-station Colgong, on the bank of River Kalbulia.	Length 4 or 5 rassis, breadth 1 cubit.	*Nil.*
Villages Atania and Rassilpur, outpost Pirpainti, Police-station Colgong.	At places; extent not given; will follow on receipt of report.	*Nil.*
Village Immamnagger, outpost Pirpainti, police-station Colgong.	Ditto ditto	Outpouring of sand and water.
Village Burgowri in police-station Sultanganj, bank of a pond in a guard at the village opened.	Ditto ditto	*Nil.*
Kalgawan in Police-station Sultanganj .	3 or 4 bighas.	*Nil.*

Letter No. 1444 G., dated Purnea, the 11th September 1897, from J. H. Bernard, Esq., Collector of Purnea, to the Commissioner of the Bhagalpur Division.

With reference to your memorandum No. 103-P. W. of the 26th ultimo, forwarding copy of the Bengal Government, Judicial Department, letter No. 4620-J. of the 14th idem, I have the honour to state that many fissures were caused in this district by the earthquake. No more particular note was made of their character than is given in paragraph 1 of the District Engineer's letter No. 180 of the 17th June last, a copy of which was submitted to you with this office memorandum No. 780-G. of the 22nd idem. I observed several fissures. They ran in different directions, and apparently more or less followed the course of rivers, water-courses and roads. The configuration of the ground appeared to rule their course rather than the direction of the seismic wave.

Letter No. 761 G., dated Malda, the 27th September 1897, from J. H. Lea, Esq., Magistrate of Malda, to the Commissioner of the Bhagalpur Division.

With reference to your letter No. 103-P. W., dated 25th August 1897, forwarding copy of Judicial Circular No. 4620-J. of the Government of Bengal, in connection with the earthquake of 12th June, I have the honour to report that the District Superintendent of Police and myself have made personal enquiries as to cracks and fissures, etc., in the ground, the result of the earthquake, and that I find that cracks opened out all over the low-lying or diara lands of the district, varying from a few feet to half a mile in length. The long cracks were generally very narrow, from 1 to 4 inches, while some short cracks were several feet wide and 5 or 6 feet deep. From these wide cracks in many places sand and water spouted out, and from one fissure close to Gomastapur Thana on a char near the River Mahananda, the Sub-Inspector of that thana states that he saw water and sand and sulphur spouting out for 20 minutes after the earthquake was over.

2. I could not find that these cracks extended as a general rule in any particular direction, but where they occurred on char lands, close to the Ganges, Mahananda or Kalindri rivers, where they mostly did occur, they ran generally parallel to the river. In a few places also highlands in the vicinity of the rivers sank a small distance. No fissures or other surface disturbances were observed in the highland tracts of the Barind.

Letter No. 3266 R., dated Dumka, the 28th October 1897, from R. Carstairs, Esq., Deputy Commissioner, Sonthal Parganas, to the Commissioner of the Bhagalpur Division.

2. In a village called Satar in Taluk Rohini, Subdivision Deoghur, there was a fissure of about 18 cubits in length and 4 to 6 inches in width from east to west, from which gushed a small quantity of sand and hot water. There is a small stream passing by the place where the fissure took place, but no change in it has been observed.

3. In village Karharia, in the Godda Subdivision, there appears a fissure in the earth. It was on both sides of a river and at right angle to it. Sand and water outpoured from it. Before the earthquake there was no water in the bed of the river, but after the fissure had formed it was observed that water was trickling down from the bank of the river. It was also seen that the water was oozing out from the ground. The fissure was 120 yards long and 4 to 5 inches wide. With a stick of 3 cubits its bottom could not be found. There were also little cracks about the place.

4. In no other subdivision was any appearance of fissure reported.

5. There were no landslips in the hills.

Letter No. 547G., dated Bankipore, the 20th September 1897, from J. A. Bourdillon, Esq., Officiating Commissioner of the Patna Division, to the Chief Secretary to the Government of Bengal.

4. In Bihar the public buildings developed cracks. The clock tower in the Bayley serai was seriously damaged, and was subsequently condemned by the

District Engineer. There was a fissure in the cutcherry compound 50 feet long by 1 foot, which is said to have absorbed the heavy rain which followed the earthquake, and had to be filled up. The hot springs at Rajgir are reported to have discharged discoloured water for three days.

* * * * * * *

11. Except in the district of Patna, as described above, no such phenomena as fissures in the earth, outpouring of sand and water and filling up of river channels were observed in any of the districts, nor has there been any landslip in the hills.

Letter No. 101G.-Mis., dated Calcutta, the 22nd October 1897, from E. V. Westmacott, Esq., Commissioner of the Presidency Division, to the Chief Secretary to the Government of Bengal.

With reference to your letter No. 4620J., dated the 14th August 1897, and in continuation of my No. 95G.-Mis., dated the 11th September following, on the subject of earthquake of the 12th June 1897, I have the honour to report that no fissure in the earth, or outpouring of sand or water, or filling up of river channels were observed in the 24-Parganas or Khulna.

Sadar Subdivision.

Shonadanga.
Syamnagar.
Khidirpur Bil.
Gurgaria River bed close to Muragacha.

Meherpur Subdivision.

In the neighbourhood of Shikarpur and Hogulbaria, along the course of the Matabhanga River, and in the sand banks and *chars* of that river.

2. In Nadia fissures or cracks were observed in the places noted in the margin, and sand or water spouted forth from them. No upheaval of river beds is reported to have occurred in any place in Nadia, Jessore or Murshidabad.

3. Two small holes, four feet in diameter and four feet deep, were observed in village Dudsur, thana Sailkupa in the Jhenidah subdivision of the district of Jessore. In the Magura subdivision cracks were observed on the banks of the River Madhumati, near a place called char Bonni. Sinking of land is also reported from the following villages :—

Name of villages.	Depressions.
Sarsuna	9′ × 6′ × 4½′
Satapara	7½′ × 7½′ × 9′
Parsarsuna	6′ × 6′ × 6′
Gazirganti	18′ × 6′ × 4½′
Bagdanga	6′ × 4½′ × 1½′
Sablat	7½′ × 7½′ × 3′
Amean	6½′ × 4½′ × 4½′
Sabekkhatore	12′ × 6′ × 6′
Satakhall	7½′ × 7½′ × 3′

4. In the Sadar subdivision of the district of Murshidabad, fissures accompanied by discharge of sand and water were observed in nine places in Thanas Goas and Jellinghi. These were chiefly in marshy lands and in old river beds. The fissures were generally of considerable size, the longest observed being at a village named Bhuttomintolah in thana Jellinghi, and measuring two miles long

and from two feet to half an inch wide. In the Kandi subdivision, about 25 fissures discharging black clay, sand and water to be observed near Chandipur in thana Gokurna. These fissures are said to have been from 200 to 600 feet long and from three feet to half an inch wide. In the Jangipur subdivision fissures were seen in the bed of the river Bhagirathi discharging black sand. There were also cracks in a field near Rajanagar which discharged black sand.

Letter No. 3127, dated Dacca, the 15th November 1897, from the Magistrate of Dacca, to the Commissioner of Dacca Division.

In continuation of my No. 2140, dated 20th July 1897, and with reference to your No. 1300, dated 26th August 1897, I have the honour to forward a statement showing thana by thana the information asked for by Mr. Oldham.

2. I beg to apologise for the delay which has occurred in submitting this report, which was due to the papers being mislaid by my office.

FISSURES IN THE EARTH.

SABHAR.—Public road about 16 *haths* long, near village Kalinagar has subsided.

KAPASIA.—Several *dhan* and jute *khets* in village Nandia have subsided.

NAWABGANJ.—Land from a place of the field in village Baldi to the *khal* about 1½ feet broad, has subsided.

RUPGANJ.—Some places in villages Hargaon, Chaipara, Ballabdi, Shukerail, Badhurpur *bil*, Char Rahimuddi, Natubdi, Tarail, have subsided.

NARSINGDI OUTPOST.—Several places from Kharua river to Hatidoa river and on the side of the Narsingdi road have subsided. Some lands in village Char Bhagalia have subsided.

MANIKGANJ STATION.—Some parts of river bank in village Bhadar have cracked. Some pieces of land in village Shaitya have subsided. Some parts of land in village Samabari have subsided.

MUNSHIGANJ.—Several places in villages Char Balaki, Char Kajuli and Baisagram have been cracked. Several pieces of land in village Raipur have subsided.

SRINAGAR.—A piece of land, about 2,000 *haths* in length and 3 *haths* in breadth in village Janginagar, has subsided.

A piece of land, about 40 *haths* in length and 40 *haths* in breadth has subsided.

OUTPOURINGS OF SAND AND WATER.

KERANIGANJ.—In village Jinjira, land 6 *haths* long and 1½ *haths* in breadth has cracked, and black sand and water was thrown up. In some seven places in a *char* of the Dhaleswari river, about 1 or 1½ *pakhi* of land have subsided 1½ to 3 feet; water and black sand were thrown up. About 3 *pakhis* of land in village Washpur have subsided; water, sand and clay were thrown up. About 3 *pakhis* of land in Kamrangi *char* have subsided. Two or 3 *pakhis* of land in a *char* in the Dhaleswari river near village Abdulpur have subsided into the Dhaleswari river; land about 80 or 90 *haths* long and 4 *haths* broad has subsided; water and sand were thrown up.

JAIDEBPUR.—Some lands in village Baraitali have been cracked; black sand was thrown up.

SABHAR.—Some portions of land on the south and western side of Kaliakari outpost have cracked; water and sand were thrown up; and also in villages Nayanagar, Akura, and Hijaltali.

KAPASIA.—Three houses in village Khirati have subsided; water and sand were thrown up; same occurrence took place in village Nandia.

Five houses in village Aral have subsided; water and sand were thrown up.

NAWABGANJ.—About a mile long and 1 foot broad of land in village Gazikhali has cracked; large quantity of water and sand were thrown up; and about 2 *pakhis* of land were covered with sand.

About 2 *pakhis* of land on the bank of the Dhaleswari river near village Malikanda have subsided, and formed a deep tank. About 3 *kanis* of land in village Char Ambaria have subsided; water and sand were thrown up. Some damages were done to villages Nagorkandi, Baliapara, Narsinghpur, Nurapur and Mamdabad.

A *khal* about 50 *haths* in length has been formed in village Baidarbagh. A small *khal* has been formed in village Kaitakhali.

RUPGANJ.—Some places in village Naopara have cracked; water and sand were thrown up. A *khal* has been formed in village Gadai Char. Some places in villages Baganagar, Haregaon, Darikandi, Khadimpara, Jhaogara, Jagardi, Hargaon, Dutterbari have cracked, sand and water were thown up; and about 30 *haths* of land in village Kalagachia have been cracked with sand.

NARSINGDI OUTPOST.—Some lands in village Satirpara have cracked; water and sand were thrown up; both sides of the Baher Char *khal* have subsided; black sand was thrown up.

RAIPURA.—Several places in the jurisdiction of Raipura Station have cracked, and water and sand were thrown up.

MONOHORDI.—Several places in villages Char Bagar, Kachikata, Dairer Par, Tamakkandi, Monohardi, Baladi, Sukundi, Daibardi, Arjun Char, Nama, Madhupur, Mirzapur, Kutubdi, Dudibil, Anundpur Rampur, Lakpur, Narandi, Harirampur, Parpur, Chalak Char, Kirtibashdi, Simalia, Char Doulatpur, Paratali, Rudradi, Hakibpur, Maijdia, Asadnagar, Gazaria, Chundunpur, Bengail, Sajardi and Char Kasimnagar have cracked; water and black sand were thrown up.

MANIKGANJ STATION.—A piece of land near Jaigir Bandar has cracked; water and sand were thrown up.

Several pieces of land in village Biswanathpur have cracked; water and mud were thrown up. Some damages occurred in village Ukra. Some pieces of land in village Char Hijli have subsided; water was thrown up.

Some pieces of land in village Takuni have cracked; water and sand were thrown up.

GHEOR OUTPOST.—Several pieces of land in the jurisdiction of Gheor outpost have cracked; water and sand were thrown up.

HARIRAMPUR.—Some pieces of land in Baragarabil have cracked; water and sand were thrown up.

MUNSHIGANJ.—About one *kani* of land in village Raghur Char has subsided; water was thrown up.

A piece of land in village Alipura has cracked, and water was thrown up. About one *kani* of land in village Bhater Char has subsided; water was thrown up.

Letter No. 1330J., dated Mymensingh, the 2nd November 1897, from E. B. Harris, Esq., Magistrate of Mymensingh, to the Commissioner of the Dacca Division.

With reference to your No. 1300-G., dated the 26th August last, forwarding copy of Government letter No. 4620, dated the 14th idem, I have the honour to refer you to this office No. 942-J., dated the 3rd July 1897, in which I gave an account of the damage caused by the earthquake of the 12th June 1897.

2. In the Jamalpur, Netrakona and Sadar subdivisions fissures were innumerable. There were a good number in parts of Kishorganj; and none at all in the Tangail subdivision. All the smaller rivers in the first three subdivisions had their beds upheaved in places, particularly the Katcha Matia, Kharia and Mirgi rivers. Most of the tanks and wells in these parts were more or less silted up.

3. As regard landslips, several have occurred since the 12th June 1897, the majority of which no doubt have been caused by seismic shocks. Some, of course, are due to constant rainfall. As no observations were made at the time, it is impossible to distinguish landslips during the earthquake and those caused by the subsequent rain. The Garo Hills, which border the district to the north, bear marks of numerous landslips.

Extract from Notes on the earthquake of the 12th June 1897, by the Munsif of Isvarganj, in the District of Mymensingh, forwarded with his letter, dated Isvarganj, the 20th August 1897, addressed to the Officiating Director, Geological Survey of India.

* * * * * * *

(3) Formation of the springs of sand and mud.

During the earthquake these springs were formed at several places here. I have seen with my own eyes springs forming upon the bank of the river. The pressure with which the sand, mud and water were thrown up by these springs was very great. At several places these were thrown up over 10 feet high. The sand and water were forced up at a very rapid rate, and the forcing up continued even 24 hours after the earthquake was over. In consequence there was something like inundation at several places. The fields were flooded over and the water reached the houses of several people. The people were afraid of the entire subsidence of the place. I have heard of the people of Gauripur, Kalipur, Bhowanipur within this Munsifi, actually preparing floats to save themselves from drowning. Besides many of the people were flying away in wild confusion in all direction soon after the shock for the very fear of life. This country is high; the Brahmaputra was long ago silted up; the people here had thus no experience of inundation; and hence that awful panic.

Another effect was that arable lands were entirely covered over by the layer of sand forced up through these springs. So much sand and mud were thrown up that it is estimated that about 2 annas[1] of the land within this Munsifi, Isvarganj has been entirely covered over with sand at places 3 to 4 feet deep, by which these lands have become utterly useless for cultivation.

With reference to these sand springs it is necessary to note here that I had occasion to notice the nature of the subsoil here during the course of the excavation of certain wells. I found that near the surface of the land there is a layer about 9 or 10 feet deep which is generally composed of loose sands. I found both red and white sands in their composition. Below this there is another layer of thick mud with sprinkling of sand. This layer is from 4 to 6 feet deep. Below this there is a layer of semiliquid putrid mud. This layer is very thick. A bamboo pole was forced into this layer. It went down some 15 to 20 feet without much resistance. I believed this layer to be over 50 feet deep. It does not appear what is below this layer. This appears to be the state of the soil throughout this district. Throughout this district the fissures were formed only on the upper sandy layer, and were in no place more than 9 or 10 feet deep. This also explains why everywhere here mud and sand were thrown up in abundance.

Letter No. 1074 G., dated Chittagong, the 13th October 1897, from F. R. S. Collier, Esq., Officiating Commissioner of the Chittagong Division, to the Chief Secretary to the Government of Bengal.

With reference to Government letter No. 4620J., dated 14th August 1897, calling for certain information in connection with the earthquake of 12th June last, I have the honour to submit copies of the reports submitted by the Subdivisional Officer of Brahmanbaria and the District Engineer of Tipperah, and to state that no other fissures are reported from any other place in this division. No landslips have occurred in any district.

Report of the Subdivisional Officer of the Brahmanbaria,

THANA BRAHMANBARIA.

1. A slight fissure about 200 feet in length, 2 inches wide, and about 2 cubits or more deep in Syampur *char* land, opposite to Akhaura, in thana Kasva.

THANA NASIRNAGAR.

2. A *khal* about a mile long has opened at Chatalpur.

[1] *i. e.*, one-eighth.

THANA KASVA.

3. Three fissures about 500 cubits long about 2 inches wide and about half a cubit deep in village Kharampur. They poured out sand. Many small ditches appeared and poured out sand. Long, wide and deep fissures were seen in the surrounding *char* lands near Mogra. Sand and water were spouted out. Some portions of land subsided and at points the subsidence was about 5 inches below the normal ground level.

THANA NABINAGAR.

4. A fissure about 300 cubits in length, about 4 cubits wide, and about 2½ cubits deep at Madhupur. It threw up sand.

2. No landslips were noticed in this subdivison.

Report of the District Engineer of Tipperah.

Begs to state that there has neither been any fissure in the earth nor any landslip within the area of this district, except the tapping of a big spring about 8 inches in diameter in a pucka well under construction at Chandpur, emitting sand and water and filling in the well.

(*a*) A long fissure about 500 feet in length and average 18 inches wide on the road leading to Agartala, about one mile from the British boundary. Direction of crack, east to west.

(*b*) Several fissures in the earth at Agartala of the above description and direction, and out pouring of sand only in some place, only to the height of the level of the ground.

(*c*) One thatched shed sank down half of its length about 30 inches.

(*d*) The water of a tank was 6 feet deep before earthquake, but only 3 feet after it.

Letter No. 1592XX.—8G., dated Dhubri, the 8th September 1897, from A. G. Hallifax, Esq., I.C.S., Deputy Commissioner of Goalpara, to the Secretary to the Chief Commissioner of Assam.

With reference to your memorandum No. 5148-59G., dated the 9th August 1897, requesting to supply certain information as to extent to which fissures in the earth, outpouring of sand and water, etc., have been observed on the occasion of the last earthquake, I have the honour to state that fissures in the earth were observed throughout the Dhubri and Goalpara towns, more especially on the river banks. There is not a single road in the town which escaped damages caused by fissures in the earth. The earth was cracked in all directions. The outpourings of sand and water were also observed in a good number of cracks, both in the towns and in the interior of the district. The effects of the earthquake in the interior of the subdivision were similar to those experienced in the town. Most of the wells have been filled up, and the ground in various places has been covered with sand and water. Many of the roads in the interior have been damaged owing to cracks. Reports have been received that a good number of river channels has been filled up with sand, whereby some ferries have been temporarily closed. Landslips were found at three places on the Bhumesvar Hill, but caused no damage to the crops, as the land below it is covered with grass jungle.

Letter No. 2675, dated Gauhati, the 26th November 1897, from Captain P. R. T. Gurdon, I S.C., Deputy Commissioner of Kamrup, to the Secretary to the Chief Commissioner of Assam (through the Commissioner, Assam Valley Districts).

With reference to your memorandum No. 5148-59G., dated the 9th August last, asking for a special report on the extent of fissures, outpourings of sand and water, the filling up of river beds, etc., owing to the earthquake, I have the honour to submit the following report regarding the Gauhati subdivision; a separate report by the Subdivisional Officer of Barpeta is submitted with its enclosures.

2. You are aware that in several places in this district deep fissures were formed owing to the earthquake. In the Bordwar Tea Estate, a garden situated at the foot of the Khási Hills, two fissures were measured by Mr. Gilman. They were found to be 40 and 45 feet deep, respectively. The fissures varied in width from 2 to 4 feet. It is observable that the fissures that opened near rivers were in a direction parallel to the banks. The strand road from Sukleswar ghât to Bhorolumukh furnished a striking illustration of this.

Throughout the length and breadth of the sadar subdivision cracks were very numerous. The road from North Gauhati to Tambulpur, notably the portion between Kamalpur and Rangia and that between the 5th and 6th mile of the Rangia-Tambulpur road, and the road to Hajo from Tambulpur *viá* Barama and Nalbari, and the adjoining fields, were fissured in several places. In many instances cattle are said to have lost their lives by falling into the cracks.

3. As regards effusions of sand and water, it is reported that in nearly all the tahsils the rice-fields opened in fissures, and through these were ejected sand and water, which sometimes rose to a height of several feet, and on falling formed sand craters. I may mention that I personally saw these sand geysers in the rice-field of Nalbari, where I was in camp at the time of the earthquake. The geysers rose to a height of from 3 to 4 feet. The water was not hot, nor was there any sulphurous smell, as has been reported by some correspondents. I should like to draw attention to the fact that earth-waves were distinctly visible from the resthouse compound, which is situated close to a large *pathar* or series of rice-fields. The waves could be seen following one another at intervals, the *áhu* rice falling and rising as the waves progressed. The sight was a most extraordinary and interesting one. I have forgotten to state that the sand geysers were subsequent to the great shock and continued for quite half an hour. In some places roads were rendered impassable, and the houses became uninhabitable on account of the sand that was forced up.

4. River beds were raised and rendered shallow by sand emitted from underground and by the upheaval of the beds. Several rivers, formerly very deep, have now become shallow and fordable in places. The Ghoga stream, on the Tambulpur road, which was formerly very deep, had its bed silted up, and could easily be forded. The beds of the Pagladia, Dimila, Motonga, Borolia, Chenguri, the

Hajosota, the Barnadi, and many hill streams in Tambulpur have been considerably raised, and the water from them overflowing the banks inundated the whole country on both sides. Interior traffic and communication by river was retarded owing to the shallowness of many of the rivers. The beds of irrigation canals in Tambulpur were raised and the water stopped.

5. Landslips are reported to have occurred in this subdivision. Near Chouki, 5 miles to the north of North Gauhati, a small landslip occurred from a hill on the roadside, but not so as to render the road impassable. Further to the north, near Chutiapara, huge rocks fell down the Kohora and Deoduar Hills. In Hajo several rocks have rolled down the hills, and the temple of Siddheswari, which stood on one of these hills, is no longer in existence.

6. In Bhutan the shock of the earthquake seems to have been certainly severe, if we can judge from reports. A portion of the Gomchichitong hill to the north of Dewangiri fell. The Bhutan boundary pillar at the foot of this hill was broken, and the high land near it subsided. A portion of the road from Dewangiri to Oranggaon, within the jurisdiction of Bhutan, was blocked up by a landslip from the Orang hill. People having to pass by that road now take a circuitous route by the bed of the Dia stream. The Ridaja Hill to the north of the Orang hill is reported to have been "levelled to the ground." This hill was formerly very high, its summit being covered with snow nearly all the year round. The report is, however, hardly credible.

The road leading to Susa town was blocked up near Solikhar by the fall of Nadangsing and Jirim hills. Foot passengers can still pass by the road, though riding is impossible.

Portions of the Oangla and neighbouring hills, with the houses of the Lama, fell down. The iron bridge over the Monas is reported to have collapsed. The principal *mantraghar* (or place of worship) of the Desa Rája and the stone house of Gorajung Rája were levelled to the ground. Besides these, there were numerous landslips within the jurisdiction of Bhutan, among smaller hills, which have blocked up roads and rivers in places.

Letter No. 366, dated Barpeta, the 23rd September 1897, from Babu Madhub Chandra Bardalai, Subdivisional Officer of Barpeta, to the Deputy Commissioner of Kamrup.

With reference to your memorandum No. 1613, dated the 17th ultimo, forwarding copy of the letter No. 6[illegible]2, dated Calcutta, the 26th July 1897, from R. D. Oldham, Esq., Officiating Director, Geological Survey of India, to the Secretary to the Chief Commissioner of Assam, I have the honour to report as follows.

2. That immediately after the occurrence of the earthquake of the 12th June 1897, the earth opened in fissures in every direction, and as far as it has since been ascertained by local enquiry, everywhere within this subdivision, the openings being wider and greater in length in places higher up than in places lower down near to the Brahmaputra; while on the other hand geysers rose, throwing up sand and water from different heights ranging from 2 feet to 12 feet. Bits of coal,

old logs, and other vegetable substance came out of the springs with the sand and water. The springs were more numerous in low lying places than in high tracts towards the north near the Bhutan hills.

3. Simultaneously, with the springs, the river beds were raised high as to make them nearly of the same level with the banks, with the result that the volumes of water imbedded hitherto in the rivers, added to the subterranean water thrown out of the springs, overflowed all the places, high and low, the flood rising to the highest recorded flood level the day after the earthquake.

4. That from the undulations observed, specially in the roads, it is pretty certain that the wave of the force of the earthquake moved in the direction of south-west to north-east.

5. From the subsequent high floods that have inundated the subdivision, there could not be much doubt that the river channels have been raised, and that the lands near the river banks have generally subsided to a depth varying from 3 to 7 feet or more, while the tracts of the subdivision towards the north nearer the Bhutan hills remain higher as before.

I beg to enclose herewith, in original, a detailed report submitted by my Sub-Deputy Collector, Babu Abhya Sanker Guha, who was specially deputed to make local enquiries and report on the points in question, for your perusal.

Memorandum, dated Barpeta, the 19th September 1897, by Babu Abhya Sanker Guha, Sub-Deputy Collector.

The following report is submitted to the Subdivisional Officer, Barpeta, with reference to memorandum No. 1613, dated the 17th August 1897, from the Deputy Commissioner of Kamrup.

When the earthquake of 12th June occurred I was out on tour in the Paka Mauza. The very night of the disturbance I went by boat from Kahikuchi to Lachima. Since then I have travelled by land and water in the rural tracts all over this subdivision for the purpose of enquiring into the condition of the people and crops and damage done by earthquake. I have thus been able to observe personally the effect of the great shock over wide areas in the shape of fissures in the earth, outpouring of sand and water, and filling up of river channels, etc. I have also made enquiries on the subject, from which I learn that the phenomena above mentioned have been widespread so far as the Barpeta subdivision is concerned.

2. The fissures have been of different kinds in different localities. In some places they have been many and extensive, tearing up the ground in a very rough manner; in others they have been few, and their size small. In several places rice-fields and public roads have been badly injured by them, some roads have been rent lengthwise, while on some deep gaps have occurred crosswise, letting in strong currents of water from the submerged fields. In several places again the earth has subsided more or less alongside the rents, and this has been specially marked on the banks of rivers and streams, such as the Kaldia and Singra, the Chaulkhoa and the Manás.

3. Immediately after the earthquake we took refuge on an open field not far away from a Nepali *basti* on the Singra river, and there the earth opened in wide fissures, emitting sand and water. This took place so quickly and in so many directions that we had to make a precipitous retreat into our boats. This subdivision having been extensively flooded immediately after the earthquake, the fissures cannot be observed so well as in the higher districts; but that they have been widespread is evident not only from what can be seen in those tracts which are dry, but also from soundings taken in water. In travelling by country boat my boatmen have found varying depths at close intervals while pushing the boat by means of bamboo poles. Also in wading through water on foot (I was obliged to do this, as boat journey was not everywhere practicable), I frequently slipped into deeper gaps, thereby showing that the soil below the water was fissured more or less. In the northern and elevated parts of this subdivision the cracks are still seen, although they have been filled up to some extent by earth washed away by rain or obliterated by cattle. I enclose herewith a rough sketch (not printed) showing some of the fissures in villages Nuntola and Bairapur in the Roha tahsil and a statement showing those in the villages Bhaluki, Balipara, Pakaketkibari, Tuplipanbari, Nityananda Panbari, Raipur, Kukuabatabari, Dalaigaon, Muguri, Haguri, Sariha, Chakla and Patacharkuchi in the Bajali tahsil. The length, breadth, depth, and directions of the fissures are mentioned.

4. As already stated, I was in a boat at the time of the earthquake, and the country being open on all sides, I could clearly observe the springs pouring out sand and water. I saw several spouts on the Singra River itself, one of which rose about 7 or 8 feet high, close to our boats. The boats escaped providentially. Some of the crew and the supervisor kanungo of the Barpeta circle, who had accompanied me, jumped overboard in great terror, and managed to reach the shore. Some geysers rose close to the beach, and several were seen further inland, like fountains playing. From their distance I think some were as high as 10 to 12 feet. The roar produced by these somewhat resembled that of a bore. These outpourings continued till a couple of hours after the earthquake, but their force gradually faded away as the country was flooded. However, nearly two and half months after the great earthquake I found water oozing out, though in minute quantities, from some of the sandy craters caused by the geysers of 12th June in Mauza Domkachakabansi. A villager told me that water came out of these whenever there was a severe shock. From enquiries I have learnt that geysers have been common all over the subdivision. As the water-bearing strata were forced up, the result was the immediate flooding of the whole subdivision, high and low portions alike. The water soon subsided, however, in the higher parts, and as it flowed down to the lower tracts, the inundation in the latter increased, which has been further augmented by two successive floods, the third higher than the second. Bits of coal, old logs, and other vegetable substance were forced up with the springs, exciting the wonder of the ignorant villagers. Rice-fields, wells, tanks, *nullas*, and creeks were covered with sand; and houses were damaged or destroyed where the geysers occurred inside or close to them. Granaries containing paddy have also been injured or destroyed in this way.

5. One of the most curious phenomena resulting from the earthquake of 12th June was the lowering of high, and the raising of low places. Many localities which never used to be under water before were flooded immediately after the earthquake; on the other hand, beds of rivers and *bils* have been raised. This raising has been affected in three ways; one by sand deposited by geysers another by subsidence of the banks, and the third by upheaval. That there has been actual upheaval of river beds, etc., can be inferred from the fact that portions of several roads have been raised in a curious fashion. Undulations are seen on the surface of roads which are not under water, and several bridges have been raised owing to the timber posts which supported them having been forced up by the upheaval. One such bridge is to be found on the road leading from Tengagaon to Roha, where the centre somewhat resembles the apex of a triangle.

6. The Singra was a deep stream before the earthquake, and we could not generally fathom it with the bamboo poles, about 20 feet long, which we carried for pushing the boats. But after the earthquake it became so shallow that our canoes, which drew about a foot of water, grounded in several places. In the Kapla *bil*, in the Sarukhetri mauza, my *holong* boat, which drew about 2 feet of water, grounded several times. I learnt that the Kapla was a very deep *bil* before the earthquake. I observed the same phenomenon in the Cháulkhoa, the Mara Manás, and the Kaldia rivers. In the Bajali tahsil I found two or three tanks quite dry, the interior having been filled up by silt and raised to a level with the surrounding banks.

Letter No. 939-G., dated Tespur, the 26th August 1897, from Lieutenant-Colonel M. A. Grey, B.A., I.C.S., Deputy Commissioner, Darang, to the Secretary to the Chief Commissioner of Assam (through the Commissioner, Assam Valley Districts).

4. In the Sadr subdivision there were fissures everywhere in low-lying lands, and in several places the cracks were several feet wide and deep on the west side of the Bharalu river. Large quantities of water and sand were ejected from the ground. The Tezpur-Balipara tramway line was very severely injured in this way between the Sessa and Rangapara Stations. I visited this portion of the district on the two following days—the 13th and 14th June—and can only say that the extraordinary way in which the rails were thrown about, and twisted into all manner of curious shapes, almost baffles description. The whole of the low lying tract of the country about the Rangapara station was a mass of little geysers, out of which sand and water had poured out. In some places the jets of water were reported to have been from three to four feet in height. The sand thrown up had a peculiar smell, like sulphur, and in some parts was of a blackish colour, though as far as my personal experience has enabled me to speak, the ejected sand was all white. The same thing also occurred pretty well all over the Mangaldai subdivision. In many places the deposits of sand covered several *bighas* of land. The whole of the Chapori near Mangaldai itself was completely riddled with fissures, some being more than 200 yards long. The

deposits of sand were much greater on the Chapori than elsewhere, and covered the land in some places to a depth of four feet. At Singrimari tea garden a foul smell came from the sand and water spouted up, as well as sand. The farthest case eastwards of the earth opening and sand and water being poured violently up, was at the Singlijan tea garden, near Helem, about 50 miles east-north-east of Tezpur. There the water burst out actually in the midst of the coolie lines, and was thrown up several feet high. This is remarkable, as being an isolated case so far east of Tezpur. The garden in question is situated at the very foot of the Duffla Hills.

5. The beds of some of the rivers were also thrown up several feet by the earthquake. A small river at the Tangani tea garden ran dry and filled up slowly during the night. The bed of the Daiphang River southward remained dry for five days after the earthquake. The Nonai rose suddenly and flooded some villages near Nalbari. The Kulsi flooded portions of mauzas Barantola, Dalagaon, including Bholabari tea garden, and submerged the main road from Kalaigaon to Paneri. The Diggaj did the same.

Letter No. 720, dated the 7th July 1897, from the Assistant Engineer, Mangaldai Subdivision, to the Executive Engineer, Central Assam Division.

As it may be of some scientific interest to ascertain the depth from which the sand and water were forced up the fissures in the ground during the great earthquake of the 12th June last, I have the honour to report, in continuation of this office No. 690, dated 30th June 1897, that at the moment the earthquake was felt, I was supervising the sinking of Dalgaon well. It was between 5-20 to 5-25 P.M. according to my watch. The well was sunk to a depth of 25 feet below ground just before the earthquake, and after the earthquake it sank 6 inches of itself giving a total depth of 25½ feet. The sand met with at depth 25 feet was coarse river sand with pebbles. The next day when I sent down the dredger, it stuck into sand and it was with great difficulty that it could be extracted, when very fine blue sand with a slight mixture of clay was brought in the dredger. This sand had filled in the well to a height of nearly 4 feet, on removing the sand up to the bottom of the well curb and a foot below it, the same coarse sand which I was working before the earthquake was found and the well sinking was stopped at sanctioned depth of 27 feet below ground. The depth of fine sand which has been brought up the fissures in the ground appears therefore to be not less than 27 feet.

2. The pucka well in the Subdivisional Officer's compound, Mangaldai, which was sunk to a depth of 33 feet below ground had been filled in with the same fine sand to a height of 16 feet above the bottom of well curb and the brick steining cracked badly. This sand I am now removing for examination of the well, which has suffered badly, inasmuch as the lower portion of the steining is holding an inclined position and a portion just below the top has bulged out. The depth of fine sand according to this well is not less than 33 feet below ground

Letter No. 686, dated North Lakhimpur, the 30th October 1897, from H. A. C. Colquhoun, Esq., B.A., I.C.S., Subdivisional Officer, North Lakhimpur, to the Deputy Commissioner of Lakhimpur.

With reference to your memorandum No. 492G., dated the 21st August 1897, I have the honour to forward a report supplying the information available.

1. (*a*) Fissures in the earth and outpouring of sand and water were very general throughout the subdivision west of the Subansiri. They occurred generally on the banks of rivers and on low lying or swampy ground. The fissures were usually of a few inches in breadth and two feet in depth, and often exceeded 100 yards in length. The emission of sand and water was accompanied in most cases by sulphurous smells. General subsidence also occurred in parts affected by fissures. This is especially noticeable along the left bank of the Dikrang for four miles above Narainpur. The bank has been deeply fissured, and the surrounding country inundated owing to the subsidence of the soil. At Kadam tea garden, again, an acre or two of tea has been destroyed owing to the soil having become water-logged, and the garden has been subjected to unusual floods. It is probable that these floods have been caused in fact by silting up of the Dikrang and Kadam river beds, but I am not prepared to say to what extent. That considerable subsidence has occurred is, however, unquestionable.

(*b*) Neither fissures nor subsidence have been reported from the three mauzas east of the Subansiri.

Letter No. 749G., dated Sibsagar, the 8th September 1897, from Bernard V. Nicholl, Esq., I.C.S., Deputy Commissioner of Sibsagar, to the Director of the Geological Survey of India, Calcutta.

The following is a summary of the information received from the tahsildars subordinate to me.

The occurrence of cracks in the earth from which sand was thrown up, similar to those reported from Jorhat and Golaghat, also took place in the western portion of this subdivision.

The spots where these phenomena were observed are all in the neighbourhood of water courses. Some people were driven from their houses by the appearance of sand and water coming up through the floor. A considerable portion of one road in the same locality sunk, and will have to be thrown up again to raise it above water level. A crack described as over 200 feet in length and 10 or 12 cubits in depth and running north and south made its appearance in another road. A tank 10 feet in depth is reported to have been completely filled up with sand; while a low lying cattle-track has been converted into a raised path by the sand forced up from below.

Letter No. 1125G., dated Jorhat, the 1st September 1897, from B. C. Allen, Esq., I.C.S., Assistant Commissioner, Jorhat, to the Deputy Commissioner of Sibsagar.

I have the honour to submit a report on the points mentioned in paragraphs 1 and 2 of letter No. 692, dated the 26th July 1897, from the Officiating Director Geological Survey of India, copy of which was forwarded with your memorandum No. 670-71, dated the 19th August 1897.

2. *Fissures in the earth and outpourings of water and sand.*—This phenomenon was not uncommon in this subdivision, but no record was made either of the size or number of the fissures that appeared. In Jorhat town, in the Dacca patti, the earth cracked in several places, and in spite of the cracks not being more than 6 or 7 feet in length and 5 or 6 inches broad, water and sand were thrown up in considerable quantities. In the Domgaon, a mile north of the town, the soil was much broken up, and between one and two hundred fissures, varying from a few inches to 15 or 20 feet in length, appeared. The largest of these must have been nearly a foot broad. Here also there was a considerable effusion of sand, water, and mud.

The largest cracks reported were those on the Ladoigarh road, near Nokachar tea estate, one of which was nearly 2 feet in breadth, the road being an unbanked one; these cracks were probably due to a fault in the soil.

3. No information has been received of landslips in the hills.

Letter No. 955G., dated Golaghat, the 9th September 1897, from Lieutenant W. M. Kennedy, I.S.C., Assistant Commissioner, Golaghat, to the Deputy Commissioner of Sibsagar.

In reply to your memorandum No. 670-71G., dated the 19th ultimo, forwarding a copy of letter No. 692, dated the 26th July last, from the Officiating Director, Geological Survey of India, directing me to furnish the information regarding the recent earthquake, called for in paragraphs 1 and 3 of that letter, I have the honour to submit the following reports.

Rangamati mauza.—A fissure, 3 miles long and from 1 to 3 feet broad, was formed from the old Garhali to the new road near the Dhansiri river. It extended for about 3 miles, and sand and water were emitted from it to a height of from 1 to 2 feet. Near the Dhansiri river there was a fissure 30 or 40 *nals* in length and 6 or 7 *nals* in breadth. The surrounding land has subsided 3 or 4 cubits. In Mohora Bilota village near Gela Nadi, a fissure, 150 *nals* in length and 1 or 2 inches in breadth, was formed. In Garaimari *chapari* a fissure, 200 *nals* long and 5 or 6 inches broad, and on the west of the *chapari*, a fissure, 120 *nals* long and 2 or 3 inches broad, were formed, from both of which sand and water were discharged. Also at Baukula village a fissure, 250 *nals* long and 4 or 5 inches broad, was formed, from which sand and water were emitted. In a *chapari* near Tinsukia a fissure, 180 *nals* long and 4 or 5 inches broad, appeared, vomitting sand and water. On a *chapari* near Dirai *suti* the land was fissured, the length of the opening being 210 *nals*, and the breadth 3 or 4 inches. From this also sand and water were discharged, and also from a fissure 210 *nals* in length and 3 or 4 inches in breadth which appeared in Botokoi village near Bena *bhil*. In this mauza there may have been other fissures too in other *chaparis* or in the jungle which were not noticed.

Ahatguri mausa.—In Rangamuri field a fissure, 60 or 70 *nals* long, 1 cubit broad, and 8 or 10 cubits deep, was formed, from which broken pieces of wood were discharged. Sand and water poured out from a fissure in Ramdhani *bhil*, the length of the fissure being 40 or 50 cubits, breadth 1½ cubits, and depth 7 or 8 cubits. In Charani Alli field a depression like a pond was formed, covering about 3 bighas of land, the depth of the water being 12 or 13 cubits. Broken pieces of wood were observed floating on the surface; near the Brahmaputra and the Lohit rivers several fissures were formed, and in some places the land sunk 8 or 10 cubits.

Namdoyang mausa.—In the *Lákhiráj Khát* of Karuabahi *sastra* a fissure half a mile long and about 1 foot broad was formed, from which sand, water, and broken pieces of wood were discharged, several *bhils* were filled up with sand and other *bhils* were deepened. Mari, Dhansiri, and Dijahi and other *jans* were in parts filled with sand.

In Bez and Bilotia villages some fissures appeared in the wood.

Athgaon tahsil.—Only one small fissure 2 *nals* long and half a cubit broad was formed; a small quantity of sand and water was emitted.

Golaghat tahsil.—In Mauza Monkhoa, lot No. 5, one fissure was formed, in length 100 *nals* and in width 1 or 2 cubits, from which water and small pieces of wood are said to have been discharged to a height of 5 or 6 cubits, and in some places the land sunk.

In lot No. 6 fissures are reported to have appeared at Salmara, Mohkuti, Naparnua, Bholuguri, Butuli Khoa, and Hauntli Khend. The dimensions of these fissures could not be ascertained by the tahsildar, as the land is now under water, but some of these are said to have been 24 or 25 *nals* long and 2 to 4 cubits wide. Minor fissures are said to have been formed on the banks of Nobhil in Khumlai mauza, but to have been immediately filled up with sand. In this tahsil only the lands bordering on rivers and *bhils* were fissured, the soil being sandy and no fissures appeared in the interior.

Missamara mausa.—In Borgohain *chapari*, in the jungles, some very small fissures are said to have been formed, from which water and sand were discharged. These alleged fissures are now under water owing to the floods.

As regards paragraph 3 of the Officiating Director's letter quoted above, I am informed that no hillmen from the Himalayan tracts visit this subdivision. In any case they would not visit the plains till the cold weather sets in.

Letter No. 1000G., dated Kohima, the 14th October 1897, from Captain H. W. G. Cole, I.S.C., Officiating Deputy Commissioner of the Naga Hills, to the Secretary to the Chief Commissioner of Assam.

3. In the plains portion of the district, observations were confined to the cart-road connecting Golaghat and Kohima which runs through the Nambor forest. Here no measurements of fissures were taken, but they were said to be very general, and the openings were filled up by road gangs as quickly as possible. The road subsided and cracked at intervals, especially near low lying lands. Between the 20th and 21st miles of the road from Golaghat, it was noticed that sand and water spouted up in places filling old earth borrow pits.

Letter No. 292, dated Manipur, the 15th September 1897, from A. Porteous, Esq., I.C.S., Officiating Political Agent in Manipur and Superintendent of the State, to the Secretary to the Chief Commissioner of Assam.

I have the honour in reply to your memorandum No. 5148-59 G., dated 9th August 1897, to state that, after enquiry, I cannot ascertain that there has been any instance within the Manipur State of either earth fissures, outpourings of sand or water, or of filling up of river channels having occurred as a consequence of the earthquake of 12th June last.

Letter No. 3177, dated Silchar, the 2nd November 1897, from B. B. Newbould, Esq., I.C.S., Deputy Commissioner of Cachar, to the Secretary to the Chief Commissioner of Assam.

With reference to your memorandum No. 5148-59G., dated the 9th August 1897, asking for a special report giving information as to the extent to which fissures in earth and landslips have been caused by the earthquake of 12th June last, I have the honour to submit herewith a statement showing the information wanted as precisely as is possible.

In Katigora tahsil the number of fissures and the area covered by outpourings of sand and water were not recorded at the time, and now they have been obliterated. No river channels in this district were filled up by slips into the river.

Letter No. 249G., dated Sylhet, the 7th April 1898, from L. J. Kershaw, Esq., I.C.S., Officiating Deputy Commissioner, Sylhet, to the Secretary to the Chief Commissioner of Assam.

With reference to your No. 5148-59 G., of the 9th August 1897, calling for a special report on certain matters in connection with the earthquake, I have the honour to forward summary of the information I have been able to collect from the various parts of the district.

2. The four heads under which the Director of the Geological Survey required information are :—

(*a*) Extent of fissuring.
(*b*) Outpouring of sand and water.
(*c*) Filling up of river channels.
(*d*) Opening out of new *khals*.

As regards (*a*), fissuring has been universal throughout the district to a small extent on the public roads which have been cracked rather than fissured, and to a much larger extent on the banks of rivers and water courses and in the neighbourhood of tanks, bils and haors. Fissures in the latter cases were caused by the subsidence of the banks into the bed of the river or tank, and their direction was, therefore, almost invariably parallel to the banks. The extent of the fissures varied, as might be expected, according to the distance from the centre of disturbance. In Karimganj the breadth did not exceed 5 or 6 feet. In Habiganj and

Sunamganj they seem to have been more considerable. In Sunamganj the largest fissures were over 30 feet broad and extended along the river bank in some places over half a mile. In Jaintia and Karimganj there are instances of fissures extending in a continuous line right across narrow tongues of land, thus nearly separating them from the main land and forming a sort of khal. In Jaintia along the banks of the river Surma the fissures in some places are 15 feet deep and usually over 6 feet deep. In some cases the bank which was cracked at the time of the earthquake did not subside until November.

(*b*) The outpouring of sand seems to have been common everywhere in the vicinity of rivers and bils. The damage due to this cause was not on the whole very great, though in the Jaintia Parganahs near Kanair Ghat in several instances paddy was damaged by the upheaval of sand. The Subdivisional Officer of Habiganj reports that the sand thus ejected has had a fertilising effect contrary to expectation, and that the beds of tanks have interstices in the Dharma pasa thana of Sunamganj. In Mouza Bayangpur, Parganah Satbank, Jaintia, a khal was formed about ¾ mile long and was navigable for 3 malla boats[1] during the rains. Two streams in Mouza Chikuagul, Parganah Panchbhag, have changed their course. In Mouza Bugail Kandi, Parganah Dhargam, the Piyain has left its old course and now flows through Bugail bil ¼ of a mile away from its old bed.

Appendix C.

Details of observations made for the purpose of determining the velocity of movement and acceleration of wave-particle with a discussion of the formulæ employed and the results obtaining.

In this statement the values of f, or acceleration, is given in feet per second and deduced by West's formula.

The value v is deduced from Prof. Haughton's formula as given in Mallet's account of the Neapolitan Earthquake of 1857.

In the case of objects projected the value is obtained by the angle of projection being taken at 45° or 0° according to circumstances. Where the vertical difference of position much exceeds the horizontal the latter gives the minimum value; where on the other hand the vertical difference is nothing or small, the former gives the minimum value.

In every case the figures in the last three columns are given in foot-second units. These values may be converted into millimetres by multiplication by 300. The error, which is little more than 1%, is immaterial in view of the much greater errors inherent in the method of determination.

The second column states whether the value is a maximum or minimum one. The sign $<$ representing a maximum value, or that the real value is less than the given; the sign $>$ on the contrary indicating a minimum value, or that the real value is greater than that given.

[1] *i.e.*, Boats requiring three boatmen.

The first column explains itself. It is a brief description of the object utilised and a reference to its detailed description.

Nature of object and reference.		Relation of real to given value.	Overthrow and fracture.		Projection.
			f	v	v
Dacca—					
Top of pillar on race course $\epsilon=45^\circ$	p. 291 .	>	...	...	8·0
Race course pillar, not overturned	p. 318 .	<	11·2	5·6	...
Comilla—					
Top of temple projected $\epsilon=0^\circ$	p. 300 .	>	...	...	6·9
Dhubri—					
Telegraph office gate post .	p. 259 .	>	15·24	4·1	...
Gauripur Zamindar's wall . .	p. 317 .	>	8·3	2·5	...
Goalpara—					
Municipal boundary pillars .	p. 317 .	>	8·7	3·0	...
Pillar near cemetery . .	p. 263 .	>	14·7	4·6	...
Ensign Law's tomb $\epsilon=30^\circ$.	p. 262 .	>	...	...	10·84
Gauhati—					
D. C.'s compound pillars .	p. 263 .	>	13·1	4·0	...
Judge's gate pillars . .	p. 263 .	<	10·3	4·1	...
Tel. signallers' house, w. gate posts	p. 264 .	<	16·0	5·3	...
Ditto ditto	p. 264 .	<	12·5	4·6	...
Top of pillar in Civil Surgeon's compound $\epsilon=45^\circ$ . .	p. 264 .	>	...	...	8·75
Gate pillars W. of D. C.'s compound	p. 265 .	>	12·8	4·0	...
Do. western gateway	p. 265 .	>	17·1	7·0	...
Tomb of Anna Louisa Lamb, projected . .	p. 265 .	>	...	...	13·6
„ R. Beecher, do. .	p. 317 .	>	...	...	6·1
Marble cross broken . .	p. 317 .	>	10·5	...	...
Shillong—					
Ashley Hall, western gate pillar	p. 270 .	>	15·3	6·7	...
„ eastern do.	p. 270 .	>	11·7	4·0	...
Beauchamp lodge gate pillars	p. 270 .	<	12·3	4·8	...
Col. McGregor's gate pillar .	p. 270 .	>	11·7	4·3	...
Cylinder seismometer . .	p. 358 .	>	24	10·0	...

Nature of object and reference.		Relation of real to given value.	Overthrow and fracture.		Projection.
			f	*v*	*v*
Cherrapunji—					
Inglis' house gate pillars	p. 273	$<$	8·3	3·5	...
" pillar on wall	p. 273	$<$	13·9	4·8	...
Hudson's house gate pillars	p. 318	$<$	10·7	4·8	...
Cylindrical pillar	p. 273	$<$	9·1	3·6	...
Do.	p. 273	$<$	9·1	3·6	...
Rembrai—					
Stone projected $\epsilon = 45^\circ$	p. 131	$>$	...	...	16·5
Sylhet—					
Tomb of Ensign Spooner	p. 274	$>$	32	11·4	...
Gate pillar near hospital	p. 275	$>$	11·73	4·0	...
Church northern gate pillar	p. 276	$>$	24	8·1	...
" southern do.	p. 276	$>$	19·2	7·9	...
Silchar—					
Cylinder seismometer	p. 358	$>$	4	2·7	...
Bullet projected	p. 358	$>$	...	...	1·4
Gate pillar overturned	p. 318	$<$	6·5	...	...

Remarks on the formulæ used and results obtained.

Taking the attempts to deduce the velocity or acceleration of wave-particle from objects overthrown by the earthquake in order of date, we have first the formula of Prof. Haughton, published in Mallet's account of the Neapolitan earthquake of 1857. [1]

The investigation proceeds as follows and may be given in Mr. Mallet's own words:—

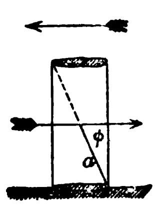

Fig. 42.

"In order to upset the body, the horizontal velocity impressed by the shock (whatever be the duration of the latter) must be sufficient to make it turn upon one of the arrises or angles of its base through an angle formed by the line, Fig. 42, joining the centre of gravity with that angle or arris, and the vertical through it.

[1] R. Mallet, Great Neapolitan earthquake of 1857. The First Principles of Observational Seismology as developed in the report to the Royal Society of London of the expedition made by Command of the Society into the interior of the Kingdom of Naples, to investigate the circumstances of the Great Earthquake of December 1857. 2 vols., London, 1862. Vol. I, p. 125.

"Let a denote the distance (in feet) of this point or edge from the centre of gravity, then the *statical work done* in upsetting the body, whose weight is W.

$$W a (1 - cos. \phi).$$

"This must equal the *dynamical work* acquired, which (as is well known) is equal to the *work stored up in the centre of gyration*, or

$$W a (1 - cos. \phi) = \frac{W \omega^2 k^2}{2 g}$$

where ω is the angular velocity of the body at starting, k the radius of gyration, with respect to the point or arris on which it turns, and g the velocity acquired by a falling body in one second of time.

"Equating these two values of the work done we find—

$$\omega^2 k^2 = 2 g a \ (1 - cos. \phi)$$

but ω, the angular velocity, is equal to the statical couple applied divided by the moment of inertia, or

$$\omega = \frac{v a \cos. \phi}{k^2}$$

squaring and substituting

$$v^2 = 2 g \times \frac{k^2}{a} \times \frac{1 - cos. \phi}{cos.^2 \phi} \text{"} \qquad (I)$$

For a pillar of rectangular section

$$k^2 = \frac{\alpha^2 + \beta^2}{3}$$

$$\text{and} \quad a = \tfrac{1}{2} \sqrt{\alpha + \beta^2}$$

where a is the height and β the side of the base; hence

$$v^2 = \tfrac{4}{3} g \times \sqrt{\alpha^2 + \beta^4} \times \frac{1 - cos. \phi}{cos.^2 \phi} \qquad (I\ 1)$$

For a cylindrical column—

$$k^2 = \frac{15\beta^2 + 16 \alpha^2}{48}$$

and

$$a = \tfrac{1}{2} \sqrt{\alpha^2 + \beta^2}$$

and since

$$\phi = \frac{\alpha^2}{\alpha^2 + \beta^2}$$

the equation (I) becomes

$$v = \frac{15 \beta^2 + 16\alpha}{12 \alpha^2} \times g \sqrt{\alpha^2 + \beta^2} \ (1 - cos. \phi) \qquad (I\ 2)$$

The defect in theory underlying these equations is the supposition that the impulse is instantaneous, it is assumed to act for an infinitely short time over an infinitely short distance.

The next attempt to utilise overturned pillars and columns as seismometers looked to them as measures not of the maximum *velocity*, but of the maximum *acceleration* of the wave-particle. This is due to Mr. C. D. West, by whom the argument is stated as follows[1] :—

" Let the surface of the earth at any instant be undergoing an acceleration of velocity of f feet per sec. per sec. Let M be the mass of the column (see. fig. 43) resting on the ground, y the height of its centre of gravity, and x its horizontal distance from the edge round which it may be supposed to turn.

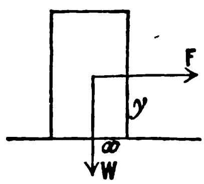

Fig. 43.

" Then the inertia of the column is equivalent to a force

$$F = Mf$$

acting horizontally through its centre of gravity and tending to overturn the column, the overturning moment being

$$Fy = Mfy$$

" This moment is opposed by the moment of the weight of the column, W x, and therefore when the column is on the point of overturning

$$Wx = Fy = MFy = \frac{W}{g} fy.$$

$$\therefore \frac{x}{y} = \frac{f}{g}$$

$$\therefore f = g \frac{x}{y} \qquad \text{(II)}$$

" If f exceeds this value the column *may* go over, if less the column *may* stand."

This formula recognizes facts as they are more than (I) and in Prof. Milne's experimental investigations it gave results in somewhat close agreement with the actual, but where the period was about 1½ to 2 seconds, there were many wide divergencies; the calculated acceleration being in excess of the actual.[2]

The formula, it will be seen, takes no account of the amplitude, or of the range of motion, *i.e.*, double amplitude, of the wave-particle, and Prof. Omori points out that the column will only overturn towards the direction from which the impulse comes when its rotation is sufficient to bring the centre of gravity over the edge on which it turns.[3]

[1] Journ. Seismol. Soc., Japan, VIII, 35 (1885).
[2] Seismol. Journ., Japan, XVII, 74 (1893).
[3] Seismol. Journ., Japan, XVII, p. 120 (1893).

But the impulse may be assumed to be imparted at the centre of percussion P (fig. 44) whose distance from the base is

$$\frac{4\,(x^2+y^2)}{3\,y}$$

that is to say when

$$\frac{2a}{OP} = \frac{OA}{OG} \text{ approximately}$$

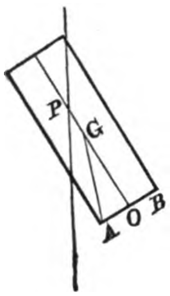

Fig. 44.

2 a being the double amplitude, or range of motion of the edge A, hence

$$2\,a = \frac{OA}{OG} \times OP = \frac{x}{y} \times \frac{4(x^2+y^2)}{3y}$$
$$= \frac{4\,x\,(x^2+y^2)}{3\,y}$$

In the same paper Prof. Omori suggests that, where the amplitude is greater than this and the period a long one, the pillar will, during the forward semiphase of the wave, acquire a velocity of movement equal to that of the wave particle, and on the backward semiphase setting in, this velocity may be regarded as having been suddenly imparted at the centre of gravity of the pillar. Equating this with the work required to turn the pillar till the centre of gravity comes over the edge on which it turns, he gives, for a pillar of rectangular section—[1]

$$v = \sqrt{\frac{8\,g\,\sqrt{x^2+y^2}\,(1-\cos\phi)}{3\cos.^2\phi}}$$

or

$$\sqrt{\frac{8\,g\,y\,(1-\cos\phi)}{3\cos^3\phi}}$$

This formula, however, though different in form, is identical with Prof. Haughton's formula (I, 1) for the overthrow of a rectangular pillar.

Besides pillars that have been overthrown it will be found that others have been broken across but not overthrown. For determining the velocity of wave-particle from this, only one formula has been proposed, though its form may be modified. This is the one given by Mallet—[2]

$$V = g\frac{F_0\,A}{W} \times \frac{k^2}{h\,\beta}$$

where

W is the weight of the mass broken off

[1] Journ. Seismol. Soc., Japan, XVIII, 121 (1893).
[2] Great Neapolitan Earthquake, I. 141.

h. The perpendicular height of the centre of gravity above the base of fracture,

F_0 The coefficient of dynamic cohesion, or the force upon the unit of surface of the material fractured, which, when suddenly applied, is sufficient to produce fracture.

A. The area of the fracture in such units.

k. The radius of gyration of the plane of fracture round the edge.

β. The width of the fractured surface.

In practice the value of F_0 cannot be directly determined, but as it is taken as half of the breaking strain under a load gradually applied, which may be represented by F, the formula becomes

$$V = g \times \frac{F A}{2 W} \times \frac{k^2}{h \beta}$$

or substituting $2x$ for β and y for h to bring the symbols into uniformity with previous formulæ

$$V = g \times \frac{F A}{4 W y x} \times k^2$$

or, since

$$W = 2 y A w$$

where w is the weight per unit volume,

$$V = g \times \frac{F}{8 w x y^2} \times k^2$$

$$= g \frac{L}{8 x y^2} \times k^2$$

Where L is the modulus of cohesion, or length of a column whose weight is just sufficient to cause fracture.

It must be noticed that this V is not v or the maximum velocity of wave-particle, but the velocity which if *suddenly applied* would cause fracture, or, in other words the *acceleration*, hence we may write the formula

$$f = \frac{F A}{4 W y x} = k^2 g \frac{F}{8 w x y^2} = k^2 g \frac{L}{8 x y^2}$$

For a wall or rectangular column

$$k^2 = \frac{\beta^2}{3} = \frac{4 x^2}{3}$$

hence

$$f = g \frac{F A x}{3 W y} = g \frac{F x}{6 w y^2} = g \frac{L x}{6 y^2} \qquad \text{(IV 1)}$$

For a solid cylinder

$$k^2 = \frac{5}{16} \beta^2 = \frac{5}{4} x^2$$

hence

$$f = g \frac{5 F A x}{16 W y} = g \frac{5 F x}{32 w y^2} = g \frac{5 L x}{32 y^2} \qquad \text{(IV 2)}$$

There is yet another means of determining v or the maximum velocity of movement of wave-particle, and that is by means of bodies which have been projected through the air by the earthquake. If we knew the exact angle at which they started on their course it would be easy to calculate the velocity with which they started from the equation

$$v^2 = \frac{a^2 g}{2 \cos^2 \epsilon (b + a \tan \epsilon)} \qquad \text{(V)}$$

where a and b are the horizontal and vertical distances through which the centre of gravity has moved (the latter downwards) and ϵ the angle with the horizon at which it was projected upwards.

In practice ϵ cannot be determined, and the only course to pursue is to adopt a value which will give a minimum value for v. Where b is very small as compared with a, ϵ may be taken as 45° and the equation becomes

$$(\epsilon = 45^\circ) \qquad v = \sqrt{\frac{a^2 g}{a + b}} \qquad \text{(V 1)}$$

which becomes, when b is nothing, as in the case of projection on level ground,

$$v^2 = a g$$

Where b is much greater than a, or the drop is much greater than the horizontal distance travelled, then ϵ may be taken as 0°, that is to say, the projection is horizontal, and the formula becomes

$$(\epsilon = 0^\circ) \qquad v = \sqrt{\frac{a^2 g}{2 b}} \qquad \text{(V 2)}$$

Of these formulæ, that for deducing the acceleration from fracture has not been used, except in the case of the marble cross in the Gauhati cemetery. In the case of the broken tombstones and Khasia monuments it could not be applied owing to the impossibility of determining value of either F or L, nor would it have been any use to test the strength of pieces of stone taken from the monuments, as the irregularity of the weathering the stone has undergone would make it impossible to assert more than that, whatever the breaking strain of the piece tested, that of the stone on the fractured surface would almost certainly be different. Similarly the irregularity and general badness of the brickwork in Assam rendered it useless to attempt to determine the breaking strain, as the strength along different joints, in the same pillar, obviously varied very much.

Generally speaking, it seemed as if the strength was such that the acceleration required to produce fracture was about the same as that required for overthrow, for, of the cases where one of two similar pillars were overthrown and the other not, there were about an equal number where the standing pillar was cracked across and where it was uninjured.

Referring to the tabular statement at the head of this appendix it will be seen that the values obtained for the acceleration are fairly concordant on the whole. As exceptions must be noticed the cylinder seismometer at Shillong, the tomb of Ensign Spooner at Sylhet, and the gate pillars of the Church at the same place. In the case of such very squat pillars, or overthrown portions of pillars, as these, it is probable that overthrow is not due to high horizontal acceleration, but to a large vertical component of the motion. They must in fact be looked upon as modified cases of projection, and it may be doubted whether the formula can be depended on in those cases where the proportions of the object overthrown are such as to give accelerations of over about 12 feet per sec. per sec.

It will be seen that at Gauhati these are a number of cases of overthrow giving values of f ranging up to 17 ft. per sec. per sec. Excluding the high values as suggested in the last paragraph, we get an average acceleration of about 12 ft. per sec. per sec. while the objects projected by the earthquake (excluding the tomb of Mrs. Lamb, where the projected pillar seems to have rolled after touching the ground), we have a velocity wave particle of from 6 ft. to 8½ ft. per sec.

If the motion of the wave-particle was a simple harmonic one, as it would be in a purely elastic wave, and as it has generally been supposed that it may be assumed to have been, without any material error, in the case of an earthquake, it would be possible to calculate, from these data, both the amplitude and period of the wave motion.[1] But if we attempt to combine the acceleration and velocity deduced we obtain a wave period of about 4 seconds, and an amplitude of about 4 feet, both results which are preposterously impossible.

The difficulty is somewhat diminished, though not removed, if we remember that the tabulated values of the maximum acceleration are those of the horizontal component only, and that the fact of stones having been projected upwards shows that the vertical component of the acceleration must have been greater than that of gravity. Taking it as only equal, that is at 32 ft. per sec. per sec., and the horizontal component as 12 ft. per sec. per sec. we get the resultant total acceleration as at least 34 ft. per sec. per sec. Combining this with a maximum velocity of 8 ft. per sec. we find that, on the supposition that this velocity and acceleration were due to a purely elastic vibration, the amplitude would have been about 2 ft. and the period 1½ sec., while if the maximum velocity was only 6 ft. per sec. the amplitude would be 1 ft. and the period 1 sec.

Here there is nothing to find fault with in the deduced period of the wave, but the amplitudes, involving a total range of motion of 4 feet and 2 feet, respectively, are far beyond what there is any reason to believe took place; and it must be remembered that the maximum acceleration and the maximum velocity of wave-particle were certainly not less than the amounts utilized in making this calculation, but were probably greater.

[1] From the formula for simple harmonic motion

$$v = \frac{2\pi a}{t} \qquad f = \frac{v^2}{a}$$

We obtain

$$a = \frac{v^2}{f} \qquad t = \frac{2\pi a}{v}$$

The difficulty is far greater when we consider the case of the projected stones near Rambrai. Taking the maximum velocity at 16 ft. per sec. and the amplitude as 1 foot, which may be regarded as certainly in excess of the amplitude of the wave motion, we obtain the incredible result that the maximum acceleration was 256 feet per sec. per sec. In other words the violence of the shock was equivalent to that of sudden arrest after a fall from a height of 1024 feet. Even if we take the impossible amplitude of 2 feet, involving a backward and forward movement of double this, or 4 feet, the acceleration is only reduced to 128 feet per sec. per sec. or equivalent to sudden arrest after a fall of 256 feet.

It must be clearly understood that, if the movement was due to elastic vibrations or to a wave motion even approximately simulating such, there can be no mistake in these figures. The stone was projected through the air a distance of 8¼ ft. horizontally and to enable it to traverse this distance the initial velocity must have been at least 16¼ ft. per sec., and if the direction in which it was projected was at an angle much greater, or much less, than 45° to the horizontal the velocity must have been even greater.

Knowing the maximum velocity of wave particle, and the amplitude of the wave motion, the maximum acceleration can be infallibly calculated; but we have seen that even assuming an impossibly great amplitude we obtain an incredible acceleration. Where then is the error? Evidently in the assumption that the high velocities determined were those of wave motion.

The results of the revision of the great triangulation in the Khasi hills show that there have been considerable changes, both horizontal and vertical, in the positions of the stations; yet the chain of triangles lay near the outskirts of the epicentral tract, where displacements might be expected to be at their minimum. The observations recorded in Chapter IX show that there have been differential movements approaching 40 feet in vertical height in parts of the epicentral tract, and it is conceivable that in places the actual changes in height and position have been far beyond those which have been measured as yet. This being so we would have, in the epicentral tract, bodily displacement of the ground, apart from true wave motion, which would probably take place by a series of jerks, but might have been a simple and single movement.

To take the case of Rambrai, if we assume that there was a permanent displacement of the ground of only 16 feet, and that the movement was approximately harmonic in its character, *i.e.*, beginning slowly, gradually increasing in rapidity and then gradually dying out, then the required velocity of 16 feet per sec. would only involve a maximum acceleration of 32 feet per sec. per sec. That the acceleration was at least this much we know from the fact that, in order to account for the projection of this block of stone, the vertical acceleration must have been at least 32 feet per sec. per sec. and the maximum acceleration in the ground consequently greater than this.

From this it will be seen that the high velocities of movement which were developed in the epicentral tract cannot be ascribed to the wave motion proper, set up by the earthquake, but must be attributed to those bodily displacements in the earth's crust which were the primary cause of the earthquake. In other words, there were, within the epicentral tract, great movements of permanent displacement, superadded to the molecular vibratory movement of the more or less purely elastic waves set up by the earthquake; and it is to the former of these, rather than to the latter, that high velocities of projection within the epicentral tract must be attributed.

Appendix D.

Details of the direction of overthrow and projection of free falling objects, and a consideration of the applicability of this form of evidence to the determination of the position of the epicentre.

In the following list are given all the cases that have been observed of objects projected or overthrown. In the case of objects overthrown by the earthquake only those whose direction of fall was not largely controlled by their form have been included. Such may be designated as "free-falling," and are almost exclusively square or round pillars or pinnacles; objects having an oblong section with one axis much longer than the other have been excluded, as they were not free to fall in any direction, but must necessarily fall more or less at right angles to their longer axis.

Nature of object and reference.		Overthrow or projection.	Azimuth.
Calcutta—			
Sir W. Jones's Monument	p. 257	O	200
Mrs. Wiltshire's ditto	p. 257	O	207
St. Paul's Cathedral spire	p. 258	O	211½
Town Hall balustrade	p. 258	P	200
Free Kirk spire	p. 289	O	260
Jalpaiguri—			
Cupolas on District Board's Office	p. 281	P	162
		P	357½
Darjiling—			
Bhutia tombs	p. 283	O	128
Chimneys at Senchal	p. 283	O	128
Rangpur—			
Images on gate-posts of Dimla Rajah's house	p 285	O	96½
Tombs in cemetery	p. 285	O	97
Do	p. 285	O	277
Pillars of Library verandah	p. 285	O	94½
Gate-post of Collector's house	p. 285	O	94½

NATURE OF OBJECT AND REFERENCE.		Overthrow or projection.	Azimuth.
KUCH BIHAR—			
Marble vase in Palace	p. 288	O	110
Clock Tower	p. 288	O	108
Urn on turret of Superintendent's house	p. 288	P	110
Gate-post of Superintendent's house	p. 288	O	102$\frac{1}{8}$
Watch Tower	p. 288	O	108
Minaret of mosque	p. 288	O	298
BUXA DUARS—			
Prevailing direction	p. 288	O	138
GOBARDANGA—			
Turret on Zemindar's house	p. 315	O	205
FARIDPUR—			
Bottles overturned	p. 317	O	29
DACCA—			
Pillar by Race course	p. 290	P	115
Nazir's Mutt	p. 291	O	335
MAIMANSINGH—			
Hindu temple	p. 293	P	48
DHUBRI—			
Telegraph Office gate pillar	p. 259	O	40
Gate pillars	p. 260	O	0
Gate pillar	p. 317	O	355
Do.	p. 317	O	145
GOALPARA—			
Tubs	p. 262	P	357
Tomb of Ensign Law	p. 262	P	355
Pillar near cemetery	p. 263	O	120
Boundary pillar No. 1	p. 317	O	50
Do. 2	p. 317	O	273
Do. 3	p. 317	O	63
Do. 4	p. 317	O	295
Do. 5	p. 317	O	235
GAUHATI—			
Deputy Commissioner's Bungalow pillars	p. 263	O	150
Do.	p. 263	O	140
Telegraph Signaller's quarters	p. 264	O	200
Top of pillar in Civil Surgeon's Compound	p. 264	P	145
Compound, west of Deputy Commissioner's bungalow	p. 265	O	200

Nature of object and reference.		Overthrow or projection.	Azimuth.
Gauhati—*contd.*			
Compound, west of Deputy Commissioner's bungalow	p. 265	O	290
Do.	p. 265	O	325
Do.	p. 265	O	270
Do.	p. 265	O	100
Do.	p. 265	O	0
Do.	p. 265	O	340
Tomb of G. T. Bayfield	p. 265	O	160
„ F. Gomes	p. 265	O	155
Cylindrical tombs	p. 265	P	315
Do.	p. 265	O	225
Miss Lamb	p. 255	P	180
Loki Rani's house, gate pillar	p. 317	O	60
Gate pillar near Telegraph Club	p. 317	O	167
Do.	p. 317	O	140
Monument to Robert Beecher	p. 317	P	165
Chhatak—			
Gate Pillar of Monument to Lieutenant H. T. Bird	p. 218	O	0
	p. 318	O	180
Shillong—			
Gate pillars	p. 270	O	180
Ashley Hall gate post	p. 270	O	0
Do.	p. 270	O	180
Colonel Magregor's gate post	p. 270	O	350
Other gate pillars	p. 270	O	175
Do.	p. 270	O	205
Do.	p. 270	O	180
Cherrapunji—			
Inglis' house gate pillars	p. 272	O	200
Do.	p. 272	O	135
Gate pillar	p. 273	O	50
„ „ Bungalow on East road	p. 318	O	257
Do.	p. 318	O	40
„ Dâk bungalow	p. 318	O	210
Do.	p. 318	O	205
Hudson's bungalow gate pillars	p. 318	O	230
Do.	p. 318	O	235
Verandah pillar	p. 318	O	23
Do.	p. 318	O	55
Do.	p. 318	O	153
Do.	p. 318	O	75
Silchar—			
Cylinder Seismometer	p. 359	O	4
Gate pillar, Mission house	p. 318	O	0

Nature of object and reference.		Overthrow or projection.	Azimuth.
SYLHET—			
Gate pillar near Government School	p. 274	O	40
„ „ Deputy Commissioner's bungalow	p. 274	O	0
Tomb in cemetery	p. 274	O	155
„ of Ensign Spooner	p. 275	O	90
Brick pillar	p. 275	O	180
Square column	p. 275	O	225
Gate pillar, New Hospital	p. 276	O	288
„ , Church	p. 276	O	0
Do.	p. 276	O	250
Vertical boiler	p. 276	O	240

In the early days of the modern development of seismology, great importance was attached to the direction of overthrow of free falling objects, as a means of determining the position of the epicentre and hence of the focus. This method was employed by Mr. R. Mallet, in the case of the Neapolitan earthquake of 1857 with a concordance in the intersection of the lines of direction obtained, so conspicuous as to give great support to the supposition on which the method was based. In the case of subsequent earthquakes, however, the method has not been found so successful, and with the growth of a more accurate knowledge of the true nature of earthquake motion, as derived from the labours of the band of workers in Japan who have practically revolutionised seismology, the method has become discredited.

It was found that instead of being a simple to and fro motion, the motion of the wave particle was extremely complicated, and that, in the case of moderate earthquakes, the maximum movement was by no means always or even usually in the direction of the propagation of the earthquake wave, but might be at any angle with it. Assuming that the same held good of more violent earthquakes it was evident that the direction of overthrow would only exceptionally be that of the propagation of the earthquake wave, and would consequently generally point in any direction except that of the seismic vertical.

Against this there has always stood the case of the Neapolitan earthquake where the direction of overthrow in the vast majority of cases pointed to the epicentre, and it has long seemed to the writer that the assumption, that the nature of the movement in violent and in moderate earthquakes was similar, went too far. It is conceivable that, within the limits where the shock has still power to cause the overthrow of gate pillars, etc., the one or two vibrations, which alone have this power, should be directly or nearly directly outwards from the centre, while further away this relationship might cease to hold good.

An examination of the tabulated directions of overthrow and projection lends some support to this supposition. At places like Shillong, which were within the limits of the epicentre, or, like Gauhati, which were close to it, there is no uniformity in the direction of overthrow. At a greater distance from the epicentre and where it has come to subtend but a small angle, it is to be remarked that the directions of overthrow almost all point towards it.

From this it would seem that the method of determining the epicentre by means of the direction of overthrow of free-falling objects is one that may be depended on, when other means fail. Certain obvious precautions must be taken. The objects whose direction of overthrow is taken must be of such a shape that they have no greatly prevalent tendency to fall in one direction rather than another and they must have been overthrown cleanly. If the surface of fracture shows great crushing at the edges, indicating that the pillar has rocked to and fro before falling, it should not be utilised, as the final direction of overthrow is almost certain not to be that in which it was first set rocking. Another precaution to be observed is that the observations must be sufficiently numerous, and the intersections lie pretty close together. This is necessary for, though it is certain that in some earthquakes the greatest and most violent motion is directly in the line of propagation of the earthquake wave, it is possible that in others the reverse may be the case, and, if so, the directions of overthrow will not, if produced, intersect at or near the right point.

Appendix E.

Details of the records of the Seismometers at Shillong and Silchar.

In 1882 seismometers of Mallet's cylinder pattern were set up in Shillong and Silchar. Each consists of a set of cylinders 12 inches in height and of the following diameters :—

No. 0	1"	No. 3	3·75"	No. 6	7·0"
„ 1	1·5"	„ 4	5·0"	„ 7	8·0"
„ 2	2·5"	„ 5	6·0"	„ 8	9·0"

The corresponding accelerations in ft. per sec. per sec. required for overthrow are :—

No. 0	2·7	No. 3	10·0	No. 6	18·8
„ 1	4·0	„ 4	13·0	„ 7	21·5
„ 2	6·7	„ 5	16·1	„ 8	24·2

Besides these there was at Silchar a square wooden post, 4·05 ft. in height, at each top corner of which a cubical recess was cut, containing a small bullet to be projected by the shock. Full details of these instruments will be found in *Memoirs* Vol. XIX, Pt. I, Appendix, pages 93-98, and need not be repeated here.

Shillong.—At Shillong the seismometer shed is close to the hospital, and was the only building left standing after the earthquake. It was used by the hospital assistant to shelter the patients, and all that is known of the effect of the earthquake is that all nine cylinders were upset in a north-north-easterly direction. The cylinders were not reerected for three days, during which several shocks occurred sufficiently violent to overthrow some of the cylinders. For the subsequent records I am indebted to Surgeon-Lieutenant-Colonel R. Neil Campbell, Civil Surgeon of Shillong.

12th June	. 5-15 P.M. 9 cylinders fell, south-south-east to north-north-east.
16th June	. during night, time not noted. 1 cylinder fell, south-west to north-east.
19th June	. 5-15 P.M. 3 cylinders fell, south-west to north-west.
Ditto	. 10-30 P.M. 2 cylinders fell, south-west to north-east.
	. during night, time not noted. 1 cylinder fell, north-west to south-east.
12th July	. 8-35 P.M. 2 cylinders fell, west-north-west to east-south-east.
2nd August	. 9-30 P.M. 3 cylinders fell, Nos. 0 and 2, west to east. No. 1 south-south-west to east-north-east.

The shock of 5-15 P.M. on 19th June is a remarkable one as, in spite of its severity, it seems to have been local; it was felt at Tura and, apparently, in Gauhati, but elsewhere I have not been able to identify it in the records received.

Silchar.—Here 2 cylinders were overthrown, No. 0 to N 4° E, No. 1 to N 4½° E; of the spheres the one in the north-east corner was thrown 4 inches to E 10° S; the south-east corner, 8½ inches to S 47° W; the south-west corner 3½ inches to S 69° W; while the bullet in the north-west corner was not displaced.

No subsequent shock affected the seismometer at Silchar.

These details were communicated by Surgcon-Lieutenant-Colonel S. Borah, Civil Surgeon.

Appendix F.

Details of the special observations made by the Telegraph Department, referred to in chapter X.

These details are extracted from the reports of the telegraph masters who were instructed to observe the intervals of time between the arrival of shocks at one station and its neighbouring ones. The name of the station in italics is that of the reporting one and what follows an abstract of the report:—

September	27th	12-29	*Shillong*, severe; felt at Sylhet simultaneously, but very slightly.
		21-38	*Shillong*, severe and prolonged; felt by Gauhati simultaneously, very severely.
,,	30th	19-46	*Shillong*, severe; felt by Gauhati about 1 minute before us.
October	3rd	7-0	Gauhati, Goalpara and Dhubri, felt a severe shock not noticed at Shillong.

October	5th	9·55	*Shillong*, two slight shocks followed by a very severe one; felt severely at the same time by Gauhati.
"	6th	4·1	*Shillong*, severe; felt by Gauhati at the same time.
"	7th	10·22	*Shillong*, severe; felt slightly by Gauhati at the same time.
"	9th	1·7	*Shillong*, very severe; felt at Gauhati severely, simultaneously, not noticed by Sylhet. *Dhubri*, reports the same shock, message sent to Gauhati and no reply for 30s.; (this appears to be due to a delay in replying and not to a true interval of 30s. between the shock being felt at Dhubri and Gauhati).
"	11th	12·45	*Shillong*, smart; felt at the same time by Gauhati slightly; not noticed by Sylhet.
"	13th	14·44	*Shillong*, very severe; felt by Gauhati 2s. after us, whence it was reported as 'smart'; not noticed by Sylhet.
"	14th	8·19	*Shillong*, severe; felt by Gauhati 2s. before us; Gauhati reports it as 'severe.'
"	18th	10·35	*Shillong*, severe; felt by Gauhati 2s. after us, 'very severe'; by Sylhet simultaneously but slight; original signal sent from Sylhet. *Dhubri* reports the same shock, a signal sent to Gauhati was replied to immediately.
"	21st	13·46	*Shillong*, severe; felt 3s. or 4s. after Gauhati; not felt by Sylhet.
"	22nd	9·37	*Shillong*, severe; felt at same time with Gauhati.
		15·32	*Shillong*, severe; felt by Gauhati and Sylhet at same time; *Gauhati* sent original signal; Mangaldai felt the shock at the same time.
"	25th	5·48	*Shillong*, slight, felt by Gauhati same time, not felt by Sylhet; *Gauhati*, lasted 60s. original signal received from Shillong, time taken for earthquake to reach Gauhati one minute from time of original signal.
"	27th	12·31	*Shillong*, a slight shock followed by a smart one; felt by Gauhati in the same way, but 5s. after us; not felt by Sylhet.
"	31st	8·55	*Shillong*, severe; felt at the same time at Gauhati.
November	2nd	4·31	*Shillong*, severe; felt slightly by Gauhati at the same time.
"		10·55	*Shillong*, severe; felt at the same time by Gauhati. *Gauhati* original signal from Shillong, interval between shock felt at Shillong and Gauhati 1 m.
"	2nd	11·48	*Shillong*, slight, felt by Gauhati 5s. before us. *Gauhati*, simultaneous shock at both places.
"	13th	13·11	*Shillong*, smart, signal received from Gauhati 2s. before shock.

November 15th	4·50	*Shillong*, severe ; felt 10s. after Gauhati.
„ 17th	20·17	*Shillong*, very severe, felt by Gauhati and Sylhet at the same time.
„ 26th	9·50	*Shillong*, severe, felt by us about 2s. after Gauhati.
December 17th	17·42	*Gauhati*, felt 3s. before Shillong.

Appendix G.

Details and Discussion of the results of the Revisionary Triangulation of the Khasi Hills, carried out by the Great Trigonometrical Survey in the season 1897-98.

The accumulation of independent evidence, from many witnesses and widely separated places, all pointing to the fact that the earthquake had been accompanied by noticeable changes in the relative heights of peaks in the Khasi and Garo Hills, led the Government of Assam and the Director of the Geological Survey almost simultaneously to represent to the Government of India the desirability of testing the accuracy of these statements by a revision of the triangulation of the hills. The representations met with a favourable reception; it was decided that retriangulation should be taken in hand during the cold weather of 1897, and as much done as was compatible with the other calls on the staff of the Great Trigonometrical Survey. In pursuance of this decision, a programme of work to be done was drawn up by Major S. G. Burrard, R.E., Officiating Superintendent of Trigonometrical Surveys, in consultation with myself.

At the outset it became evident that what was desirable was not possible, owing to the calls on the Trigonometrical Survey due to the total solar eclipse, and to the regular work which could not be interrupted. Only one observer could be deputed for the revisionary triangulation, and the only instrument available, though an excellent one, was not of the power considered necessary for primary triangulation. In these circumstances a compromise was made between what was desirable and what was possible, and the decision come to was to reobserve certain triangles in the Khasi hills, and, if time allowed, certain others in the western Garo Hills. This latter part of the programme it was not possible to carry out, and the triangles actually observed were those represented on Plate XLIII.

In coming to this decision it was recognised that a triangulation so much in the air, and unconnected with any points which could with any degree of certainty be regarded as undisturbed, would give no information as to absolute displacements, whether vertical or horizontal. All that was looked for was a discovery of whether there had been any relative displacements of the trigonometrical stations; if none such were found, it would be certain that no general displacement, which would be detected, had taken place. With such an object in view it was obviously necessary that the triangles selected for reobservation should be situated where there was the greatest inherent probability of their having undergone distortion. At the time the decision was come to, the exploration of the epicentral region, described in Chapter IX, had not been commenced, and we were still under the impression that the focus most probably lay under the southern part of the Khasi Hills.

Another principle that was accepted as a guiding one, was that there was no use in reobserving what are known as Tower Stations; that is stations where, in the absence of natural elevations, brick towers had been built on the alluvium, from which to observe. If retriangulation was necessary for geodetic purposes, all these stations would require refixing, for within the area over which earth fissures were formed, it would be impossible to assume that any of them had not been disturbed by displacements of the alluvium on which they rested, and this quite independent of any change or absence of change in the underlying rock.

A group of triangles extending northwards from the southern margin of the Khasi Hills was accordingly selected, and as there happened to be an isolated hill in the Sylhet plain, Taramun Tila, which had been selected as one of the points the original primary triangulation, it was decided to include this.

These preliminaries having been arranged the work was taken in hand by Mr. J. Bond, Extra Assistant Superintendent, and the results have been embodied in a report by Major Burrard, from which the following tabular statements of the changes observed are taken.

Changes in length of sides.

Side.	1860 value.	1898 value.	Difference.
	Feet.	Feet.	Feet.
Taramun Tila—Mopen	99101·5	99106·3	+4·8
Mopen—Rangsanobo	95013·1	95018·0	+4·9
Rangsanobo—Thanjinath	60421·3	60424·7	+3·4
Mopen—Mosingi	65344·6	65344·6	0·0
Rangsanobo—Mosingi	54152·5	54154·8	+2·3
Rangsanobo—Mun	67892·7	67895·9	+3·2
Thanjinath—Mun	47884·1	47884·0	—0·1
Mosingi—Mun	84893·2	84897·6	+4·4
Mosingi—Mautherrichan	83931·8	83933·0	+1·2
Mosingi—Laidera	64350·8	64353·4	+2·6
Mun—Laidera	63007·7	63007·4	—0·3
Mun—Dinghei	72154·3	72156·7	+2·4
Laidera—Mautherrichan	72373·1	72377·0	+3·9
Laidera—Dinghei	57583·0	57584·1	+1·1
Mautherrichan—Landau Modo	50746·7	50755·3	+8·6
Dinghei—Umter	75209·0	75211·3	+2·3

Changes in heights of Stations.

Station.	1860 value.	1898 value.	Difference.
Taramun Tila	144	150	+ 6
Mopen	2,581	2,577	— 4
Rangsanobo	...	...	...
Thanjinath	4,440	4,443	+ 3
Mosingi	5,794	5,798	+ 4
Mun	6,212	6,214	+ 2
Laidera	6,180	6,186	+ 6
Mautherrichan	6,288	6,312	+24
Dinghei	6,067	6,074	+ 7
Landau Modo	5,160	5,177	+17
Umter	3,367	3,670	+ 3

Displacement of Stations.

Station.	Latitude.		Longitude.		Total.	
	Amount.	Direction.	Amount.	Direction.	Amount.	Direction.
	Ft.		Ft.		Ft.	
Mopen	2	N	5	W	5	NW
Thanjinath	6	N	2	E	6	N
Mosingi	0	...	3	W	3	W
Mun	4	N	0	...	4	N
Laidera	2	N	•	...	2	N
Mautherrichan	1	N	5	W	5	W
Dinghei	8	N	4	W	9	NW
Landau Modo	9	N	7	W	12	NW
Umter	7	N	8	W	11	NW

The figures in these tables refer only to the principal stations; besides them I am indebted to Mr. Bond for the following information regarding the displacements of other stations, which seems worth publication, though the data were less complete and the calculations less rigorous than in the case of those printed in Major Burrard's report.

Changes in height and position of Secondary Stations.

Station.	Alteration in		
	Height.	Position.	
	Ft.	Ft.	Direction.
Suair	+ 2·6	7·1	N
Rableng	+ 2·7	7·1	N
Shillong	+ 4·2	7·1	N
Somullon	+ 5·5	10·3	N
Laitbli	+ 9·0	2·1	NE
Mairang	+ 10·8	?	?
Kollong Rock	+ 14·4	5·6	W
Sniang	?	9·2	W

A cursory inspection of these tables shows that there have been differential movements of the stations, with respect to each other, which are too large and too irregular to allow of their being attributed to errors of observation. The tabulated displacements appear also, at first sight, to indicate that there has been a general elevation and extension of the hills, such as might follow on a bulging upwards of the surface due to the intrusion of a large mass of molten matter underground. A more detailed examination, as will be shown, does not bear out this conclusion.

In starting any calculation, it was necessary to assume one side of one triangle unaltered and accept this as a base; but it is clear that within the area over which the triangulation spread no single side was left unaltered and there is consequently no fixed base to start from. To quote Major Burrard's report.—

> "The above results go to show that all Mr. Bond's triangulation lay within the area affected by the earthquake: no reliable base is consequently forthcoming for the computation of his observation. Whatever side or height we start from, we find that all other sides and heights have altered, but the errors of our initial side and height pervade the calculations, and the movements caused by the earthquake are given differently whenever we change our basis.

For the results tabulated above the side Rangsanobo—Taramun Tila was adopted as the initial base for the triangulation, and the height of Rangsanobo as the initial height, Mr. Oldham being of opinion that these southerly stations are least likely to have been affected."

On which I need only remark that I am still of the same opinion, but consider that it should have led to the adoption of Taramun Tila rather than Rangsanobo as the starting point to which changes of elevation should be referred.

I had suggested that, as compression in a north-south direction was to be expected, while compression in an east-west direction was less likely to be met with, the assumed fixed base should be a side of a triangle bearing about east and west. In the final calculations the side Rangsanobo-Taramun Tila was adopted as the base, but whether from a desire to adopt a base of which one extremity might be considered as unchanged, or for convenience of calculation, or because it gives the smallest amount of general displacement, there is nothing to show. What now remains to be investigated is the probability of any change having taken place in the length of this side, and the effects such change would have on the deduced values of other stations.

Taramun Tila is a small hill of tertiary beds, rising out of the Sylhet plain near Chhatak. It lies outside what I believe to be the limits of the epifocal area and, as it is a hill station, is not liable to the displacement which would probably have affected a station built on the alluvium in this neighbourhood. The position and height of Taramun Tila may consequently be regarded, with considerable probability, as unaltered.

Rangsanobo, on the other hand, lies near the southern edge of the Khasi Hills, and apparently within the limits of the epifocal area. In this case a displacement is probable, and this would probably be such as to cause a shortening of the distance between it and Taramun Tila. Consequently it is probable that the present length of this side is shorter than of old.

The effect of this shortening would be to increase the apparent length of all other sides, for, the base being assumed to be greater than it really is, this would lead to the other sides being calculated as larger than their true length, in a corresponding degree. Moreover, as the error would be cumulative it would lead to just such a stretching out of the ground as seems to be indicated by the tabulated results.

The supposition that the apparent stretching of the hills is really due to the adoption of too high a value of the initial base, is confirmed on a more detailed examination of the tabulated changes.

It will be noticed that the sides Mopen—Rangsanobo—Thanjinath, which run nearly east and west, have apparently lengthened 4·9 feet and 3·4 feet, respectively. Connecting these three stations with Mosingi and Mun, we have four sides with a considerable amount of northerly departure in them. Of these one appears to have shortened 1 foot, another is unchanged, and the remaining two have lengthened 2·3 and 3·2 feet, respectively. Here the increased length which should have been found if the shape of the triangles had been unaltered, is greatly diminished or has disappeared; this may be attributed to a compression of the hills in a meridional direction, for the next east-west side, that joining Mosingi to Mun, again shows an extension of 4·4 feet. North of Mosingi and Mautherrichan the sides again exhibit a marked diminution of the apparent expansion, but the distance between Mautherrichan and Laidera has increased 3·9 feet, in a W. by N. direction. Beyond this the changes get very irregular, and it is impossible to say how far they may be due to change in the assumed fixed base.

The conclusion pointed to in the last two paragraphs comes out still more clearly when the table showing the displacements of the stations is examined. In this, as in all the other lists, I have arranged the stations in order from south to north, arranging those which are on nearly the same parallel in order from west to east. It will be seen from this that the apparent displacements of the three stations on the south of the Khasi hills indicate an extension of 5 and 6 feet on either side of the starting point, Rangsanobo. Northwards of these, the displacements decrease in a marked manner till we reach Mautherrichan and Dinghei, to the north of which they increase conspicuously.

The true explanation of these facts I take to be, that the assumed value of the base Rangsanobo—Taramun Tila was in excess of the real value. This led to an apparent increase in all other sides which, so far as the calculations go, would be cumulative and lead to an apparent expansion of the whole chain of triangles. Northwards of Rangsanobo, however, this apparent expansion was masked by an actual compression of the country as a whole, a compression which was not, however, sufficient to reverse the apparent effect of the change in the base line. Northwards of Mautherrichan and Dinghei the compression appears to die out and the cumulative effect of the error of the original base becomes conspicuous once more.

Another point to notice is that a distinct increase in the compression is suggested as we go southwards. Towards the northern limit of the triangulation its effect is small. Between the latitudes of Mosingi and Mautherrichan it becomes more noticeable, and still more so between Mosingi—Mun and the three southern stations; the compression here being in two cases sufficient to completely counteract the apparent expansion. It is by no means impossible that the compression was greater still further south, and reached its maximum at the southern limit of the Khasi hills, so that the assumed unchanged base may have really suffered a greater actual change than any of the other sides.

We have seen that a detailed examination of the apparent expansion of these hills is consistent with a real compression and a shortening of the initial base. It is also indubitable that such compression is consistent, not only with what is known generally of the causes of great earthquakes, but also and more particularly with the conclusion come to, on independent grounds, as to the cause of this particular earthquake, while a real extension of the hills would be very difficult to reconcile with that explanation. Putting these two considerations together the conclusion may be adopted that the Khasi hills were not extended but compressed in a north and south direction, and that the apparent extension was due to a real, but unnoticed, contraction of the assumed initial base.

In considering the changes in the heights of the stations it must be remembered that the same dependence cannot be placed upon them as on the positions, refraction being much more liable to introduce errors into vertical angles than in horizontal angles. The changes, it will be observed, are, as a rule, small, but so far as they go seem to indicate a slight general upheaval of the hills. Even this must, however, be regarded as doubtful. The starting point was Rangsanobo, which was assumed unchanged, and calculating from it, Taramun Tila was found to have risen 6 feet. As has been explained the inherent probability is more in favour of this station having remained unaltered in height than Rangsanobo, and if this was so, then, assuming the results can be depended on, the tabulated heights of all other stations would have to be reduced by 6 feet and as a result the height of the Khasi hills would remain practically unchanged, or even diminished.[1] As already mentioned no great weight can be attached to these observations, but it is evident that over the area covered by the triangulation there has been no marked alterations in the general height of the hills.

There are two stations, however, which form marked exceptions to this general rule; Mautherrichan, with a rise of 24 feet, and Landau Modo with a rise of 17 feet. These amounts may be regarded as in excess of the possible errors of observation, and it may be taken that these peaks have risen by noteworthy amounts, even though the tabulated values may not be exact to a few feet.

If we look to the situation of these two peaks the explanation of the exceptional local elevation becomes clear. Both of them are situated on the crest of conspicuous fault scarps, of the type described in Chapter IX, and Landau Modo is close to two of the pools formed by distortion of the surface, details of which will be found in the same chapter.[2]

If we turn to the changes in the heights of the secondary stations we find the same thing repeated. The only two that seem to have undergone any conspicuous change in height are the Mairang and Kollong rock stations, both situated near the edge of fault scarps. With the exact position of Laitbli, which has risen 9 ft., I am unacquainted, but from its position it also is probably on or near the edge of one of these fault scarps.

These facts regarding the distribution of changes in the elevation of the hills afford a strong confirmation of the description of the structure of the Khasi and Garo hills given in Chapter IX, and of the explanation given of the nature of the focus and the cause of the earthquake given in Chapter X, but were not available in time for incorporation in those chapters.

Though the explanation given above of the nature and cause of the displacements that were observed is that which must be regarded as most probable, it must not be forgotten that a different explanation is conceivable. The known facts of structural geology show that certain regions have been subject to direct elevation which, so far as the surface rocks are concerned, is not due to the indirect effects of compression. Besides mountains of compression, of which the Alps and

[1] The effect of errors in the calculated length of the sides, due to an error in the assumed length of the initial base, may be neglected.

[2] See p. 156.

Himalayas are the leading types, there are mountains of faulting, the 'Schollen-gebirge' of German, and 'block mountains' of American, geologists. In these the relief is directly due to movements along the lines of faulting by which the rocks are traversed, and the principal crests and steepest slopes, though modified by subsequent denudation, follow and are due to these lines of fault.

In the case of hills of this type, their elevation far from having been due to compression, has been accompanied by an actual extension of the ground they cover. The faults are vertical or normal and the horizontal distance between two points on either side of the fault, is greater after, than it was before, the elevation. The mechanism of the formation of these mountains of faulting is not very easy to understand; it may be that the faulting and stretching are confined to the upper layers of rock and are indirect results of a compression, and consequent thickening of the more deep seated layers, through the small depth at which the level of no strain is placed makes this supposition difficult of acceptance. A more probable explanation is that over certain areas the upper layers are protected from that compression which is their general fate, and follow the movements of the rocks below the level of no strain, which are being stretched. The tension thus set up in the rocks above the level of no strain would cause them to be split by vertical or highly inclined fractures, and the horizontal extension would be taken up by subsidence along these.

Whatever may be the explanation, the facts are undoubted, and it is conceivable, though with difficulty, that in such a region tensional strains might be set up of sufficient greatness to give rise to a severe earthquake by their sudden relief. The Assam range presents the superficial features of a region of mountains of the character just considered, and it may be that the explanation of the fault scarps is not that offered in Chapter X. Possibly the elevation of the range was accompanied by extension and not by compression, and in that case the apparent extension, exhibited by the results of the retriangulation, would be in accordance with what should be expected. The small changes, exhibited by the southern triangles would be explained by the absence of fault scarps in that region, while the great changes of horizontal distance, as well as of elevation, in the northern triangles would be explained by the number of fault scarps seen in the region they cover.

If this explanation is adopted it would cause no change in the conclusions stated in Chapter X as to the position, the complexity or the extent of the seismic focus regarded as a whole, but the assumed thrust plane or planes, uniting the complex of more superficial fractures and faults, would not exist, and the strain to whose relief the earthquake was due would be one of tension and not compression. In other words it would cause no change in what can be directly determined from observed facts, though some change may be necessary in the more remote deductions as to the ultimate cause of the earthquake.

[1] It would also make the faults, to which the fault scarps of the Assam range are due, normal and not reversed faults, and the great monoclinal fold along their southern edge a flexure, in the restricted sense in which the word is employed by Suess, and not a fold. The distinction being that a fold is the result of compression, a flexure of differential elevation on either side of the disturbed tract. As a consequence the distance between two points in any given bed, situated on either side of the fold or flexure, will be less than the original distance in the case of a fold, greater in that of a flexure.

Though the possibility of a different explanation to that adopted in the text, before the receipt of the results of the retriangulation, has been indicated, it must be pointed out that though possible it is, so far as present information goes, much the less probable of the two. In the first place, even if it be granted that tensional strains might be set up in the earth's crust of sufficient magnitude to give rise to a severe earthquake by their sudden relief, it is almost impossible to understand how their relief could give rise to such an extensive and complicated series of fractures as would have to be inferred in the case of the 1897 earthquake. Then the rapid variations in throw of the great Chedrang fault are more in accordance with what would be anticipated if it had been accompanied, or caused, by compression in a north and south direction, than if it had been the result of direct elevation. The nature too of the observed displacements of the trigonometrical survey stations bears out this supposition, that is to say the smallness of the apparent extension of the sides which run more or less north and south, as compared with those that run more or less east and west, is, as has been shown, explicable on the supposition of a general compression of this tract in a N—S direction. If there had been a real extension this should have been mainly north and south, seeing that the general run of the fault scarps is about east and west, and that the stretching of the tract, if there is any, would be at right angles to this or more or less north and south. The shape of the epifocal area points to the same conclusion, its length from E to W being greater than from N to S, it follows that the displacements to which the earthquake was due would be greater, on the whole, from north to south than from east to west, and this whether they were the result of compression or extension. The apparent displacements of the trigonometrical stations, if real and due to a general expansion of the hills, would necessitate this expansion being greater from east to west than from north to south; consequently this hypothesis is not in accord with either the general structure, or the form of the focal area; it has already been shown that both are in accordance with the alternative hypothesis of a general, though not uniform, compression in a more or less north and south direction.

It will be seen from this that the explanation of the cause of the earthquake given in the text remains the most probable one, but that there is the possibility of another explanation. The final establishment of one or other hypothesis will depend on the extension of a retriangulation of these hills from a base known to have been unaffected by the earthquake.

The triangulation carried out during the season of 1897-98 has fulfilled all that could be expected of it. It has shown beyond doubt that there have been considerable displacements, both vertical and horizontal, of the hills within the epifocal area, but as it could not be founded on any origin which was unchanged by the earthquake, it can give no final measurement of the amount of these changes.

The facts established by the triangulation already carried out and the uncertainty as to the exact nature of the changes that have taken place make it more desirable that the work should be completed, and in view of the possibility of this it may be well to point out what is desirable.

It so happens that the chains of triangles of the great triangulation are singularly favourably situated for a measurement of the displacements that have taken place. At the western end of the epifocal area a chain of triangles along the 90° meridian skirts the edge of the Garo hills and, so far as they extend, is based on hill stations. On the 92° meridian another chain of triangles, that which was partly reobserved in 1897-98, runs right across the Khasi hills. At right angles to these two, a chain of triangles runs up the Brahmaputra valley, and in the stretch between the two meridional chains, the stations are almost all situated on rocky hills rising out of the alluvium.

A retriangulation should start on the 92° meridian, in the country south of the Sylhet valley. Any triangle here, whose three angles are all based on hill stations, would probably be found to be undisturbed, and might be taken as a starting point. Should it be found to have suffered distortion, which is highly improbable, the observations would have to be carried backwards, away from the Khasi hills, till an undistorted triangle was found, any of whose sides might safely be taken as an initial base.

Starting from this, triangulation should be carried northward, till the transverse chain of triangles in the Brahmaputra valley was met. Here the work would turn westward and continue down the Brahmaputra valley to Dhubri, and in this part the greatest displacements are to be looked for. From Dhubri the triangles of the series on the 90° meridian should be reobserved as far south as they are based on hill stations.

To complete the work it would be well to carry a chain of triangles from the neighbourhood of Tura to that of Cherrapunji, thus linking the two meridional series and forming a quadrilateral within the epifocal area. These triangles should be based on peaks fixed by the triangulation of the topographical survey, a triangulation which falls far short of that of the great trigonometrical survey in rigour and accuracy, but being connected with it on all sides the maximum error would fall far short of the displacements that are to be looked for in this tract.

The only previous occasion on which displacements connected with an earthquake have been actually measured is, so far as I know, that of the earthquake of 17th May 1892 in Sumatra.[1] The principal triangulation was then in progress and after the earthquake it was found that the angles observed would not correspond with these observed before the earthquake. Certain of the triangles were reobserved and it was found that the stations had been displaced, the greatest distance between those which had undergone measureable displacement being about 53 kilometres (33 miles). Beyond this some other stations were found to have been displaced, but as they had not been fully fixed before the earthquake their displacements could not be measured.

The greatest measured displacement was 1·23 metres with a probable error of ·28m.; we may consequently say that the maximum displacement could not have

1 J. J. A. Muller De Verplaatsing van einige Triangulati-Pilaren in de Residente Tapanœli (Sumatra) tangevolge van de aardbeving van 17th Mai 1892: Verhandl. K. Akad v. Wetenschappen te Amsterdam, 1 sect. III, No. 2(1895) abstracted in Peterman's Mittheilungen 1895, pp. 97-98.

exceeded 5ft. With about the same length of triangles we have in the case of the 1897 shock a maximum displacement calculated at 12ft. As has been explained, there is some uncertainty about the basis of this calculation, and if the explanation offered above is the true one, this figure requires modification, but whether the maximum displacement would be in excess or defect of it, cannot be decided in the absence of detailed calculations. In any case it seems certain that the amount must have been considerably in excess of 5ft., and it must be further borne in mind that this triangulation lies near the limit of the epifocal area, and far removed from the part where displacements were at their maximum.

Appendix H.

A Review of the extent of the Lisbon Earthquake of 1st November 1755, as compared with that of the Great Earthquake of 12th June 1897.

In a preliminary note on the earthquake, written six weeks after the event, I referred to it as 'unsurpassed by any since the great Lisbon earthquake of 1st November 1755, and rivalling this in magnitude of the area over which it was felt; surpassing it indeed, if we exclude the doubtful records of the earlier shock.'

This statement excited surprise and was even called to question in the press, yet a fuller knowledge of the extent of the earthquake of 1897 has borne it out. The surprise was a natural outcome of the very exaggerated ideas of the extent of the Lisbon earthquake which are to be found repeated from one text book to another without verification. I have thought it desirable, on this account, to append a short review of what is known of the extent over which the Lisbon shock was felt.

To begin with, no comparison of violence is possible. The data in the case of the Lisbon shock are altogether too imperfect to permit of this, nor is it of importance in determining the relative magnitude of the two shocks. Some earthquakes, it is known, may, like those of Ischia, have a great local violence but very small extent, yet it would be absurd to speak of these as of greater magnitude than others which, though nowhere rising to the same degree of violence, are felt over a kingdom or two.

The only strictly scientific comparison of two shocks would be a comparison of the energy developed in each. This measurement is unfortunately still impossible, but there is good reason to suppose that is approximately proportional to the area over which they are felt. Any way this is the only possible means of comparison in the present state of seismology, and as the results it leads to are at any rate approximately true, it is the one that I have adopted.

Before instituting a comparison it is necessary to have a clear conception of what is meant by the area over which the shock was felt. The Lisbon earthquake originated under the sea and set up large sea-waves, to which much of the loss of life in Lisbon was due, and these waves were observed everywhere along the Atlantic coasts, even to the West Indies. Yet it would be altogether misleading to include, for purposes of comparison, the whole of the Atlantic in the area over which the shock was felt. The mode of initiation of these great sea-waves is not yet fully understood; they evidently are only produced when there is a sudden displacement of a large mass of material on the bottom of the sea, and the most probable hypothesis is that this displacement is in the form of a submarine landslip. It is certain that there is no direct connection between the magnitude of the earthquake and the size of the sea-wave. Great earthquakes, even when they originate beneath the sea, may give rise to quite small sea-waves, on the other hand, large and destructive sea-waves may result from quite moderate earthquakes. In either case the wave once set up will travel till it reaches land, and the area over which it may be observed is only limited by the size of the ocean.

Rejecting the sea-wave as useless for purposes of comparison, we may turn to the consideration of the area over which the shock was felt on dry land. Throughout Spain and Portugal it was felt with varying degrees of severity. In southern France the shock was distinctly felt and appears to have been noticeable even in Normandy, but it does not seem to have been felt anywhere in England.

This statement may be considered extraordinary in face of the often repeated statement that the Lisbon earthquake was distincly felt in the Derbyshire mines. As this appears to be one of the accepted facts of seismology, its contradiction requires support, and I consequently reprint here, verbatim, the original authority on which the statement is based.

LIX.—An Account of the Earthquake, 1st November 1755, as felt in the Lead Mines in Derbyshire, in a Letter from the Reverend Mr. Bullock to Lewis Crusius, D.D., F.R.S.

ASHFORD, NEAR BAKEWELL.
Derbyshire, 3rd March 1756.

REV. SIR,

I here send you an account of the earthquake which happened at the lead mines on Eyam-edge in the peak of Derbyshire, on Saturday the 1st of November 1755, about 11 o'clock in the forenoon. I made a strict inquiry at the mines, on the 21st of February last, both for my own and your satisfaction, and can assure you that the circumstances related may safely be relied upon as matter of fact. If there be anything in my power which you would choose to have explained more particularly, please to communicate, and it shall be done with the greatest pleasure by,

SIR,
Your most obedient and obliged humble servant,
(*Sd.*) WILLIAM BULLOCK.

Francis Mason, overseer, says, that he sat in a little room, which he uses to write in; it stands about forty yards from the mouth of one of the engine shafts. He felt one shock, which very sensibly raised him up in the chair, and caused several pieces of lime or plaster to drop from the sides of the room; the roof of it was so violently shook, that he imagined nothing less than the engine shaft was run in; whereupon he immediately went out to see, and, contrary to his expectation, found the shaft open, and all things about the spot in their proper order.

Upon inquiry, I was informed by the aforesaid Francis Mason, that in a field about 300 yards from the mines, there had happened a chasm or cleft on the surface of the earth, which was supposed to be made at the same time he felt the shock, for the following reason. It lies close by a road, which he uses daily to and from the mines: in the morning when he came, there was nothing uncommon to be seen, but on his return at evening he observed a cleft about one foot deep and six inches in diameter; its continuation from one end to the other was near 150 yards, being parallel to the range of the vein on the north side. When I examined it, which was upwards of three months after the shock happened, the length of it was not much more than 60 yards, though I could perceive some vestiges of its further continuance: the depth of it was about eight or nine inches and its diameter four. As the soil was very light, and the season has been remarkably wet, it is highly probable, that the fissure is considerably closed since it was first made. These were the most remarkable circumstances which happened upon the surface of the earth. Though my enquiry was of every one in particular, that was there employed about the mine, the concurrence of whose testimonies might seem more strongly to confirm the account, yet I look upon it as unnecessary to trouble you with every man's story, which would be only a repetition of, or something similar to, what has been before related.

William Hallom, and Jo. Howson, miners, say, that at the aforesaid time they were employed in carting or drawing along the drifts the ore and other minerals to be raised up the shafts. The drift, wherein they were working, is about 60 fathoms, or 120 yards deep, and the space of it from one end to the other 50 yards or upwards. Hallom was at the end of the drift, had just loaded his cart, and was drawing it along, but was suddenly surprised by a shock, which so terrified him, that he immediately quitted his employment, and ran to the west end of the drift to his partner, who was not less terrified than himself. They durst not attempt to climb the shaft, lest that should be running in upon them, but consulted what means to take for their safety. Whilst they were thinking of some place of refuge, they were alarmed by a shock much more violent than the former; which put them in such a consternation, that they both ran precipitately to the other end of the drift. There was a miner working at the forfield, or east end of the vein about six fathoms below their level, who called out to them, imagining they were in danger of being killed by the shafts running in upon them which he supposed was the case; and told them if by any means they could get down the shaft to him, they would be more secure, because the cavity where he was working was encompassed with solid rock. They went down the shaft to him, where, after observing they had neither of them received any misfortune, he told them, that the violence of the second shock was so great, that it caused the rocks to grind one upon another. His narration was interrupted by a third shock; and after an interval of about four or five minutes, was succeeded by a fourth; and about the same space of time after, by a fifth; none of which were so violent as the second. They heard after every shock a loud rumbling in the bowels of the earth, which continued for about half a minute, gradually decreasing, or appearing at a greater distance. They imagined, that the whole space of time, from the first shock to the last, was about twenty minutes; and they tarried about ten minutes in the mine after the last shock; when they thought it advisable to examine the passage and to get out of the mine, if possible. As they went along the drifts, they observed that several pieces of minerals were dropped from the sides and roof, but all the shafts remained entire without the least discomposure.

The space of ground at the aforesaid mines wherein it was felt, was 960 yards which was all that was at that time in workmanship.[1]

From this account it is evident that we are dealing, not with the Lisbon earthquake, but with an independent one of local origin. Too much importance must not be attached to the reported time, which is an hour later than that of the Lisbon shock, as it is evidently only approximate, but the shock described is a fairly severe one, much severer than indicated by any of the accounts of the shock in or out of England, till we get to the south-western part of France.

Besides the severity of the shock there is the fact that it was felt underground almost as severely as at the surface. With regard to earthquakes generally it seems well established that, in the area of propagation, the motion that can be felt is confined to the surface and, at a very small depth below ground, it ceases to be felt. Within the area of the epicentre, however, or even within that of the earthquake core, there is no reason why this should be so, and the account of what was felt in the Eyam-edge mine points to its being on the direct path upwards from the focus to the surface; a supposition which is borne out by the large vertical component of the motion indicated in the overseer's account.

The Derbyshire earthquake may consequently be excluded from the accounts of the Lisbon earthquake; at the most it can only be connected with the greater shock as a sympathetic earthquake, and even that is doubtful.

With the exception of the Derbyshire earthquake all the other accounts collected by the Royal Society, and published in the 49th volume of its Philosophical Transactions, relate merely to the effects of the sea-waves along the coasts, or oscillations of ponds, canals, and even lakes, similar to those described in Burma,[2] in the case of the 1897 shock. One account alone mentions the earthquake as having been felt near Reading; Mr. Paunceforth's gardener stated that he felt a most violent trembling of the earth for fifty seconds. All the other accounts either definitely state that no shock could be felt, or, in a few instances, say nothing as to this, and it is probable that the violent trembling felt by Mr. Paunceforth's gardener, who was watching the washing back and forwards of water in a pond, was the result of imagination.

In the accounts of the shock as experienced in Holland and Denmark, I can find nothing to support the idea that it was felt there, only oscillations of water in ponds and canals are recorded; while the time at which the shock is said to have been felt in southern Norway, 4 A.M., shows that the shock, which was certainly

[1] Phil. Trans. XLIX, pp., 399 ff.
[2] See chapter II, page 39.

felt there, was a distinct one. The reputed feeling of the shock in Iceland and Greenland, which has always been regarded with doubt, may safely be rejected.

From this it seems that the most northerly place at which the shock is reported to have been felt was Reading, and even this is so doubtful that it may be rejected.

In an easterly direction it is said to have been felt in parts of Switzerland, and though the accounts refer mainly to disturbances of the water of the lakes, there seems good reason to suppose that the shock was sensible in parts of western Switzerland. In Italy it is said to have been felt at Milan and 8 leagues N. N. W. of Turin, but it is not clear whether it was actually felt, or only recognised by its effect in setting hanging lamps aswing. It must be remembered too that the Italian, besides being gifted with a lively imagination, is, by descent, a skilled observer of earthquakes. Even our earthquake of 1897 is said to have been felt in Italy.[1] In any case Milan and Turin can hardly be looked on as part of the main area over which the shock was felt, but as an outlying area like that round Ahmadnagar in the case of the 1897 earthquake.

To the south, it is impossible to define the area over which the shock was felt with any degree of accuracy. It was very severely felt in the north-west corner of Africa. As far south as Morocco a great number of houses are said to have fallen, and one of the hills near by to have been rent in two. This account is almost certainly greatly exaggerated, for at Funchal, in Madeira, the shock was only smart enough to make windows rattle.

To the west we have the Atlantic ocean, and it is impossible to say how far in this direction the shock might or might not have been felt had there been dry land.

The position of the epicentre cannot be fixed with the same accuracy as in the case of the 1897 shock, but the centre from which the great sea-waves started was fixed by David Milne at about 39° N. Lat, 11° W. Long.[2] The epicentre of the earthquake was not necessarily the same as the centre from which the sea-waves started, but the two are not likely to have been widely separated, and there will be no material error in assuming the two identical.

Taking the epicentre as situated in the position indicated, we find that Milan is distant about 1200 miles, or practically the distance of Ahmadnagar from the epicentre of the 1897 shock ; and Reading about 1000 miles, against a distance of over 900 from the epicentre to Bezwada, where the 1897 shock was distinctly felt.

From this it would seem that the distances from the epicentre at which the two shocks were felt were practically the same, but as I have explained above, the accounts from Reading and Milan, especially the former, do not appear to be

[1] At Leghorn a tremor is said to have been felt by some, though not living in upper stories, at about 12-15. At Catania some people are said to have noticed it, but the accounts are vague and uncertain. At Spinea di Mestre (near Venice) an undulating shock of 4 seconds, is said to have been felt in the Observatory at 12 h. 18 m. 39 s. (Boll. Soc. Sismol. Ital., III, pt. ii, pp. 251, 285, 289.) The times are mid European, and exactly one hour fast of Greenwich mean time. They correspond with that of the first phase, and it is possible that these waves, of half-second period, were just sensible to very skilled observers, favourably situated.

[2] Edin. new Phil. Journ., XXXI, 263 (1841).

such as can be accepted for comparison. If we exclude them, the area over which the shock could have been felt is very much reduced; a rough estimate which I have made, and nothing more is possible, places the total area over which the shock would have been felt, had it all been dry land, as not more than 1,000,000 square miles. A similar estimate for the 1897 shock gives about 1,750,000 square miles.

These estimates cannot be regarded as giving an exact ratio of the magnitude of the two shocks. In the case of the Lisbon earthquake the estimate must necessarily be very approximate, but it is not probable that it could be raised above that of the earthquake of 1897. At any rate the facts fully bear out the statement that the shock of 1897 rivalled that of 1755 in magnitude, and if the doubtful records of the latter are excluded, its magnitude was certainly greater.

There is one feature of the 1755 records which might lead to a different idea and that is the many accounts of its effect on ponds and lakes even as far north as Scotland and Denmark,[1] as contrasted with the absence of similar accounts in the case of the 1897 shock. This is, however, easy of explanation. In a westerly direction the country which would occupy the position of England relative to the area over which the shock was sensible, is mostly desert, sparsely inhabited and devoid of sheets of water. To the south-westwards, in the Peninsula, artificial ponds and lakes are not wanting, but there is an absence of educated and intelligent observers. To the east and north the area over which the shock was felt extends into country from which no information can be obtained.

On the other hand, when we consider that the 1755 shock extended over a populous and civilised country, that it attracted universal attention, and that all the leading scientific societies and academies of western Europe set themselves to collect information regarding it, and when we consider how comparatively few and imperfect were the observations collected, even as regards this one point of the disturbance of water in ponds, it is not surprising that in the case of the 1897 shock they are altogether wanting.

That similar oscillations of water in tanks took place I do not doubt; we have accounts of them within the area over which the shock was felt, and besides those mentioned in the text I received numerous accounts of disturbances of water in wells having been noticed. There are, besides, two separate accounts, showing that, outside the area over which the shock was felt, the undulation of the ground was sufficient to make doors swing to and fro.[2]

For these reasons it does not seem to me that the accounts of the effects of the Lisbon earthquake point to its being of greater magnitude, so far as this can be measured by the area over which the shock was felt, though it is possible that the wave motion was of somewhat different character and gave rise to surface undulations of greater size and steepness.

[1] The reputed disturbance of the North American lakes is too doubtfully connected with earthquake to be considered.

[2] Chap. II, p. 37.

Appendix I.

Bibliography of the Earthquake.

So great an earthquake has naturally given rise to a large volume of literature not only in the shape of notices in the daily newspapers, but also in scientific magazines. Nearly all of these are, however, written at second hand, and, so far as I know, the following list comprises all that can be quoted as original authorities :—

1. Thos. Heath ; An Edinburgh Record of the Indian Earthquake : *Nature*, LVI, 174 (1897).

A letter to *Nature*, giving a brief account, and an illustration on a reduced scale, of the record of the earthquake by the bifilar pendulum at Edinburgh. A letter to the same effect was published in the Calcutta *Englishman* of 6th July 1897. Both may be regarded as superseded by No. 8.

2. T. D. LaTouche. The Calcutta Earthquake ; *Nature*, LVI, 273-274.

This is a brief account of the earthquake and its effects in Calcutta, written very shortly after the occurrence.

3. The Calcutta Earthquake : *Nature*, LVI, 346 (1897).

A short notice, and reproduction of part of the record of the horizontal pendulum instrument at the Royal Geodynamic Observatory of the Rocca di Papa.

4. T. D. LaTouche : The late Earthquake in India : *Nature*, LVI, 444-44 (1897).

An extract from a private letter describing the effects of the earthquake in Assam. It expresses the idea, natural at first, but which had afterwards to be abandoned, that the origin of the earthquake was connected with the great uniclinal fold or flexure which bounds the southern edge of the Assam hills.

5. J. Milne : The Recent Australian and Indian earthquakes ; *Symons' Monthly Meteorological Magazine*, XXXII, 92-93, 1897.

Contains a statement of the times at which the effects of the earthquake were registered at Edinburgh, Shide I. W., Strassburg and Grenoble.

6. T. Moureaux : *Bulletin du Bureau central ;* quoted in *Cosmos*, VI, 652 (1897).

Records an interruption of the traces of the magnetographs in the observatory of Parc St. Maur. I have not been able to refer to the original.

7. R. D. Oldham : The Earthquake of 12th June : *Records of the Geological Survey of India*, XXX, 132-134 (1897).

A brief preliminary notice, written about a month after the earthquake, giving some of the more striking facts concerning it.

8. M. Baratta : Il grande terremoto Indiano del 12 giugno 1897 : *Bollettino della Società geografica Italiana*, 3rd series, X, 1—8, and 1 plate (1897)

An account and illustration of the records of the earthquake on the microseismographs of the University of Padua, designed and controlled by Prof. G. Vicentini.

9. Thomas Heath: Note on the Calcutta Earthquake (June 12th, 1897) as recorded by the Bifilar pendulum at the Edinburgh Royal Observatory: *Proceedings of the Royal Society of Edinburgh*, 1897, 481—488, 2 Plates.

An account and reproduction of the record of the earthquake on the instrument referred to in the title.

10. N. A. F. Moos: A short Note on the disturbance of the Magnetical and Meteorological Instruments at the Colaba Observatory during the Earthquake of 12th June 1897: *Magnetical and Meteorological observations made at the Government Observatory, Bombay, 1896;* Appendix A., pp. [1]—[7]. Bombay, 1897.

This paper is fully noticed in Chapter XI.

11. F. Omori: A preliminary note on the Indian Earthquake of June 12th, 1897. *Indian Daily News*, 23rd October 1897.

A newspaper article by Prof. Omori, written after his tour through Assam and Bengal. He estimates the depth of the focus at 20 miles, an estimate apparently based on the supposition that the focus was of comparatively small horizontal extent, and on the assumed small number of aftershocks. As has been shown the nature and form of the focus was so different from that of the Japanese Earthquake of 1891, that the analogy does not hold good.

12. Report on the Earthquake of 12th June 1897, so far as it affected the Province of Assam.

The official report of the Government of Assam, signed by Mr. E. A. Gait, Officiating Secretary to the Chief Commissioner of Assam, pp. 9 and 72, issued as a separate report, reprinted from the *Assam Gazette.*

13. A. Cancani: I pendoli orizzontali del R. Osservatorio geodinamico di Rocca di Papa, ed il terremoto Indiano del 12 giugno 1897: *Bolletino de la Società Sismologica Italiana*, III, pt. i, 235-240, and 1 Plate (1897).

A description of the records of the instruments referred to in the title. The Plate is a reproduction of the same diagram as is represented on Plate XLI of this memoir.

14. Report on the Earthquake of 12th June 1897 in Bengal.

The official report of the Government of Bengal signed by Mr. C. W. Bolton, Chief Secretary. *Calcutta Gazette* Supplement, 5th June 1898.

15. H. Luttman-Johnson: The Earthquake in Assam; *Journal of the Society of Arts*, XLVI, 473-493 (1898).

A non-scientific account of the earthquake, containing also a note by myself on some of the scientific aspects of it.

16. C. L. Griesbach: General Report on the work carried on by the Geological Survey of India for the period from 1st January 1897 to the 1st April 1898: 8°, Calcutta 1898.

Contains at pp. 16—18 a note by myself practically identical with that included in No. 15.

17. G. Agamennone: Il terremoto del India del 12 giugno 1897: *Atti della Reale Accademia dei Lincei*: 5th series, VII, 265—271 (1898).

A discussion of the records of the earthquake on the self-recording seismographs and magnetographs in European observatories.

18. G. Agamennone: Il terremoto dell India del 12 giugno 1897: *Bolletino della Società Sismologica Italiana*, IV, Pt. i, 33–40 (1898).

A short note, based principally on Nos. 1, 2 and 6.

19. G. Agamennone: Notize sui Terremoti osservati in Italia durante l'anno 1897. (1° semestre.) *Bolletino della Societè Sismologica Italiana*, III, Pt. ii (1897).

A list of all shocks recorded in Italy: pages 249 to 293 contain detailed, accounts of the records of the Italian observatories, and more brief reference to those of other European observatories. The results are discussed in—

20. G. Agamennone: Eco in Europa del terremoto Indiano del 12 giugno 1897: *Bolletino della Societè Sismologica Italiana*, IV, Pt. i, 41—67 (1898).

A discussion of the records of the Italian seismographs, which was received too late to be utilised in the preparation of Chapter XV, but has been referred to therein.

21. G. Grablovitz: Rettifica alla relazione dell' osservatorio geodinamico di Casamicciola (Ischia) sul terremoto dell' India del 12 giugno 1897: *Bolletino della Societè Sismologice Italiana*, pp. 167—168.

22. G. Agamennone: Replica alla rettifica del Prof. G. Grablovitz alla relazione sulle osservazioni fatte a Casamicciola in occasione del terremoto Indiano dell 12 giugno 1897: *Bolletino della Societè Sismologica Italiana*, pp. 169—172.

INDEX TO PLACE NAMES OF INDIAN LOCALITIES.

(Places of minor importance whose position is sufficiently indicated by the context have not been indexed.)

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GEOLOGICAL SURVEY OF INDIA.

Memoirs Vol. XXIX Pl. I.

F. Kapp & Co. photo.

Photo-etching-Survey of India Offices, Calcutta, April 1898.

ALL SAINTS' CHURCH, SHILLONG.

R.D.Oldham.

F. Kapp & Co. photo.

Photo-etching - Survey of India Offices, Calcutta, May 1898.

ROOKWOOD - SHILLONG.

R.D. Oldham.

Memoirs Vol. XXIX Pl. III.

T. D. La Touche photo.

Photo-etching - Survey of India Offices, Calcutta, May 1898.

LANDSLIPS AT BEADON'S FALLS - SHILLONG.

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R.D.Oldham. Memoirs Vol. XXIX Pl. IV.

S.K.Chakravarti photo. Photo-etching-Survey of India Offices, Calcutta, May 1898.

THE CEMETERY - SHILLONG.

R. D. Oldham.

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Photo-etching - Survey of India Offices, Calcutta, June 1898.

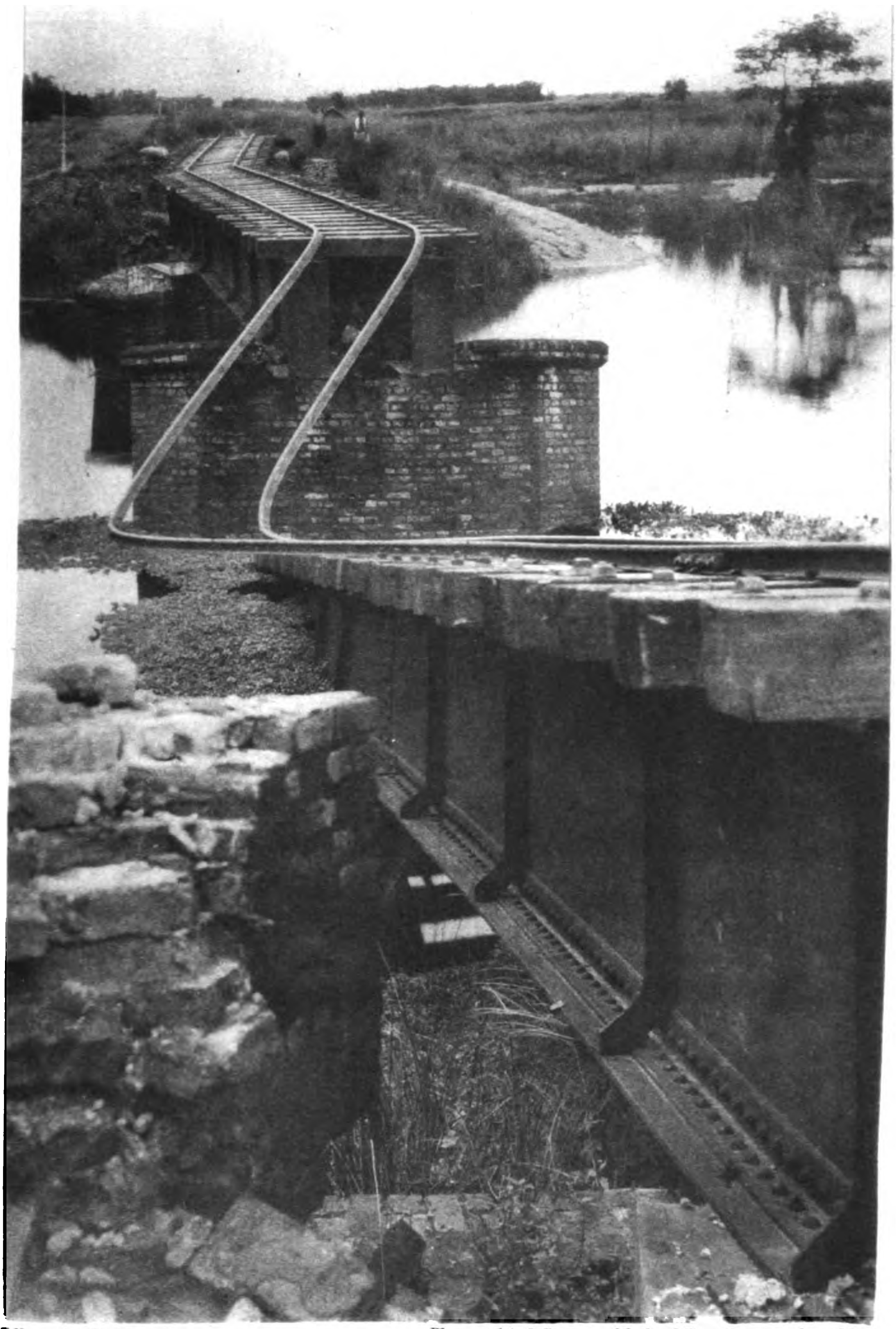
TOMBS IN CEMETERY, CHERRAPUNJI.

R.D. Oldham

G. Kernis photo.

Photo-etching-Survey of India Offices, Calcutta, June 1898.

BENT RAILS AT RANGAPARA, TEZPUR-BALIPARA TRAMWAY.



F. Kapp & Co. photo. Photo etching Survey of India Offices. Calcutta. June 1898.

MANSHAI BRIDGE
EASTERN BENGAL STATE RAILWAY.

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Memoirs Vol. XXIX Pl. VIII.

F. Kapp & Co. photo.

Photo-etching-Survey of India Offices, Calcutta, June 1898.

STATION YARD, NILPHAMARI.
EASTERN BENGAL STATE RAILWAY.

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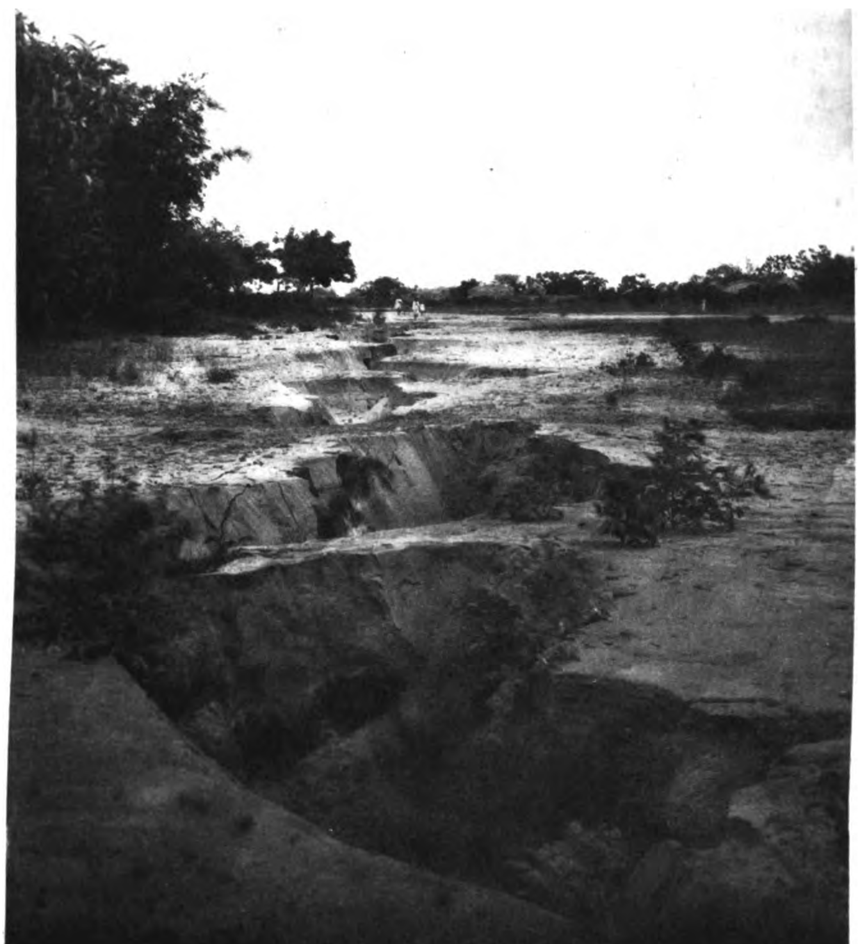
F. Kapp & Co. photo.

Photo-etching-Survey of India Offices, Calcutta, June 1898.

SAND VENTS NEAR SHAISTAGANJ STATION.
ASSAM-BENGAL RAILWAY.



T. D. La Touche photo. Photo-etching - Survey of India Offices. Calcutta. July 1898.

FISSURE AT ROWMARI.

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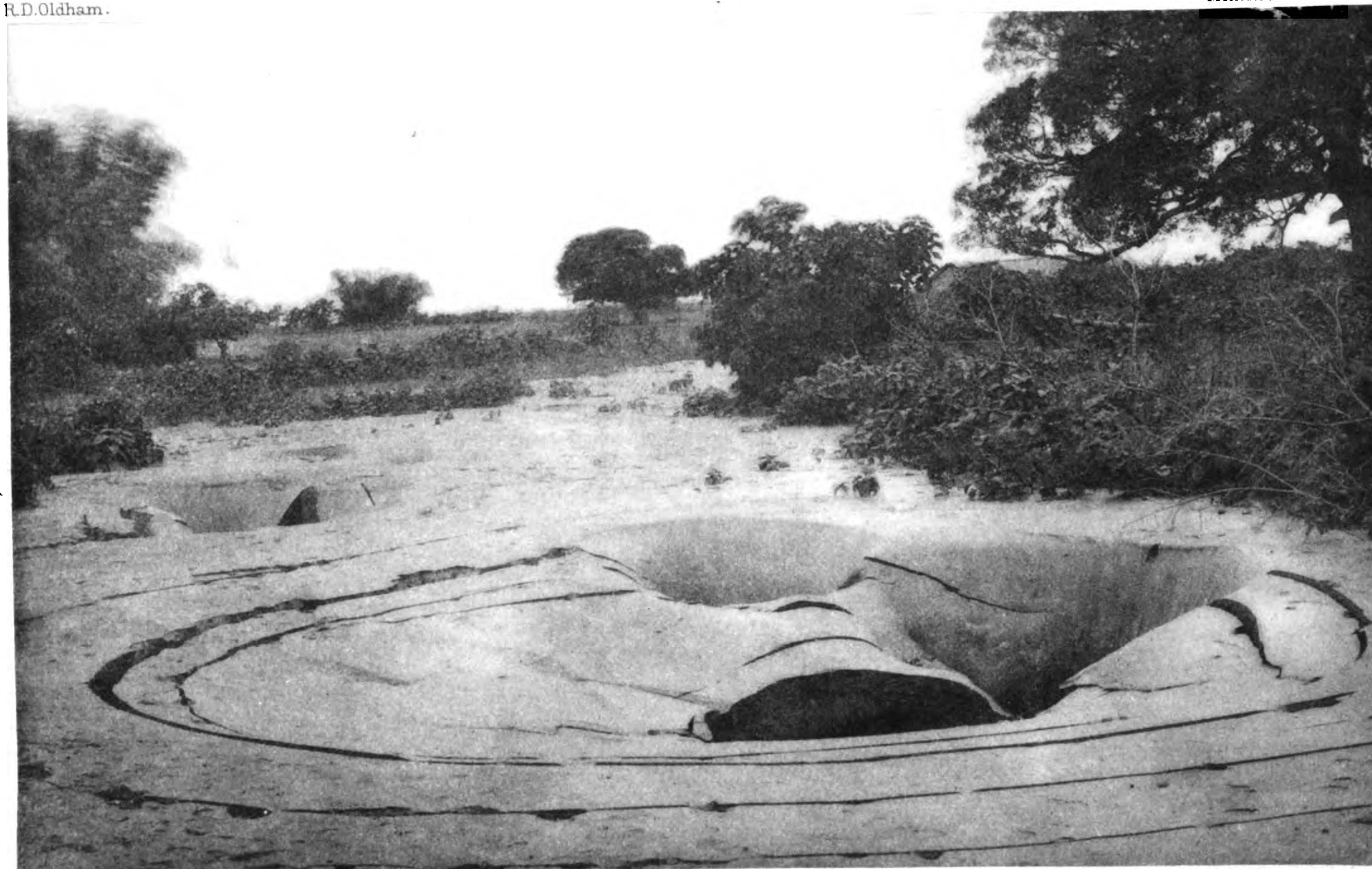

T.D.La Touche photo

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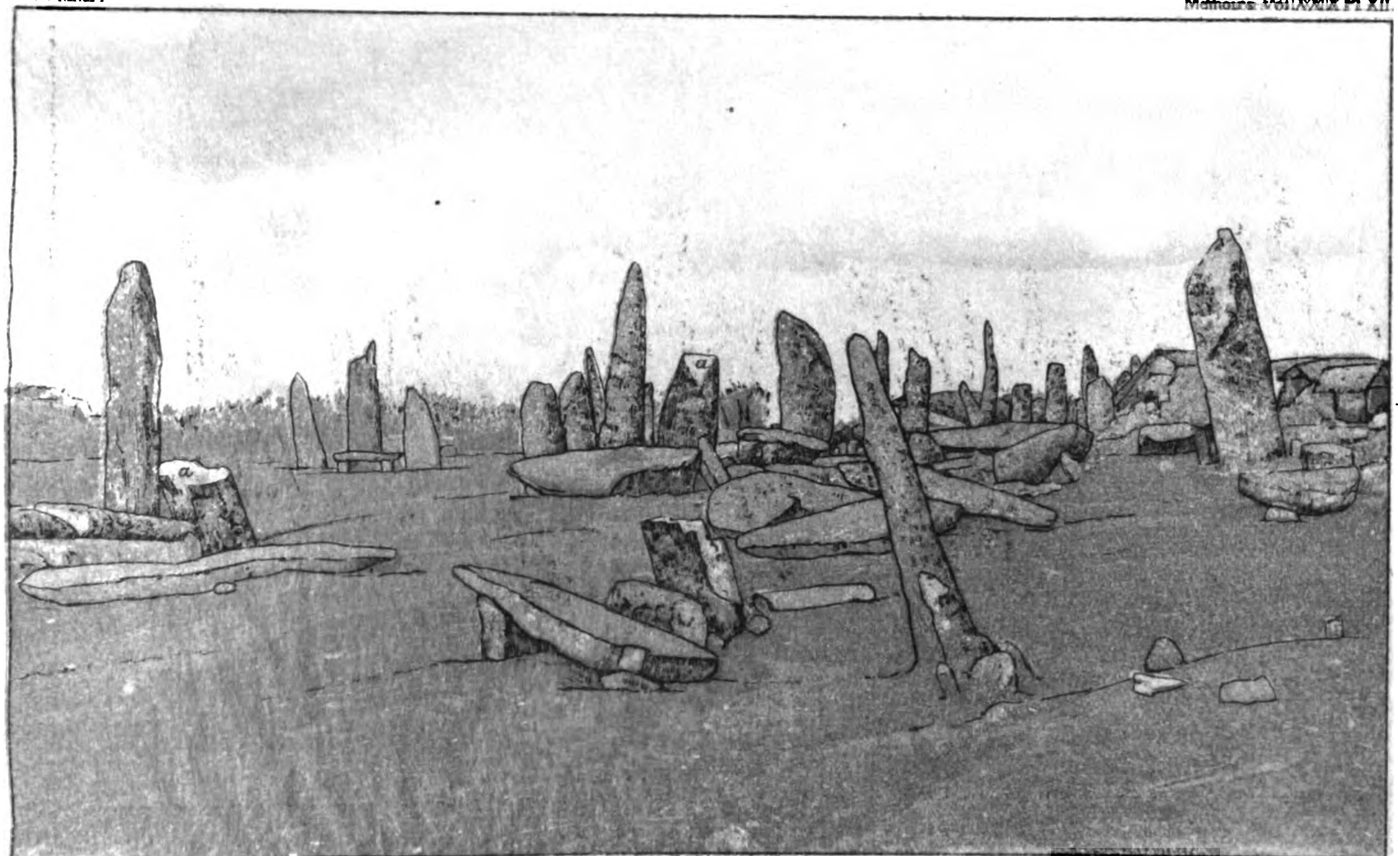
SAND VENT AT ROWMARI.

R. D. Oldham.



a. a. broken surfaces of monoliths snapped by the earthquake.

KHASIA MONUMENTS AT LAILANGKOT

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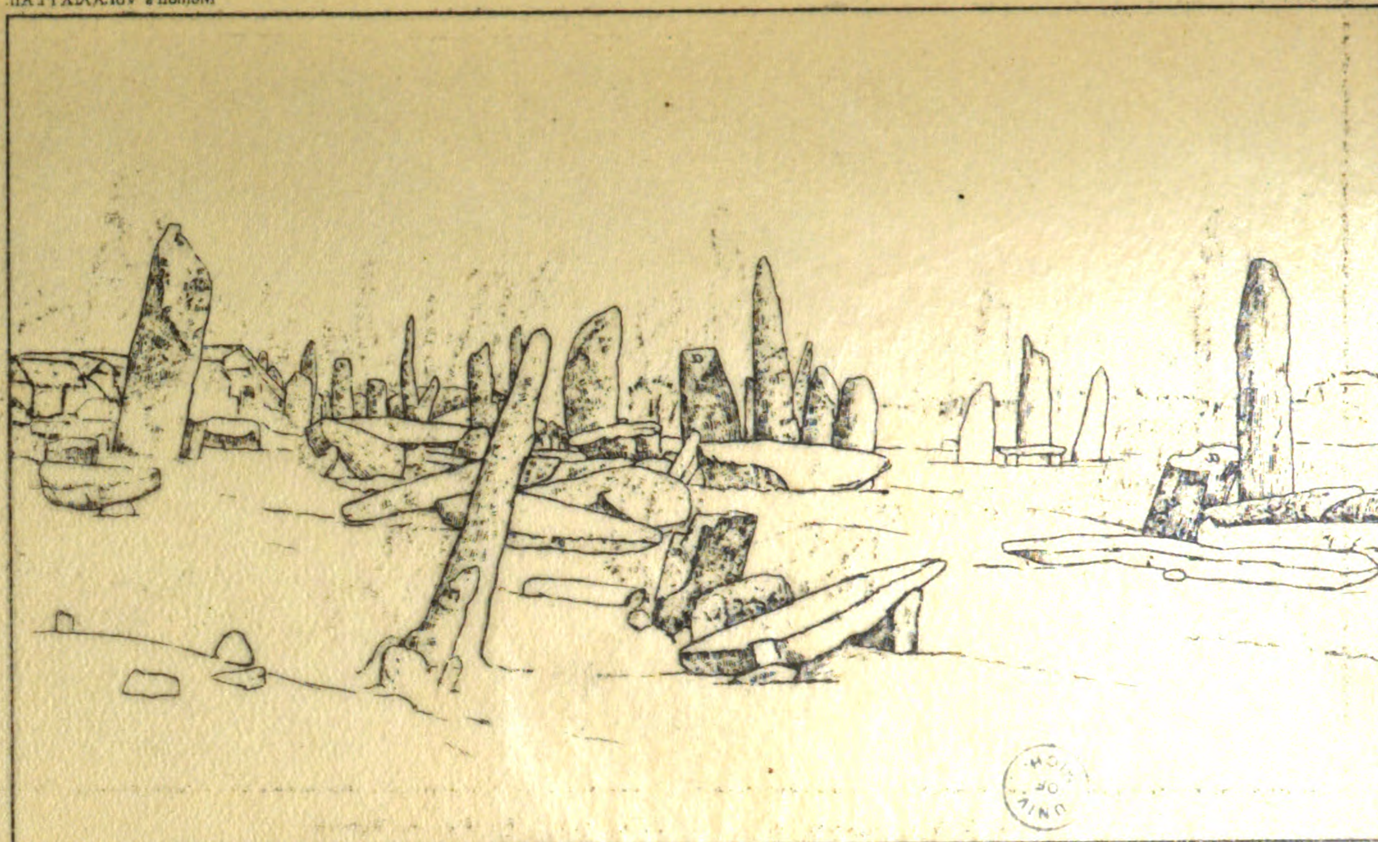

a. a. broken surfaces of monoliths snapped by the earthquake.

KHASIA MONUMENTS AT LAILANG KOT.

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Photo-etching

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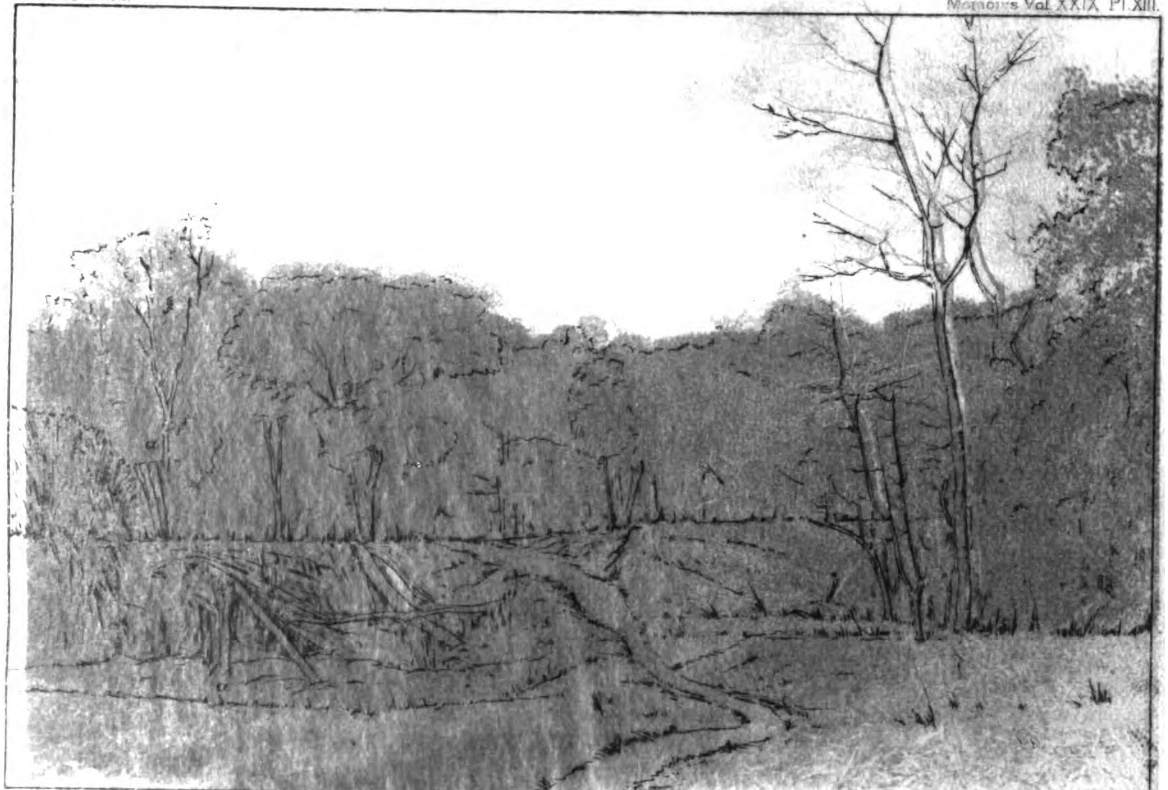
Fault

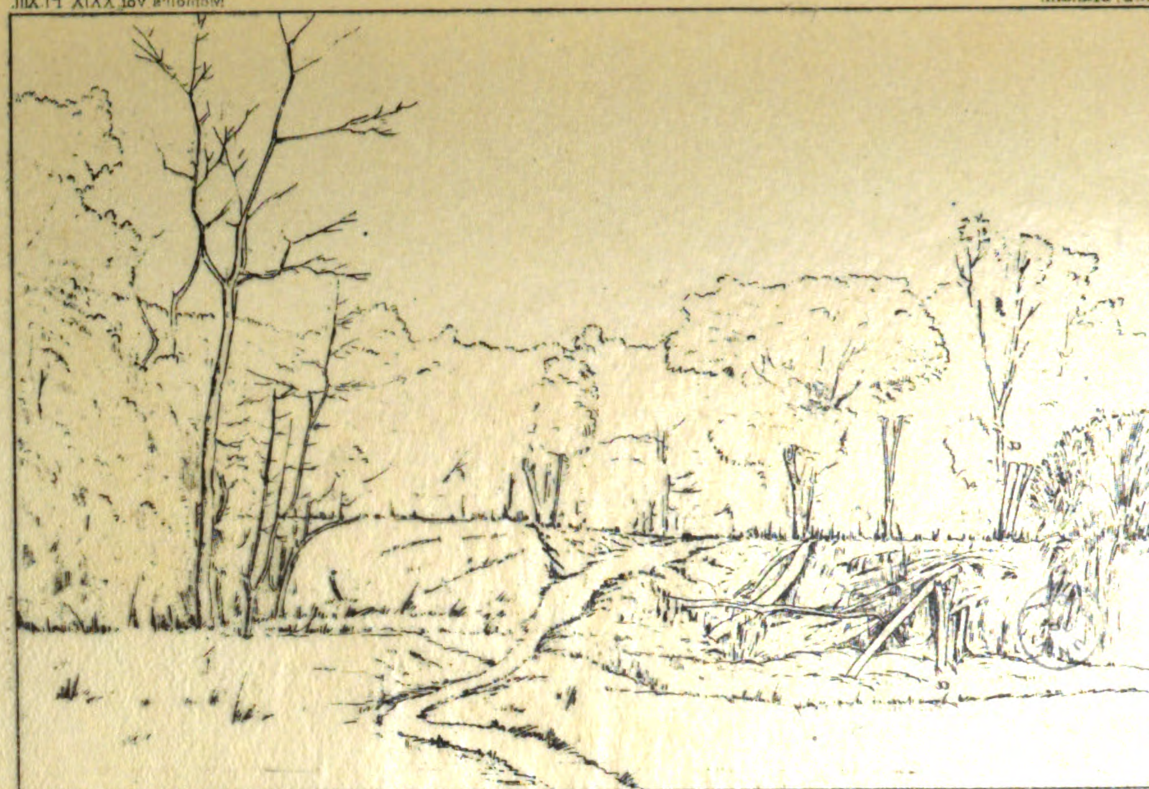


Calcutta, June, 1898.

a a. Posts of *old Garo house, the tops of which were formerly level with each other.*

FAULT CROSSING THE ROAD AT SAMIN GARO HILLS

R.D. Oldham. Memoirs Vol. XXIX Pl. XIII.



Fault

a. a. Posts of old Garo house, the tops of which were formerly level with each other.

FAULT CROSSING THE ROAD AT SAMIN GARO HILLS.

R D. Oldham.

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Photo-etching

Survey of India Offices, Calcutta, June, 1898.

FAULT CROSSING THE ROAD AT SAMIN, GARO HILLS.

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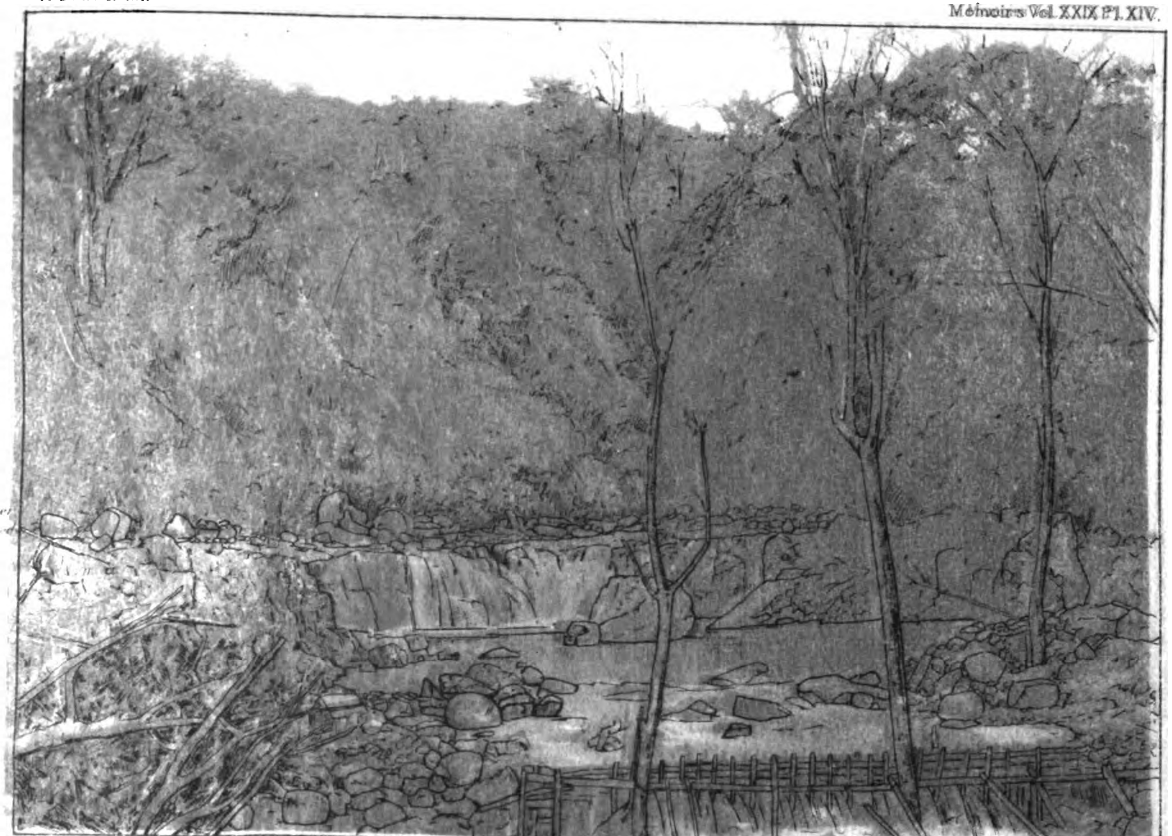

Survey of India Offices, Calcutta, June, 1898.

a. a. Fault face, cut through by the river.

WATERFALL FORMED BY THE CHEDRANG FAULT.

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a. a. Fault face cut through by the river.

WATERFALL FORMED BY THE CHEDRANG FAULT.

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Photo-etching

Survey of India Offices, Calcutta, June, 1898.

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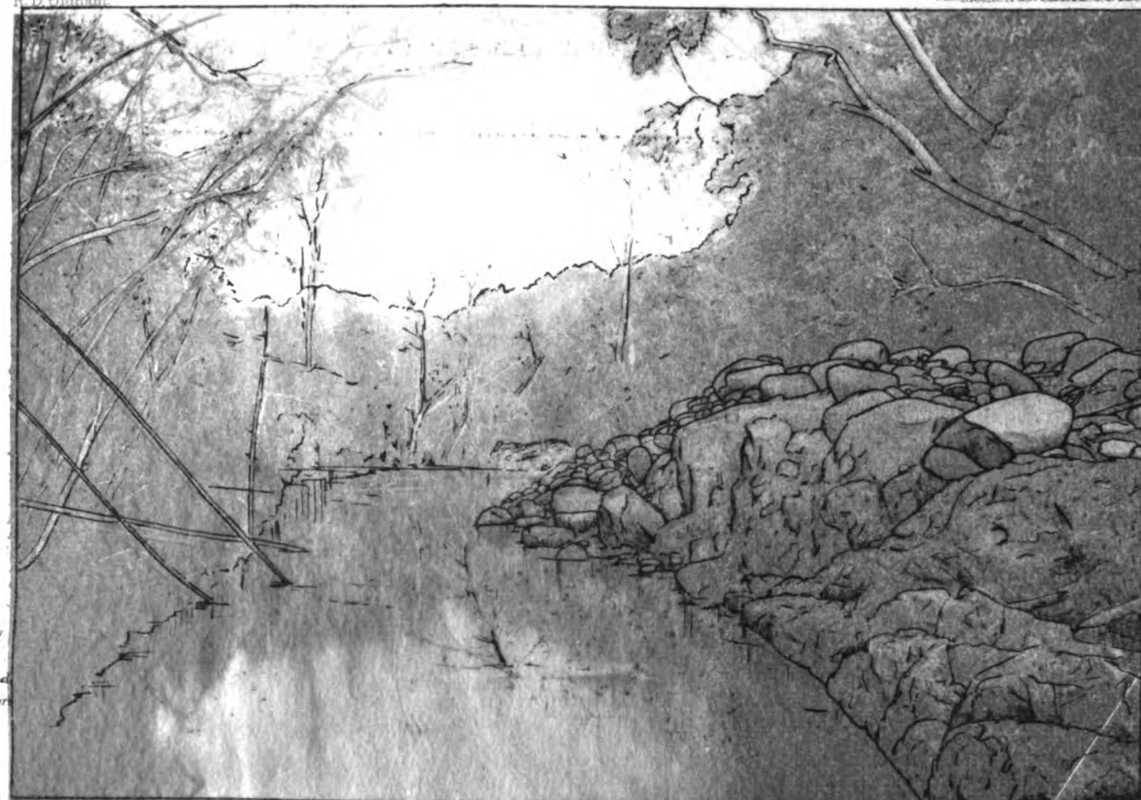

Survey of India Offices, Calcutta, June 1898.

THE CHEDRANG FAULT CUTTING THE BED OF THE CHEDRANG RIVER.

R. D. Oldham. Memoirs, Vol. XXIX, Pl. XV.

Photo etching. Survey of India Offices, Calcutta, June, 1898.

THE CHEDRANG FAULT CUTTING THE BED OF THE CHEDRANG RIVER.

R. D. Oldham.

Memoirs, Vol. XXIX, Pl. XVI.

Photo-etching. Survey of India Offices, Calcutta, June, 1898.

SLOPE FORMED BY THE CHEDRANG FAULT NEAR DILMA.

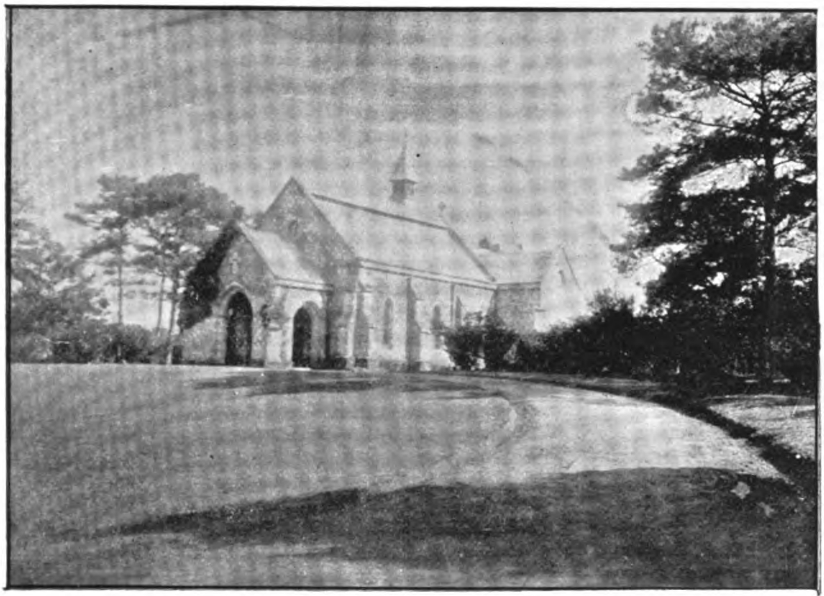

FIG. 1. ALL SAINTS CHURCH, SHILLONG.
Before the earthquake (Cf. Pl. I.)

Photo-Block. Survey of India Offices, Calcutta, June 1899.

FIG. 2. OFFICE OF THE SUPERINTENDENT OF TELEGRAPHS, SHILLONG.

R. D. Oldham. Memoirs Vol. XXIX, Pl. XVIII.

FIG. 1. GOVERNMENT HOUSE, SHILLONG.
(Before the Earthquake.)

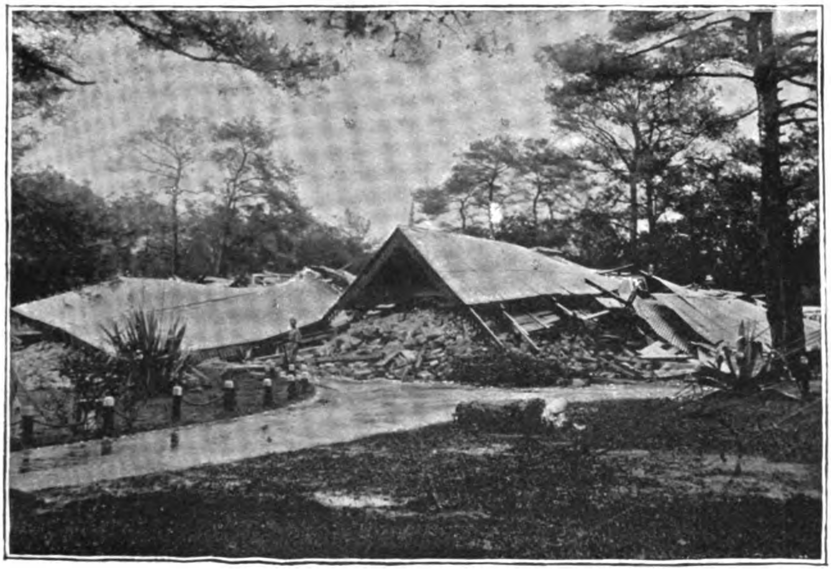

Photo-Block. Survey of India Offices, Calcutta, 1898.

FIG. 2. RUINS OF GOVERNMENT HOUSE, SHILLONG.

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FIG. 1. QUINTON MEMORIAL, SHILLONG.

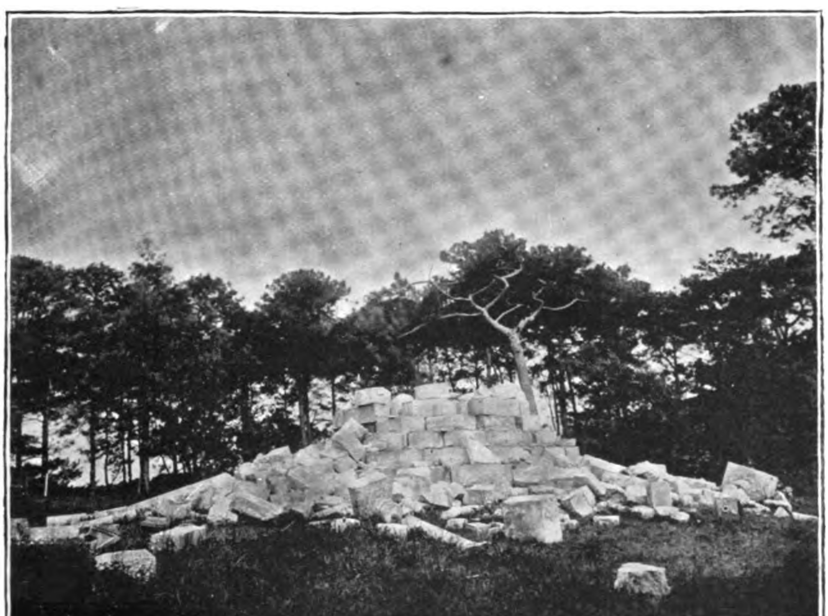


Photo-Block.

Survey of India Offices, Calcutta, June 1898

FIG. 2. THE SAME, AFTER THE EARTHQUAKE.

FIG. 1. DEPUTY COMMISSIONER'S CUTCHERRY, GAUHATI.

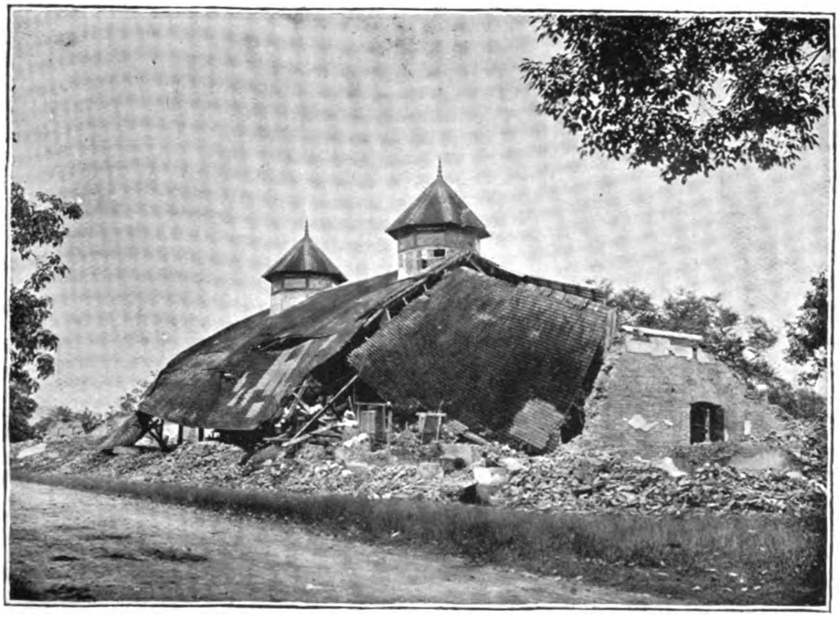


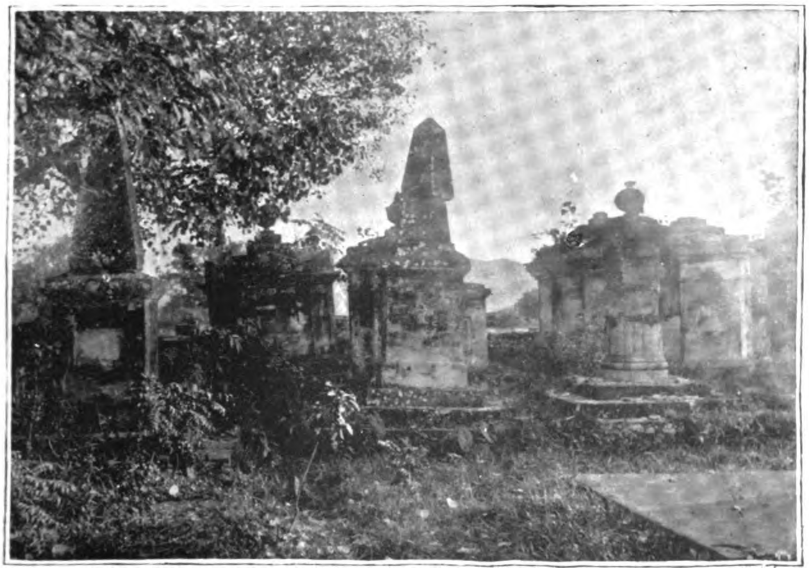
Photo-Block.   Survey of India Offices, Calcutta, June 1898.

FIG. 2. DEPUTY COMMISSIONER'S CUTCHERRY, GAUHATI.

GEOLOGICAL SURVEY OF INDIA.

R. D. Oldham. Memoirs, Vol. XXIX, Pl. XXI.

FIG. 1. GATE PILLARS OF TELEGRAPH SIGNALLERS' QUARTERS, GAUHATI.



No. 3 No. 2 No. 1

FIG. 2. TOMBS IN OLD CEMETERY, GAUHATI.
(See also Plate XXXVI.)

Photo-Block. Survey of India Offices, Calcutta, June 1899

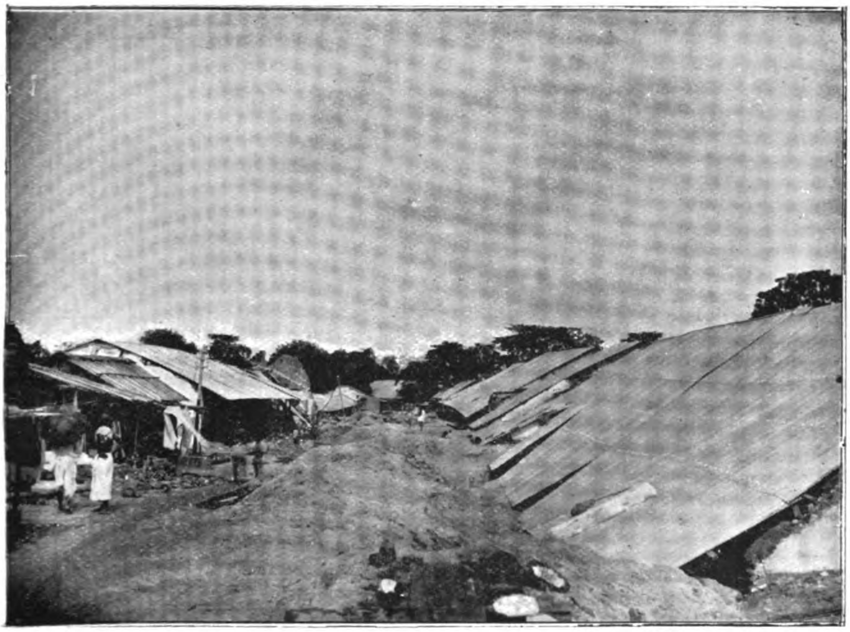


FIG. 1. GOALPARA BAZAR FROM THE EAST.

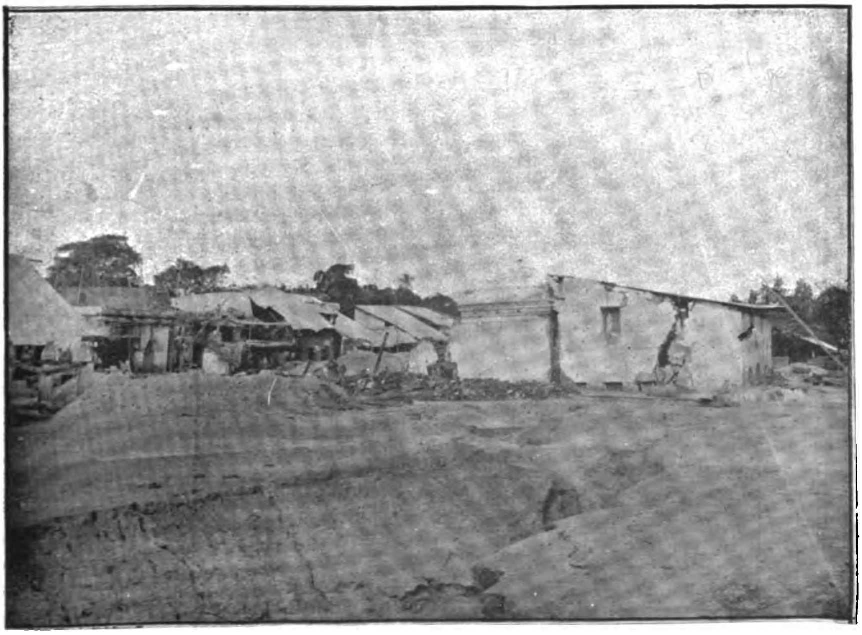


Photo-Block. Survey of India Offices, Calcutta, June 1899.

FIG. 2. FISSURE AT EAST END OF GOALPARA BAZAR.

R. D. Oldham. Memoirs Vol. XXIX, Pl. XXIII.

FIG. 1. 9, HARRINGTON STREET, CALCUTTA.

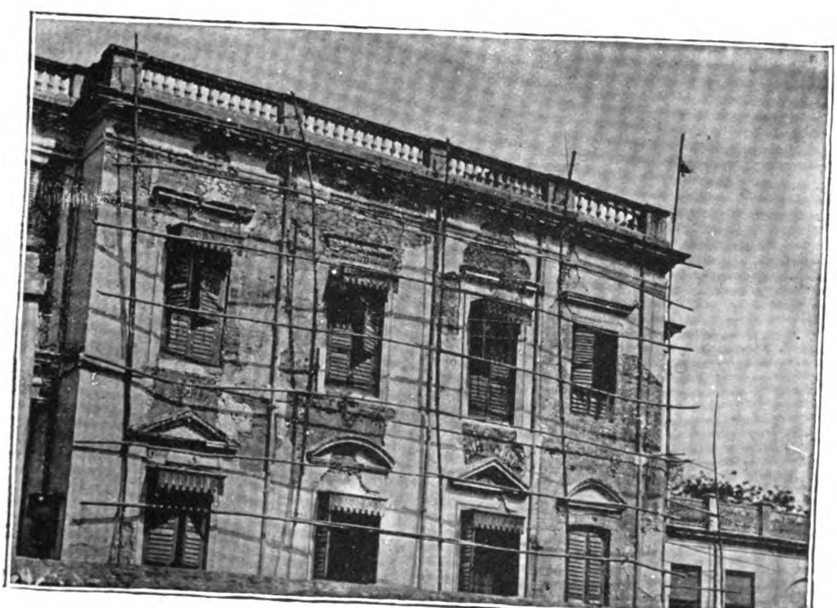


Photo-Block. Survey of India Offices, Calcutta, 1896.

FIG. 2. 6, ELYSIUM ROW, CALCUTTA.

FIG. 1. No. 114, CIRCULAR ROAD, CALCUTTA.

Photo-Block Survey of India Offices, Calcutta, 1898

FIG. 2. HOUSE IN BENTINCK STREET, CALCUTTA.

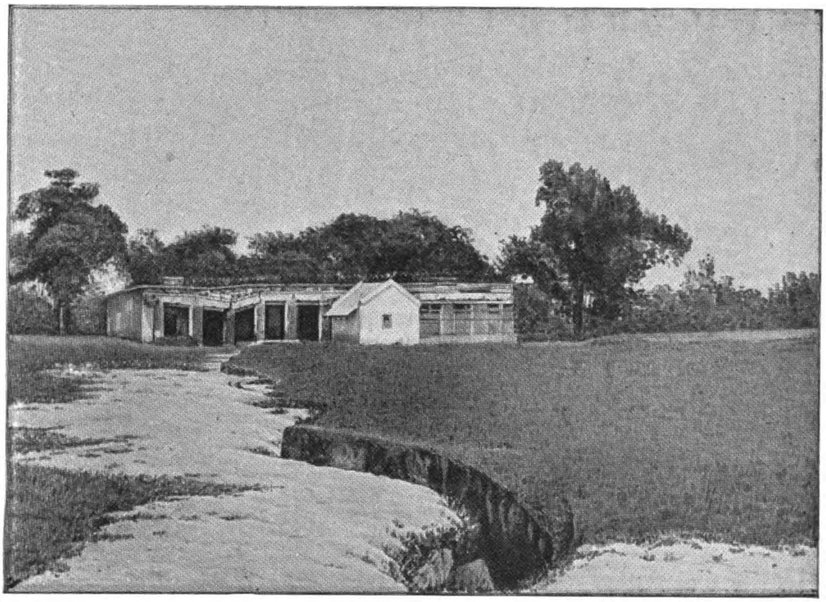


FIG. 1. FISSURE IN COMPOUND OF JUDGE'S HOUSE, RANGPUR.

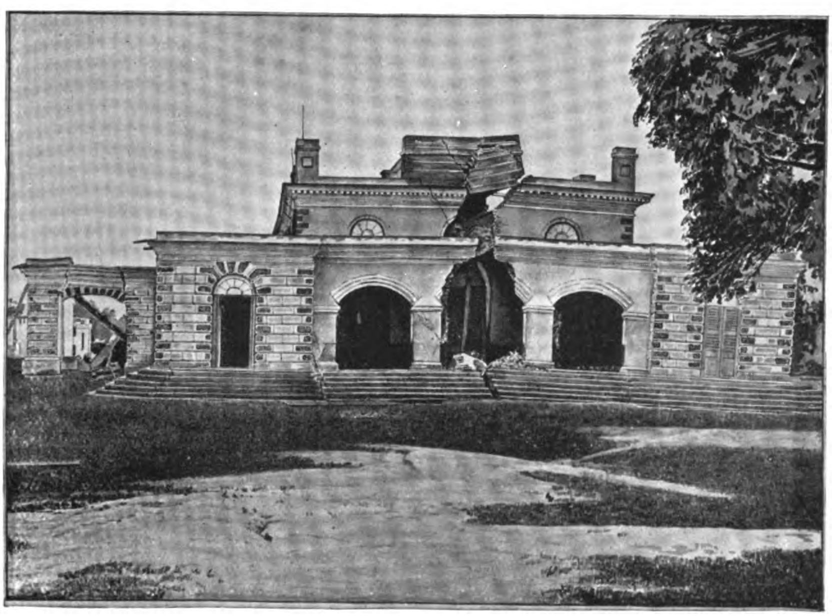


Photo-Block. Survey of India Offices, Calcutta, 1898

FIG. 2. COLLECTOR'S HOUSE, RANGPUR.

FIG. 1. BRIDGE OVER STREAM AT RANGPUR.

Photo-Block. Survey of India Offices, Calcutta, 1898.

FIG. 2. BRIDGE OVER CANAL AT RANGPUR.

R. D. Oldham. Memoirs, Vol. XXIX, Pl. XXVII.

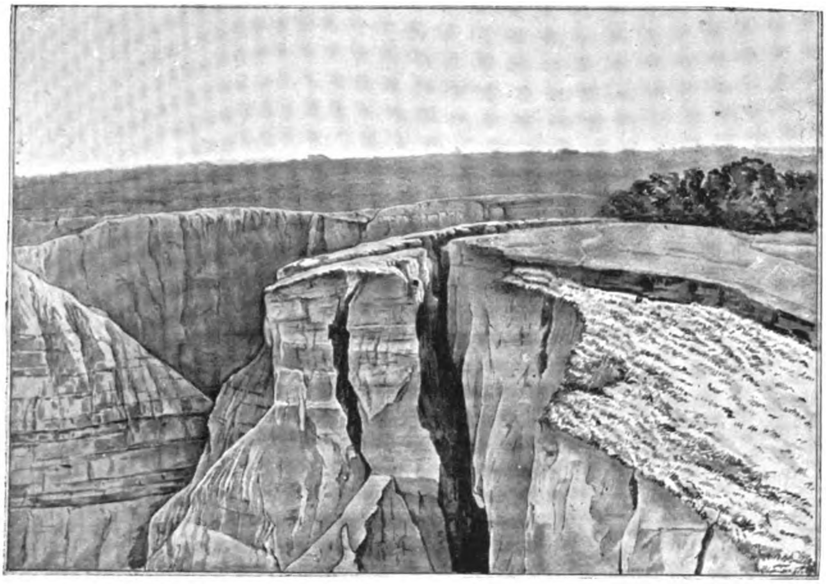


FIG. 1. FISSURES IN SANDSTONE AT EDGE OF THE BÁLPAKRÁM PLATEAU, GARO HILLS.

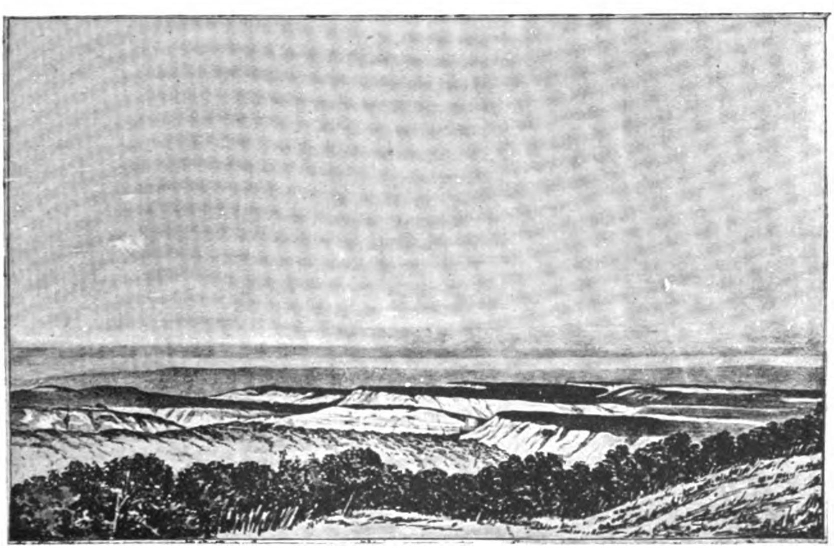


Photo-Block Survey of India Offices, Calcutta, June 1899.

FIG. 2. LANDSLIPS IN EASTERN GARO HILLS, SEEN FROM BÁLPAKRÁM.

FIG. 1. RUINS AT MUKTAGACHA.

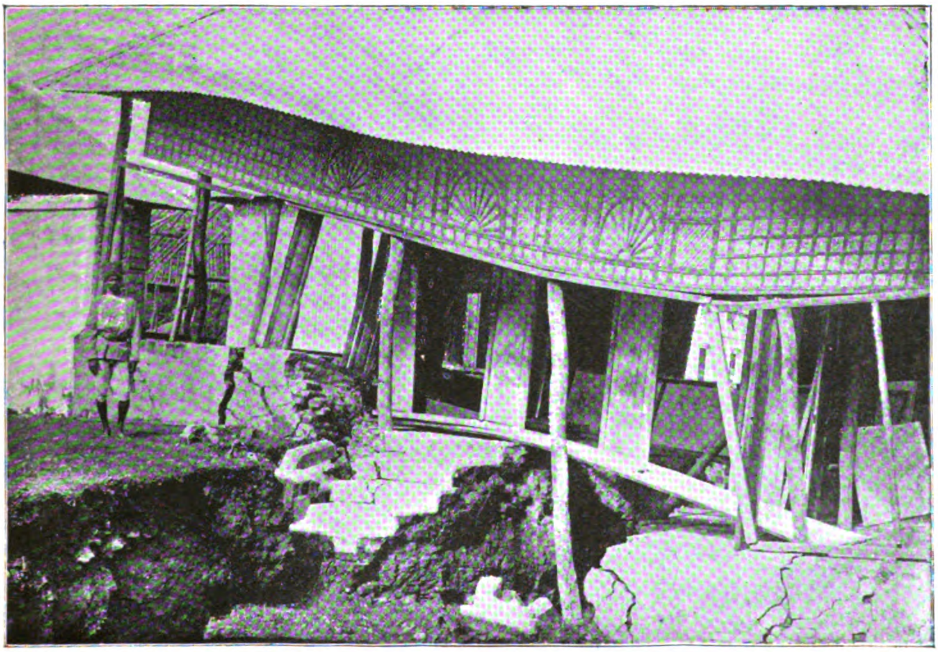


Photo-Block Survey of India Offices, Calcutta, 1898.

FIG. 2. HOUSE AT MUKTAGACHA.

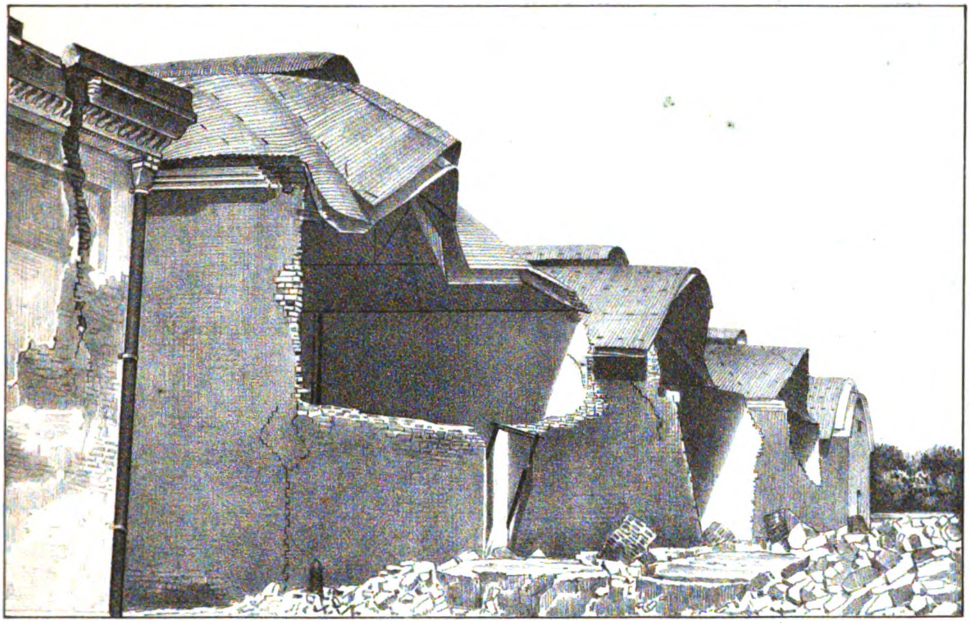


FIG. 1. GODOWNS OF JUTE MILL, SERAJGUNJ.

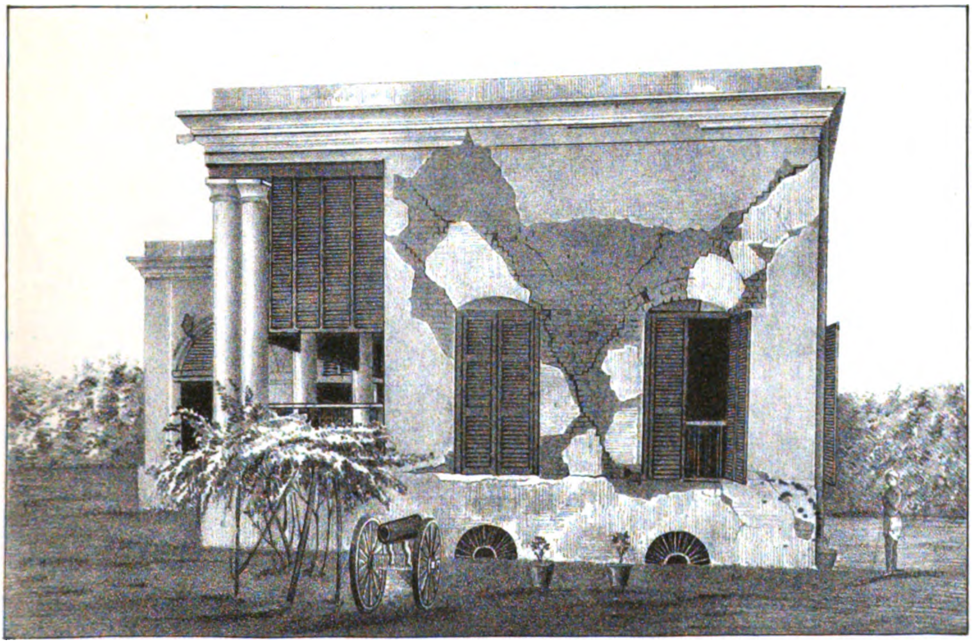


FIG. 2. MANAGER'S BUNGALOW JUTE MILL, SERAJGUNJ.

FIG. 1. LANDSLIPS NEAR CHERRAPUNJI.

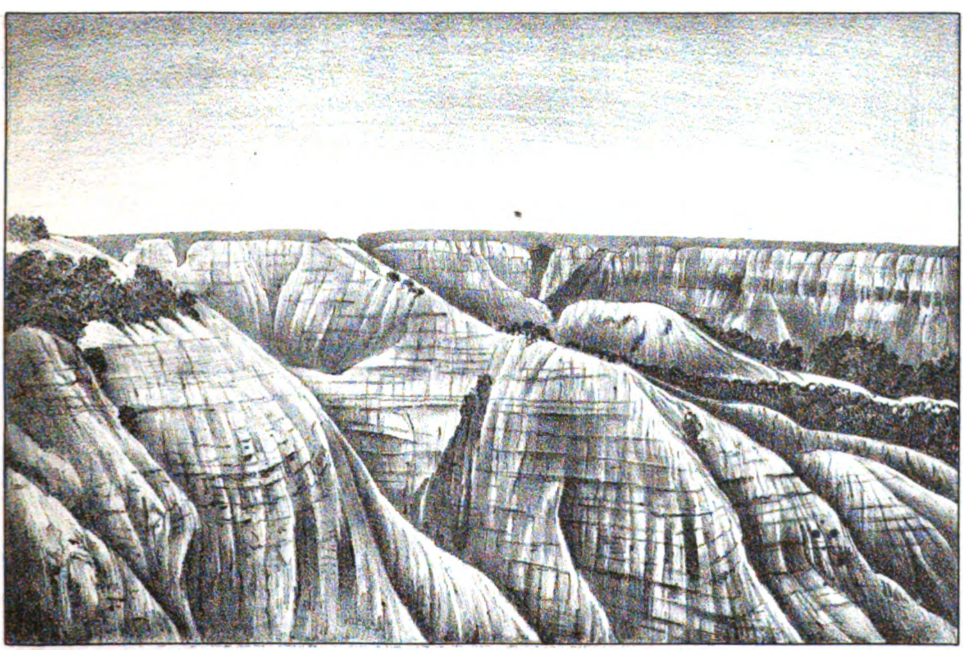
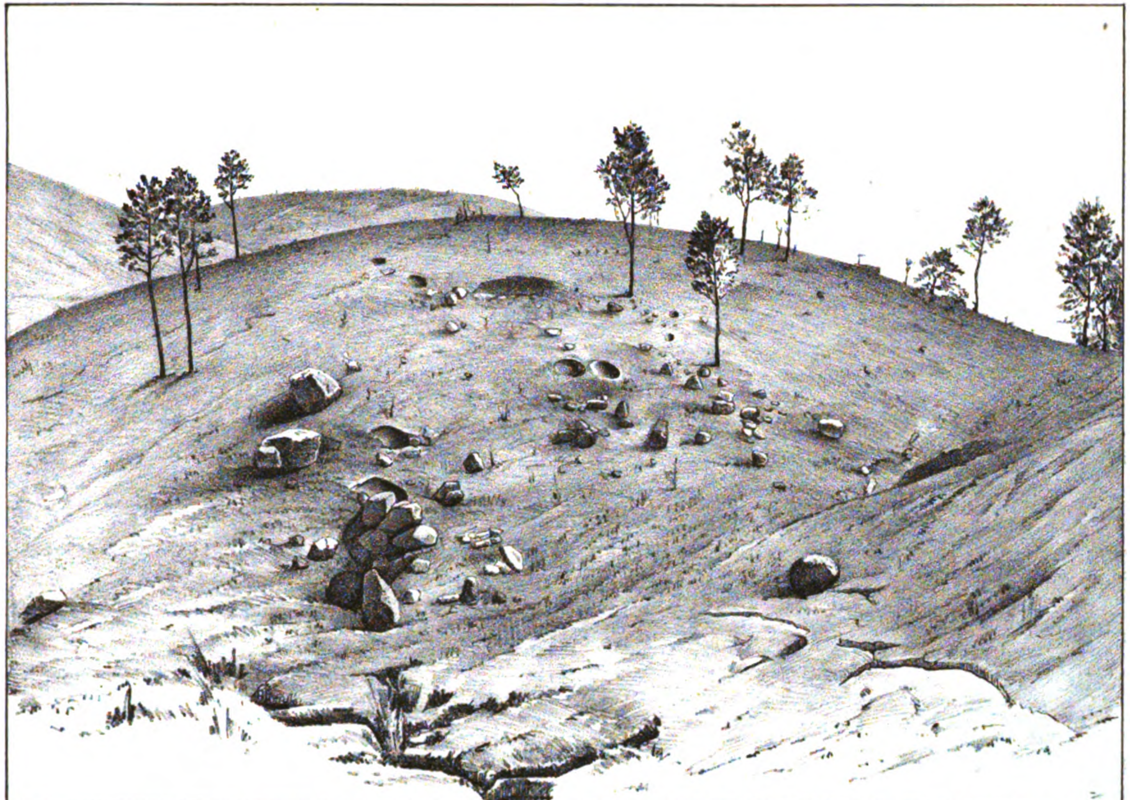


FIG. 2. LANDSLIPS IN MAHADEO VALLEY, GARO HILLS.



DISPLACED BOULDERS NEAR KANCHI, KHASI HILLS.

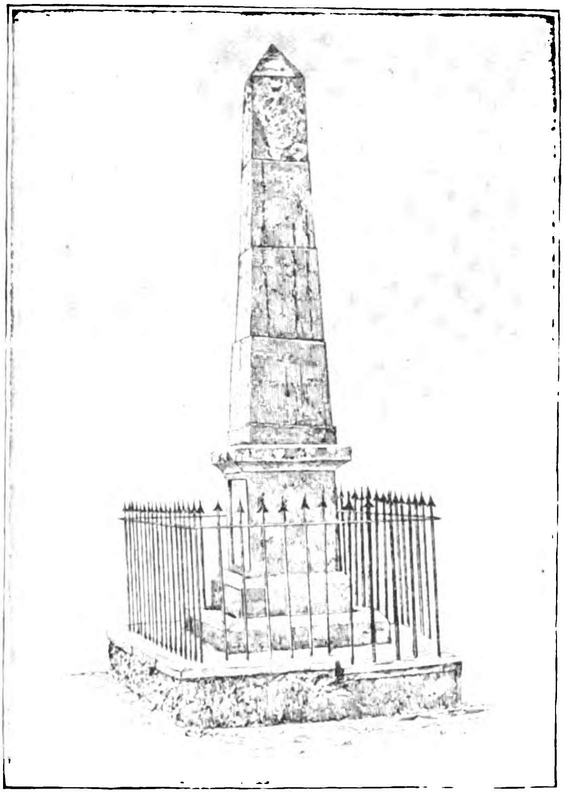


FIG. 1. TOMB IN DARJILING CEMETERY.

(Top part twisted).

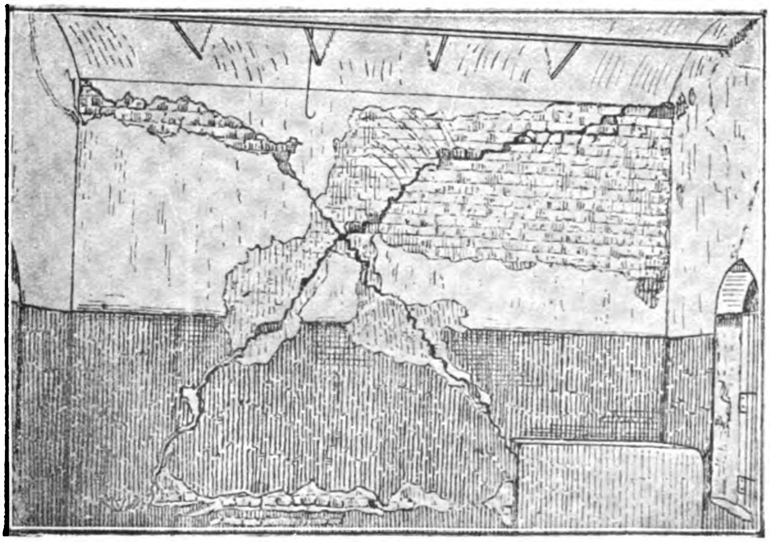
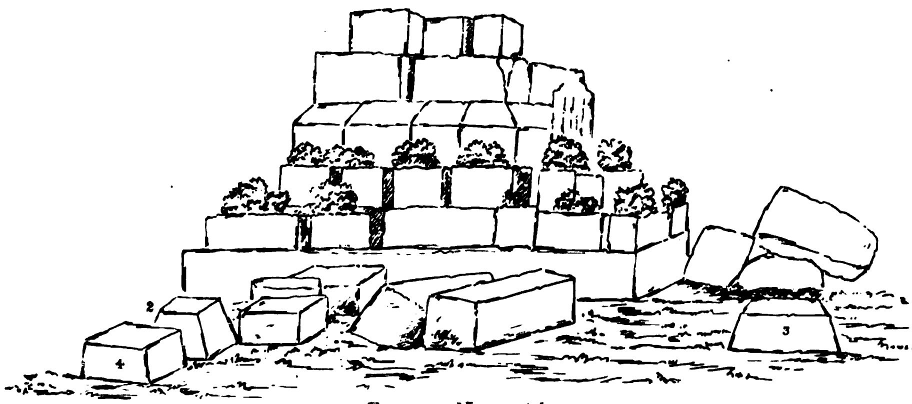
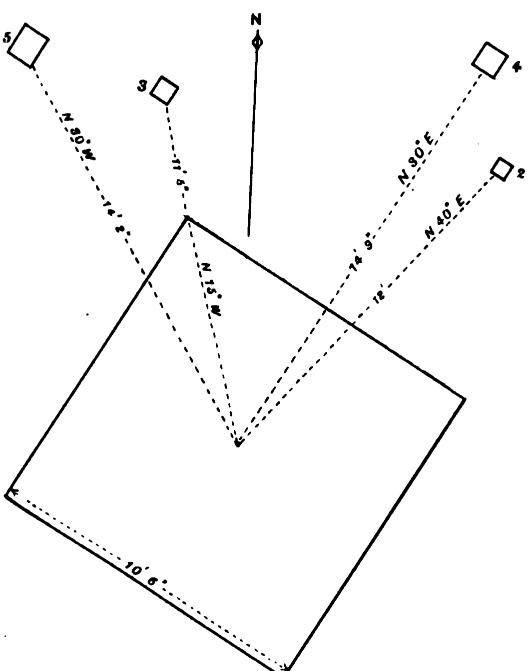


Photo-Block Survey of India Offices, Calcutta, 1898

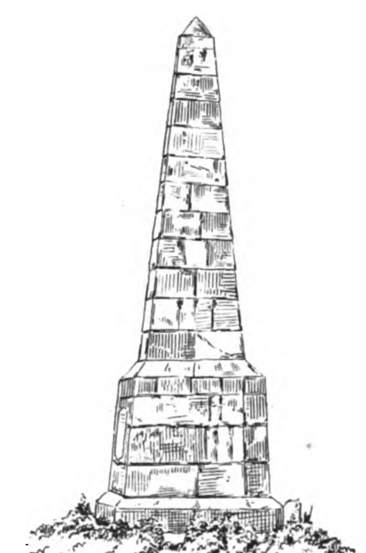
FIG. 2. CRACKS IN WALL OF JAIL, MAIMANSINGH.



From N side

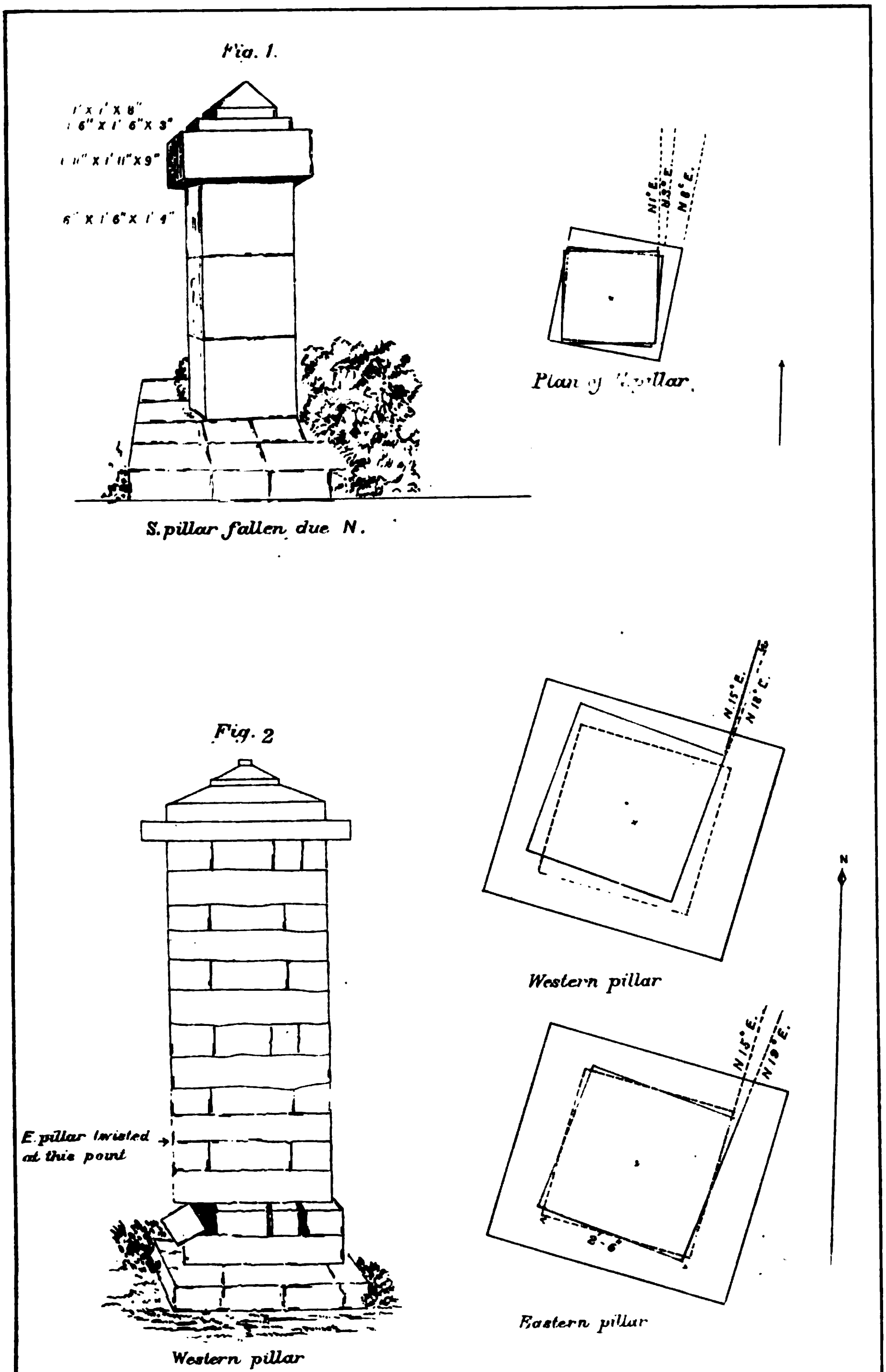


Plan showing position of 2d 3d 4th and 5th blocks from top of obelisk.

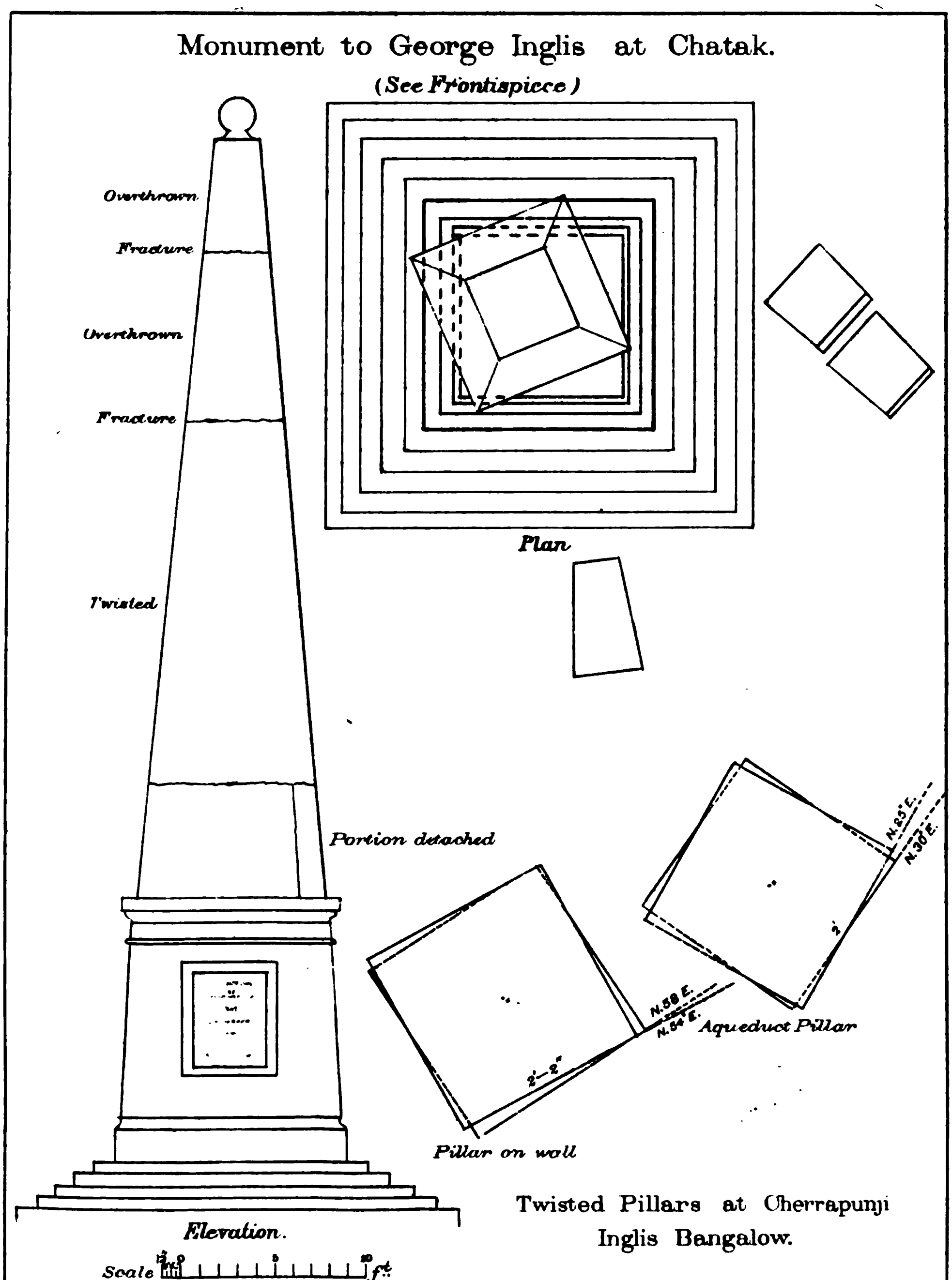


WILLANS MEMORIAL, SHILLONG.

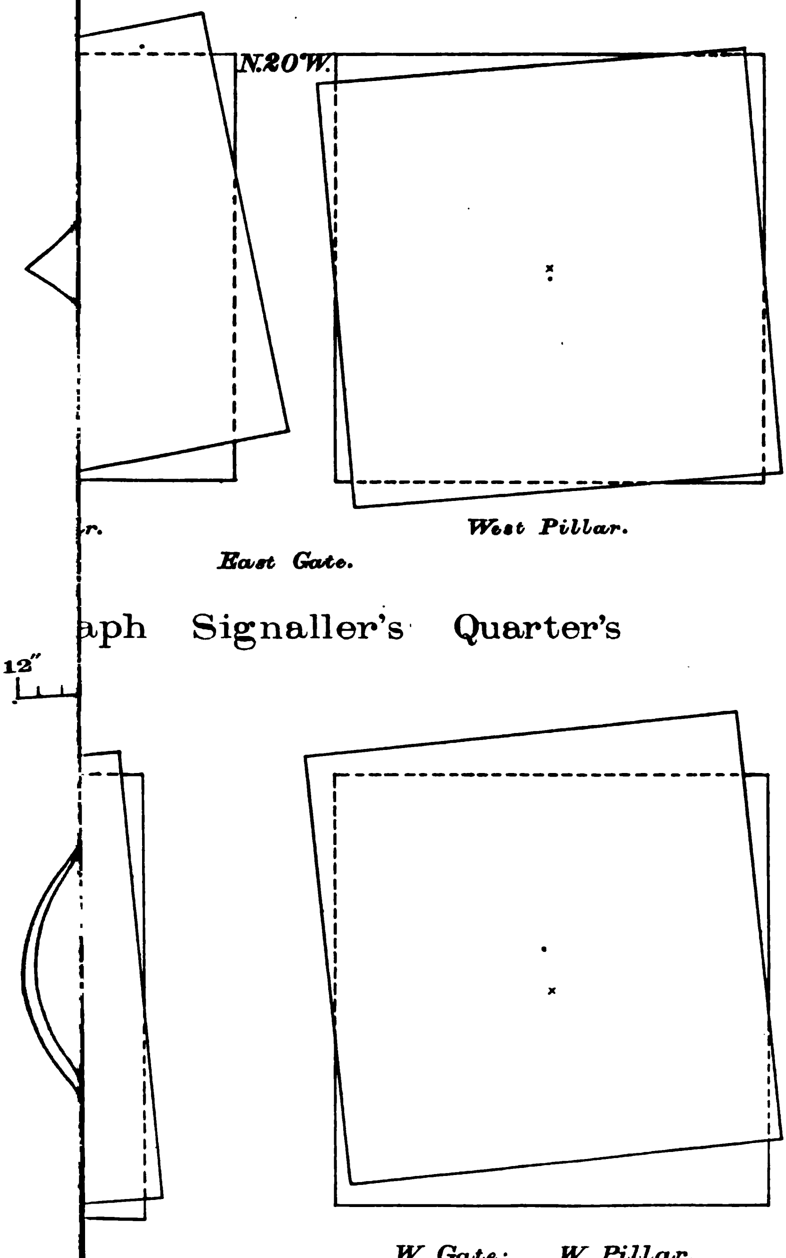
R. D. Oldham.



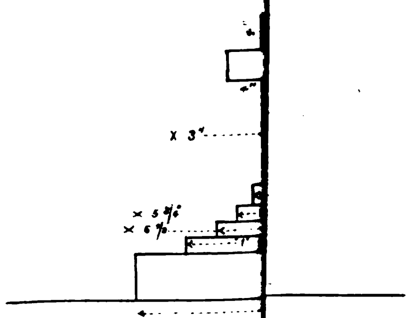
TWISTED GATE PILLARS, SHILLONG.



TWISTED PILLARS AT CHATAK AND CHERRAPUNJI.


N.20°W.
r.
West Pillar.
East Gate.
aph Signaller's Quarter's
12"
W. Gate; W. Pillar.

GAUHATI.



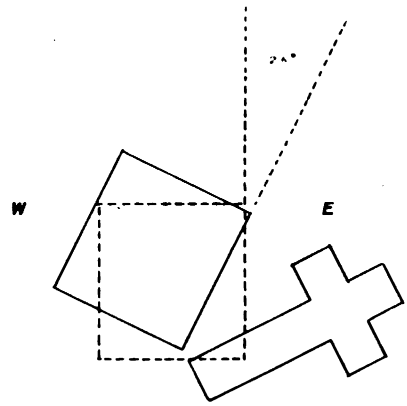
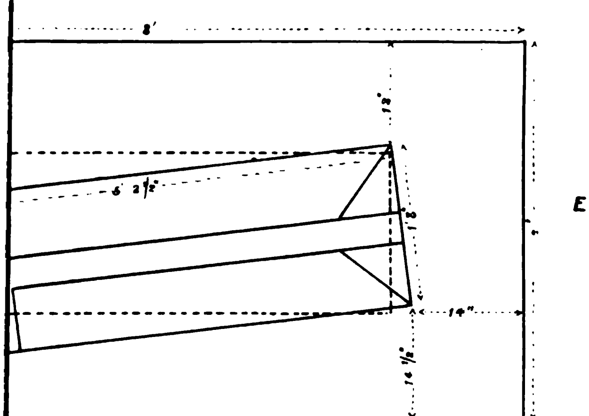


Fig. 2.



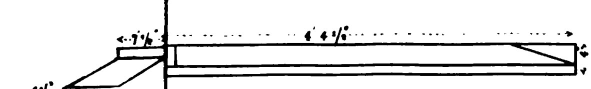
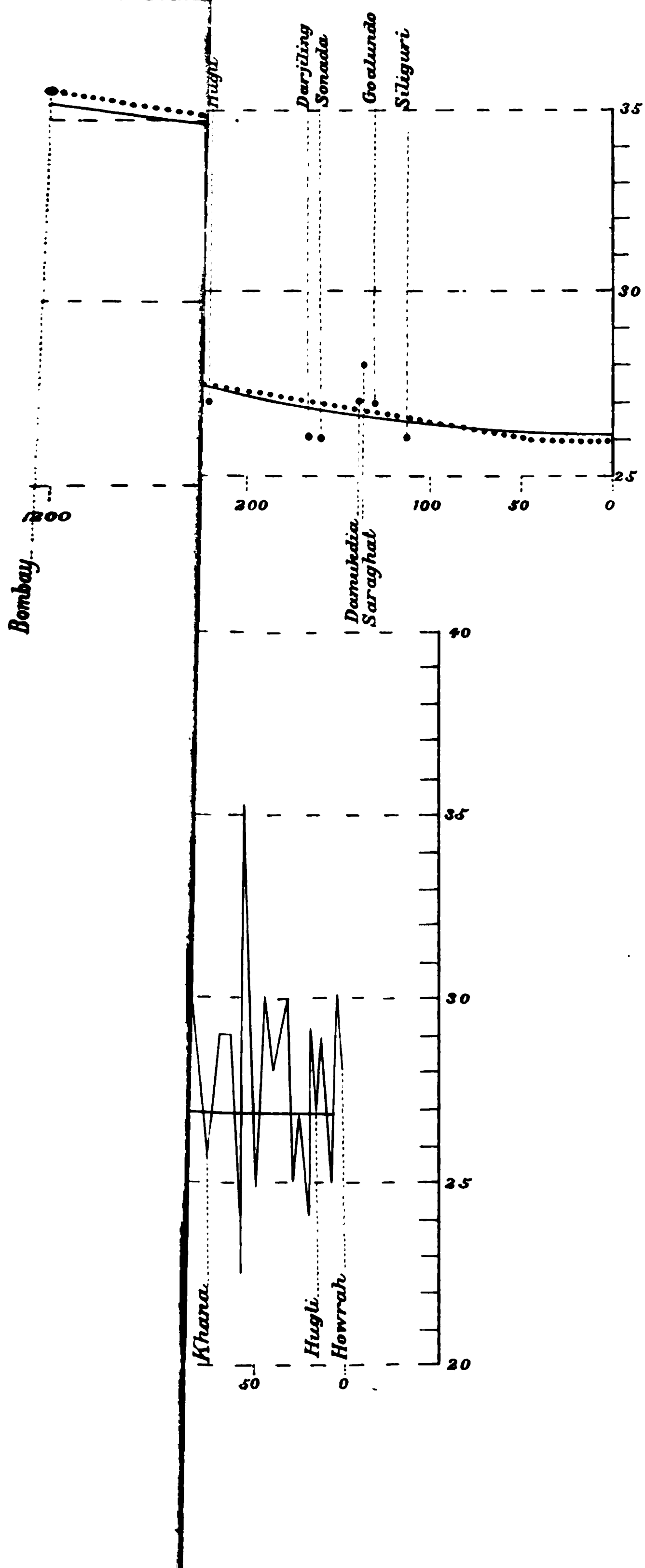


Fig. 4.


Hugli
Darjiling
Sonada
Goalundo
Siliguri
35
30
25
200
100
50
0
1200
Bombay
Damukdia
Saraghat
40
35
30
25
20
Khana
Hugli
Howrah
50
0

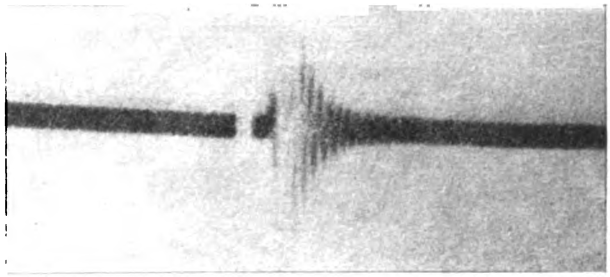


Fig. 1. Declination.

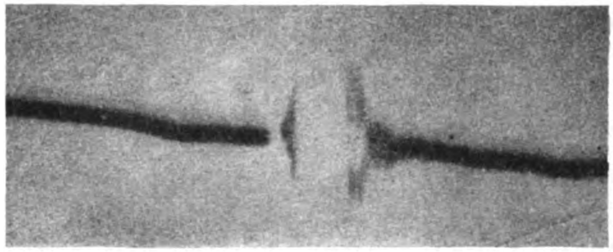


Fig. 2. Horizontal force

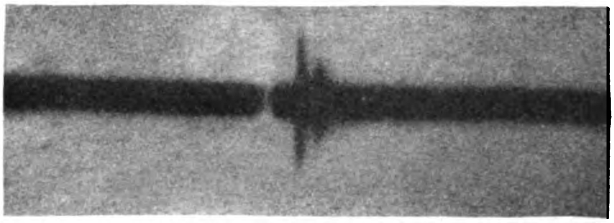
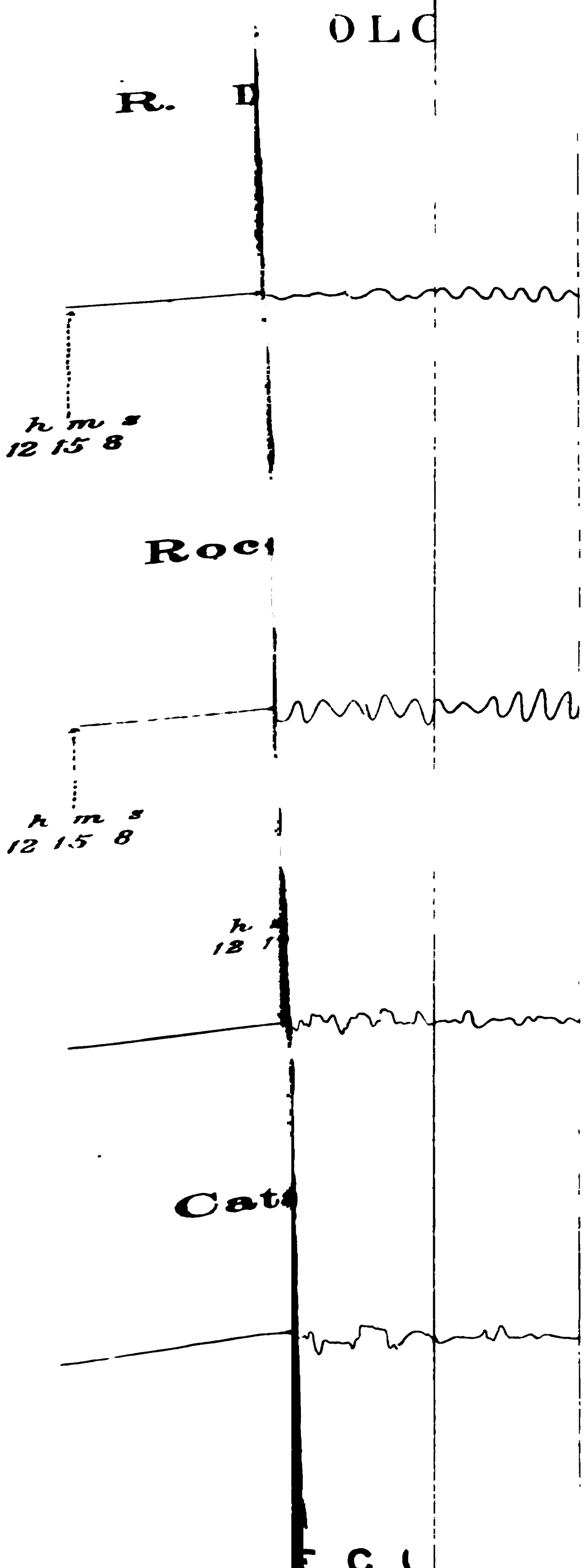
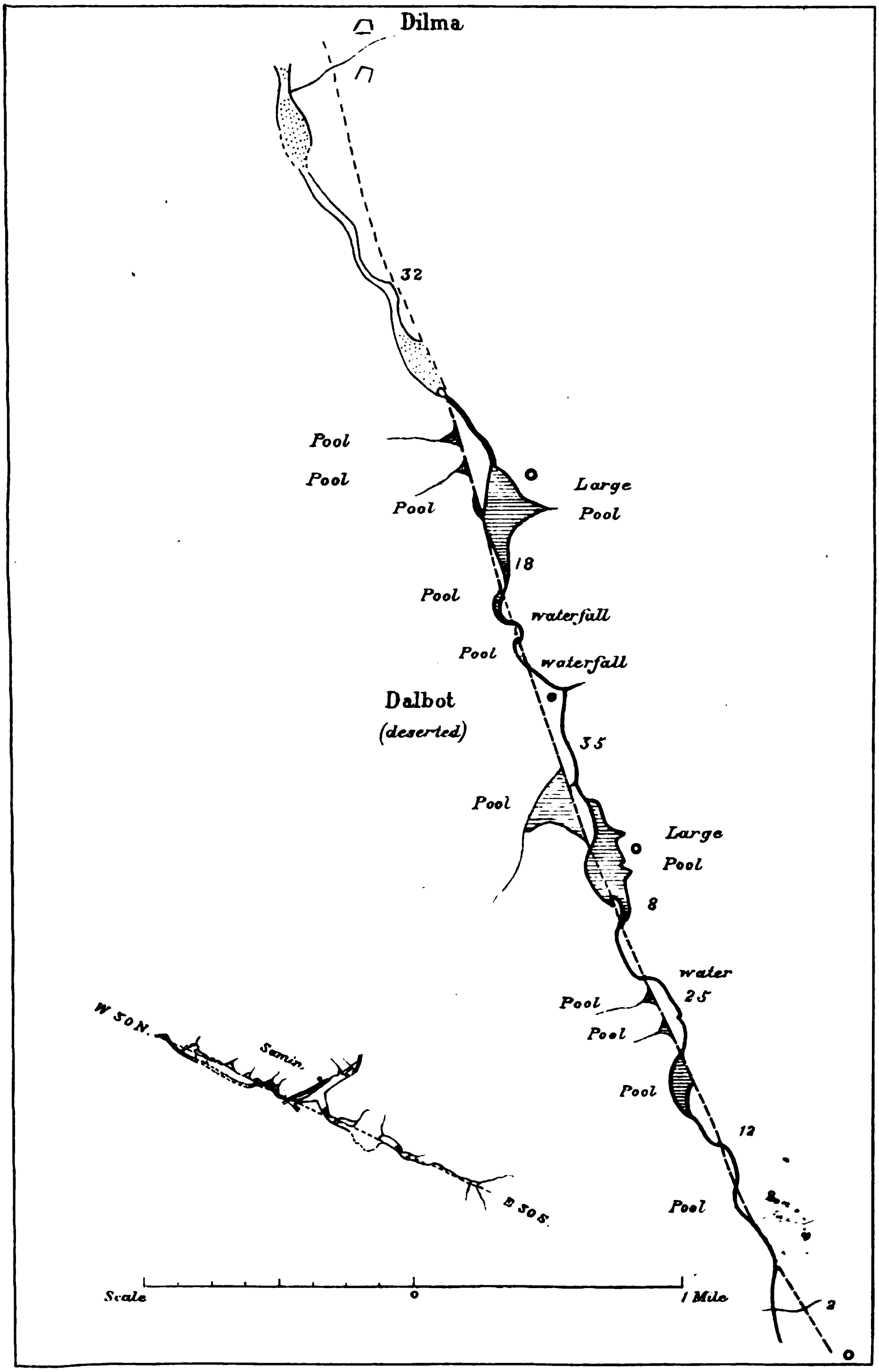


Fig. 3. Vertical force.

Photo-etching. Survey of India Offices, Calcutta, May, 1899.

RECORDS OF THE MAGNETOGRAPHS AT BOMBAY.


OLC
R. D
h m s
12 15 8
Roc
h m s
12 1.5 8
h
12 1
Cat
E C



ROUGH PLANS OF THE SAMIN AND CHEDRANG FAULTS.

(Figures represent throw in feet)

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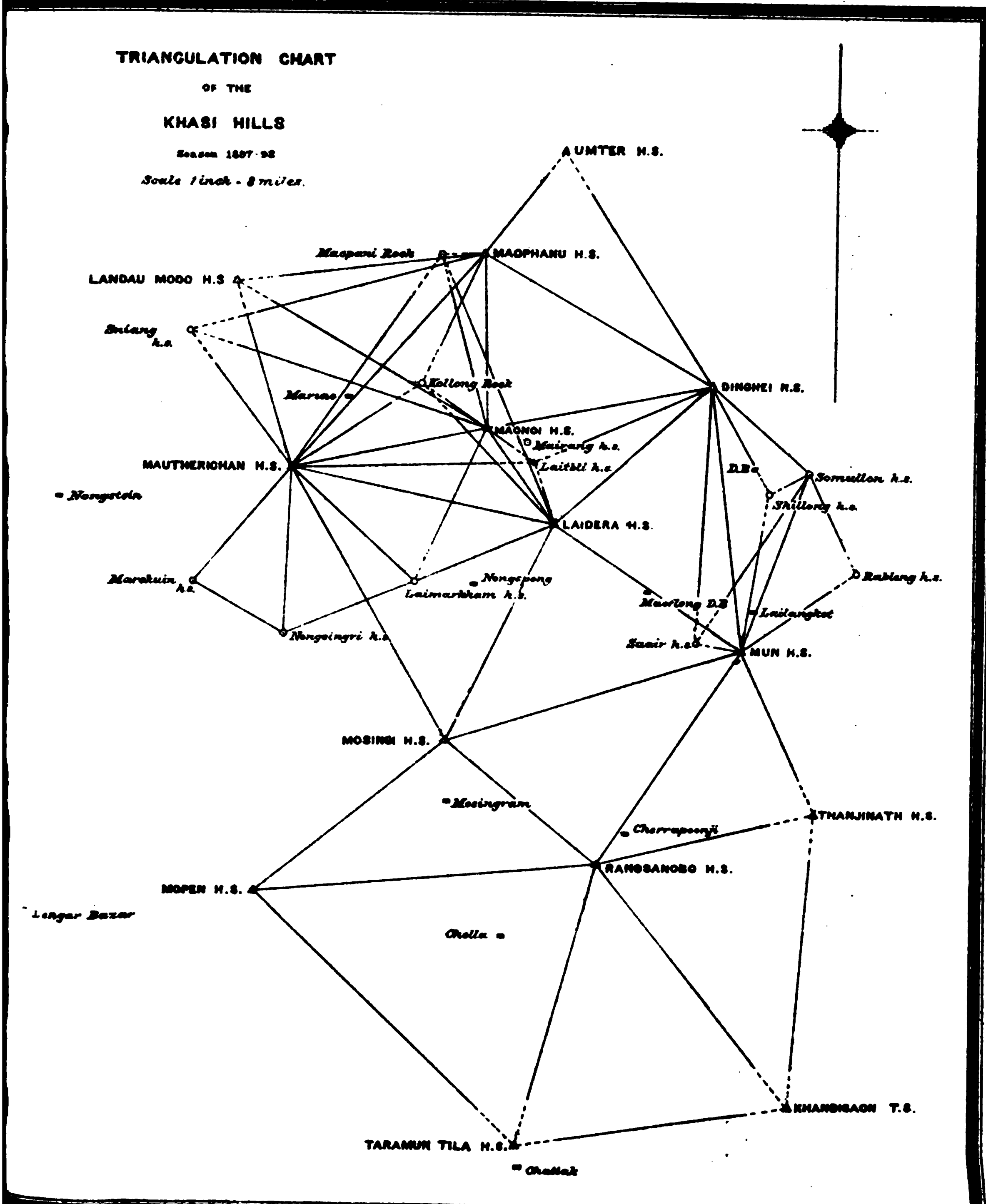


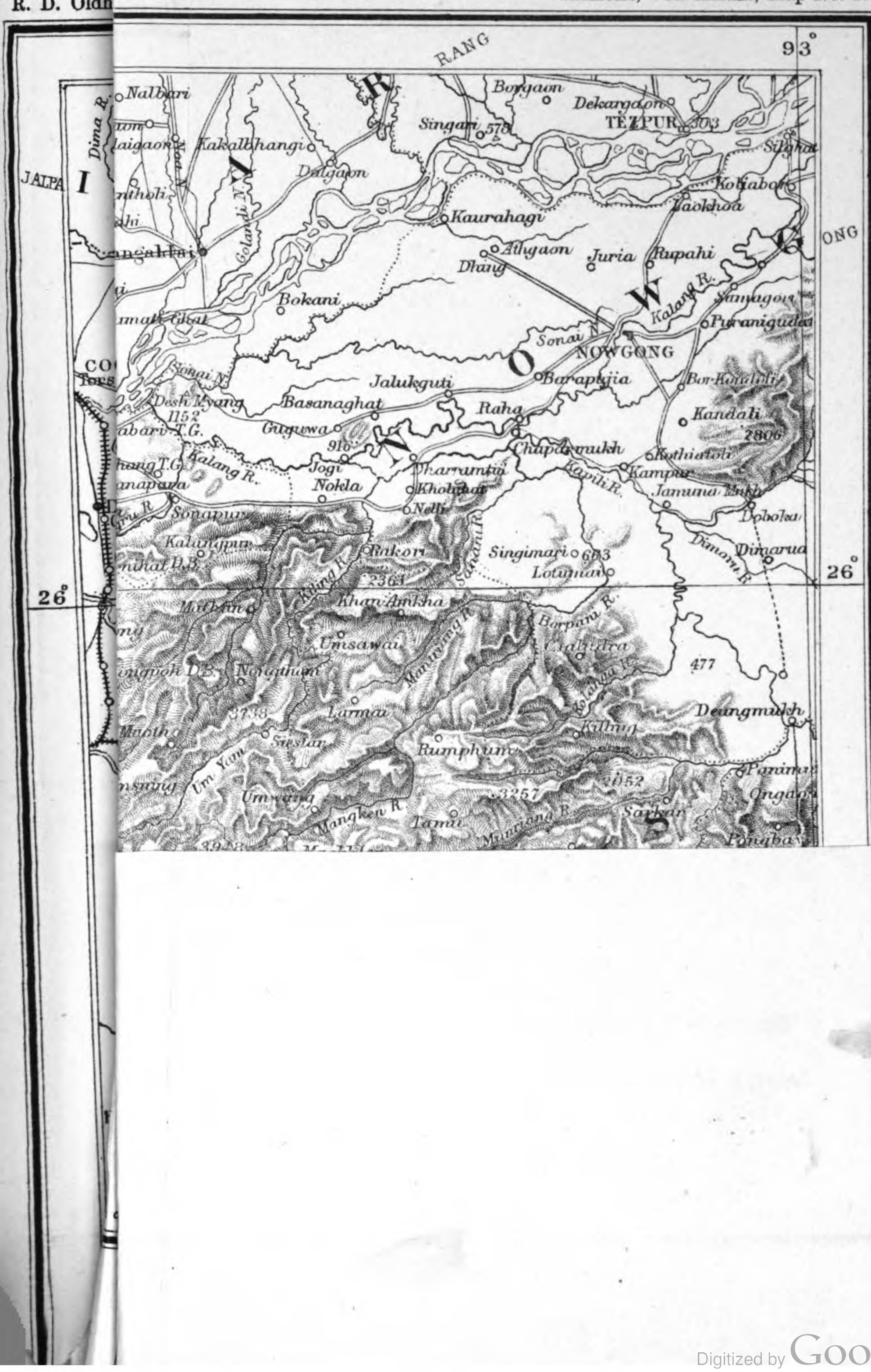
Reg. No. 881, Geol. Sur.—Mar. 99.—1,000. Photo., S. I. O., Calcutta.

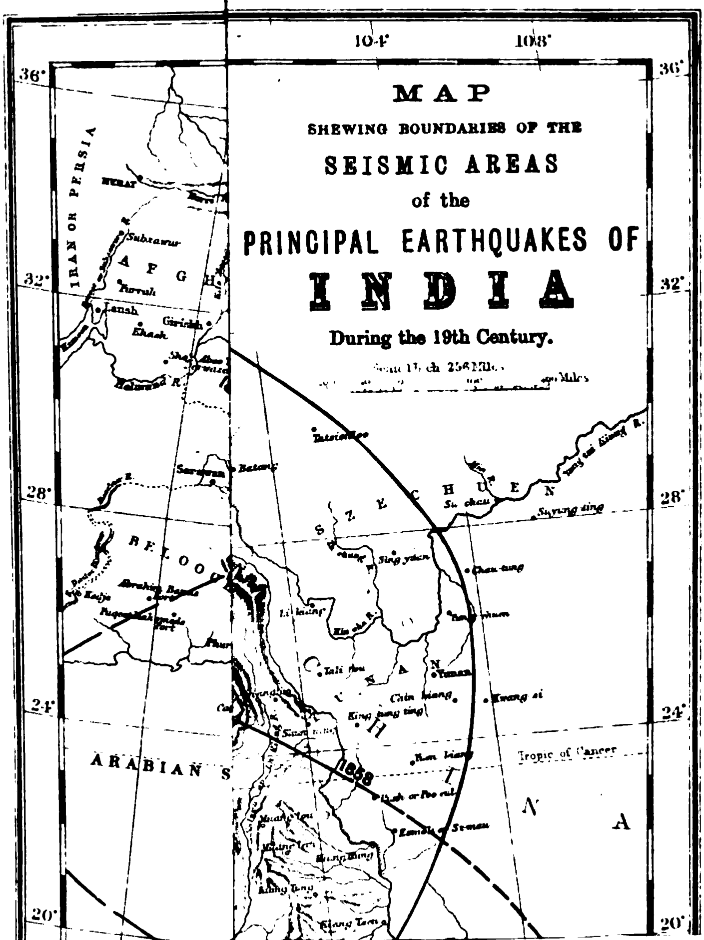
R. D. Oldham.


70°
32°
28°
24°
Isa Khel
Mianwali
Sakesar
Kundian
Khewra
Jhelum
Shah
Kanigurum
Tank
Moghal Kot
Dera Ismail Khan
Bhakkar
Mankera
Jhang
Mena
Leiah
Chaubara
Chenab
Ravi
Rangpur
Raj Ghat
Dera Ghazi Khan
Mooltan
Muzaffargarh
Kuhaf Pass
Bahawalp
375
Ahmadpur
Indus
Mithan Kot
Khanpur
B A H A W
28°
Kishangarh
R A J P
959
JEYSUL
Umarkot
Nagar Parkar
Ran
Cutc
BOMBA
CUT
G
Nawanagar

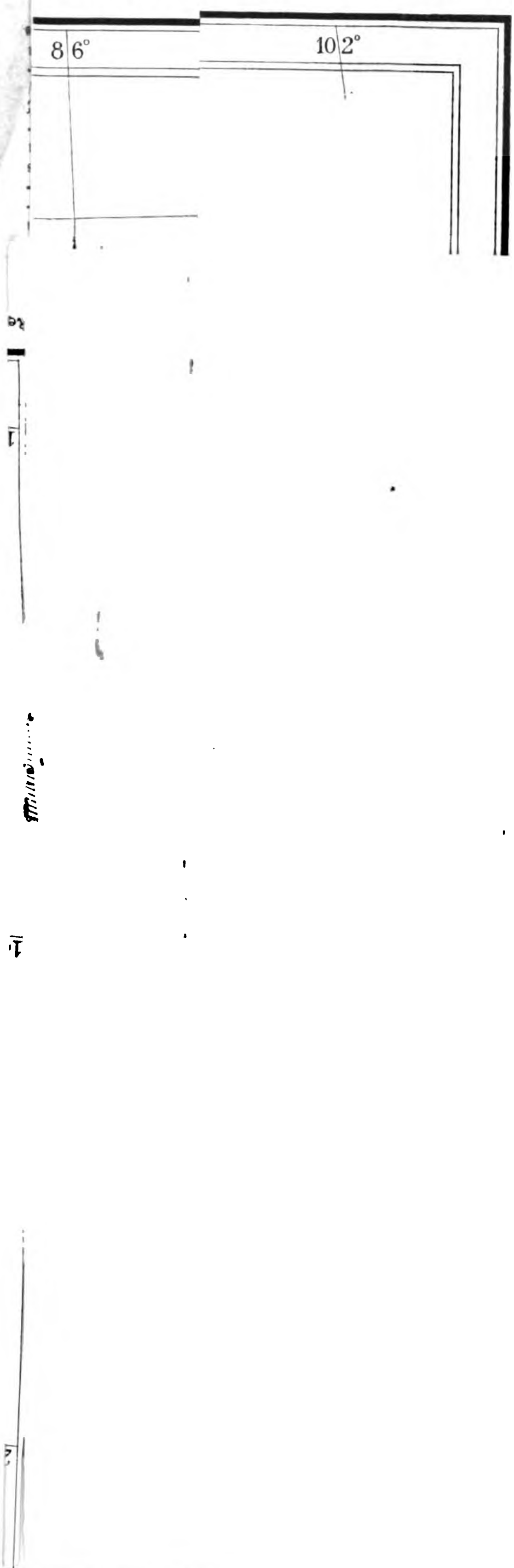
R. D. Oldh

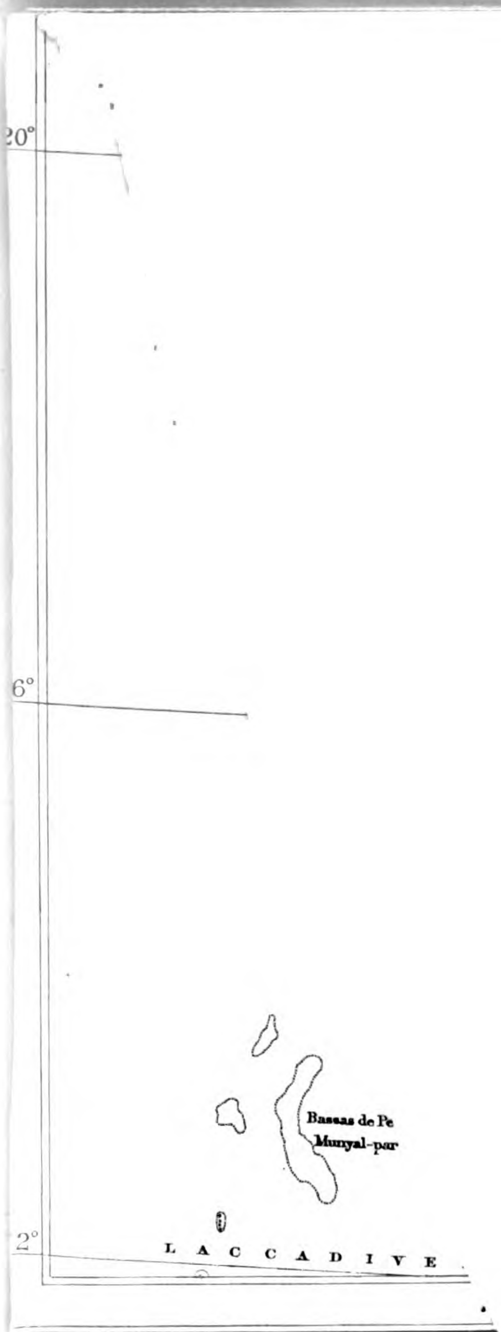
Memoirs, Vol. XXIX, Map No. 2.



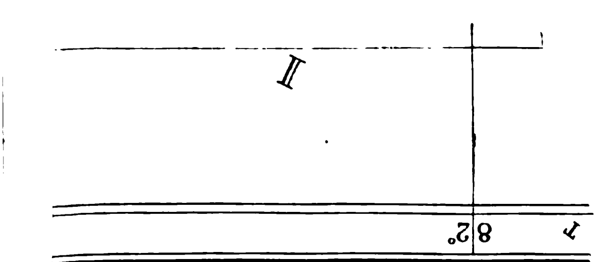

MAP
SHEWING BOUNDARIES OF THE
SEISMIC AREAS
of the
PRINCIPAL EARTHQUAKES OF
INDIA
During the 19th Century.
104°
108°
36°
32°
28°
24°
20°
IRAN OR PERSIA
HERAT
A F G H
Subzawur
Furrah
Lasah
Girishk
Ehash
Helmund R.
Sarawan
Batang
B E L O O
Ibrahim
Kelat
ARABIAN S
S Z E C H U E N
Su chau
Sunyung ting
Chau-tung
Tali fou
Yunan
Kwang si
Chin kiang
1858
Tropic of Cancer
N
A

SURVEY rs, Vol. XXIX, Map No. 1.





.g. No. 248, Geol. Sur.—Jan. 99.—1,000.



Part 2.—On the Mohpani coal-field. On Pyrolusite with Psilomelane occurring at Gosalpur Jabalpur district. A geological reconnoissance from the Indus at Kushalgarh to the Kurram at Thal on the Afghan frontier. Further notes on the geology of the Upper Punjab.

Part 3.—On the geological features of the northern part of Madura district, the Pudukota State, and the southern parts of the Tanjore and Trichinopoly districts included within the limits of sheet 80 of the Indian Atlas. Rough notes on the cretaceous fossils from Trichinopoly district, collected in 1877-78. Notes on the genus Sphenophyllum and other Equisetaceæ, with reference to the Indian form Trizygia Speciosa, Royle (Sphenophyllum Trizygia, Ung.). On Mysorin and Atacamite from the Nellore district. On corundum from the Khasi Hills. On the Joga neighbourhood and old mines on the Nerbudda.

Part 4.—On the 'Attock Slates' and their probable geological position. On a marginal bone of an undescribed tortoise, from the Upper Siwaliks, near Nila, in the Potwar, Punjab. Sketch of the geology of North Arcot district. On the continuation of the road section from Murree to Abbottabad.

VOL. XIII, 1880.

Part 1.—Annual report for 1879. Additional notes on the geology of the Upper Godavari basin in the neighbourhood of Sironcha. Geology of Ladak and neighbouring districts, being fourth notice of geology of Kashmir and neighbouring territories. Teeth of fossil fishes from Ramri Island and the Punjab. Note on the fossil genera Nõggerathia, Stbg., Nõggerathiopsis, Fstm., and Rhiptozamites, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Notes on fossil plants from Kattywar, Shekh Budin, and Sirgujah. On volcanic foci of eruption in the Konkan.

Part 2.—Geological notes. Palæontological notes on the lower trias of the Himalayas. On the artesian wells at Pondicherry, and the possibility of finding such sources of water-supply at Madras.

Part 3.—The Kumaun lakes. On the discovery of a celt of palæolithic type in the Punjab. Palæontological notes from the Karharbari and South Rewah coal-fields. Further notes on the correlation of the Gondwana flora with other floras. Additional note on the artesian wells at Pondicherry. Salt in Rajputana. Record of gas and mud eruptions on the Arakan coast on 12th March 1879 and in June 1843.

Part 4.—On some pleistocene deposits of the Northern Punjab, and the evidence they afford of an extreme climate during a portion of that period. Useful minerals of the Arvali region. Further notes on the correlation of the Gondwana flora with that of the Australian coal-bearing system. Note on reh or alkali soils and saline well waters. The reh soils of Upper India. Note on the Naini Tal landslip, 18th September 1880.

VOL. XIV, 1881.

Part 1.—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts, being fifth notice of the geology of Kashmir and neighbouring territories. Note on some Siwalik carnivora. The Siwalik group of the Sub-Himalayan region. On the South Rewah Gondwana basin. On the ferruginous beds associated with the basaltic rocks of north-eastern Ulster, in relation to Indian laterite. On some Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on the lower trias of the Himalayas.' On some mammalian fossils from Perim Island, in the collection of the Bombay Branch of the Royal Asiatic Society.

Part 2.—The Nahan-Siwalik unconformity in the North-western Himalaya. On some Gondwana vertebrates. On the ossiferous beds of Hundes in Tibet. Notes on mining records, and the mining record office of Great Britain; and the Coal and Metalliferous Mines Acts of 1872 (England). On cobaltite and danaite from the Khetri mines, Rajputana; with some remarks on Jaipurite (Syepoorite). On the occurrence of zinc ore (Smithsonite and Blende) with barytes, in the Karnul district, Madras. Notice of a mud eruption in the island of Cheduba.

Part 3.—Artesian borings in India. On oligoclase granite at Wangtu on the Sutlej, North-west Himalayas. On a fish-palate from the Siwaliks. Palæontological notes from the Hazaribagh and Lohardagga districts. Undescribed fossil carnivora from the Siwalik hills in the collection of the British Museum.

Part 4.—Remarks on the unification of geological nomenclature and cartography. On the geology of the Arvali region, central and eastern. On a specimen of native antimony obtained at Pulo Obin, near Singapore. On Turgite from the neighbourhood of Juggiapett, Kistnah district, and on zinc carbonate from Karnul, Madras. Note on the section from Dalhousie to Pangi *viâ* the Sach Pass. On the South Rewah Gondwana basin. Submerged forest on Bombay Island.

VOL. XV, 1882.

Part 1.—Annual report for 1881. Geology of North-west Kashmir and Khagan (being sixth notice of geology of Kashmir and neighbouring territories). On some Gondwana labyrinthodonts. On some Siwalik and Jamna mammals. The geology of Dalhousie, North-west Himalaya. On remains of palm leaves from the (tertiary) Murree and Kasauli beds in India. On Iridosmine from the Noa-Dibing river, Upper Assam, and on platinum from Chutia Nagpur. On (1) a copper mine lately opened near Yongri hill, in the Darjiling district; (2) arsenical pyrites in the same neighbourhood; (3) kaolin at Darjiling (being 3rd appendix to a report on the geology and mineral resources of the Darjiling district and the Western Duars). Analyses of coal and fire-clay from the Makum coal-field, Upper Assam. Experiments on the coal of Pind Dadun Khan, Salt-range, with reference to the production of gas, made April 29th, 1881. Report on the proceedings and result of the International Geological Congress of Bologna.

Part 2.—General sketch of the geology of the Travancore State. The Warkilli beds and reported associated deposits at Quilon, in Travancore. Note on some Siwalik and Narbada fossils. On the coal-bearing rocks of the valleys of the Upper Rer and the Mand rivers in Western Chutia Nagpur. On the Pench river coal-field in Chhindwara district, Central Provinces. On borings for coal at Engsein, British Burma. On sapphires recently discovered in the North-west Himalaya. Notice of a recent eruption from one of the mud volcanoes in Cheduba.

Part 3.—Note on the coal of Mach (Much) in the Bolan Pass, and of Sharag or Sharigh on the Harnai route between Sibi and Quetta. New faces observed on crystals of stilbite from the Western Ghâts, Bombay. On the traps of Darang and Mandi in the North-western Himalayas. Further note on the connexion between the Hazara and the Kashmir series. On the Umaria coal-field (South Rewah Gondwana basin). The Daranggiri coal-field, Garo Hills, Assam. On the outcrops of coal in the Myanoung division of the Henzada district.

Part 4.—On a traverse across some gold-fields of Mysore. Record of borings for coal at Beddadanol, Godavari district, in 1874. Note on the supposed occurrence of coal on the Kistna.

VOL. XVI, 1883.

Part 1.—Annual report for 1882. On the genus Richthofenia, Kays (Anomia Lawrenciana, Koninck). On the geology of South Travancore. On the geology of Chamba. On the basalts of Bombay.

Part 2.—Synopsis of the fossil vertebrata of India. On the Bijori Labyrinthodont. On a skull of Hippotherium antilopinum. On the iron ores, and subsidiary materials for the manufacture of iron, in the north-eastern part of the Jabalpur district. On laterite and other manganese ore occurring at Gosulpore, Jabalpur district. Further notes on the Umaria coal-field.

Part 3.—On the microscopic structure of some Dalhousie rocks. On the lavas of Aden. On the probable occurrence of Siwalik strata in China and Japan. On the occurrence of Mastodon angustidens in India. On a traverse between Almora and Mussooree made in October 1882. On the cretaceous coal-measures at Borsora, in the Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from the Daltonganj and Hutar coal-fields in Chota Nagpur. On the altered basalts of the Dalhousie region in the North-western Himalayas. On the microscopic structure of some Sub-Himalayan rocks of tertiary age. On the geology of Jaunsar and the Lower Himalayas. On a traverse through the Eastern Khasia, Jaintia, and North Cachar Hills. On native lead from Maulmain and chromite from the Andaman Islands. Notice of a fiery eruption from one of the mud volcanoes of Cheduba Island, Arakan Notice.—Irrigation from wells in the North-Western Provinces and Oudh.

VOL. XVII, 1884.

Part 1.—Annual report for 1883. Considerations on the smooth-water anchorages or mud banks of Narrakal and Alleppy on the Travancore coast. Rough notes on Billa Surgam and other caves in the Kurnool district. On the geology of the Chuari and Sihunta parganas of Chamba. On the occurrence of the genus Lyttonia, Waagen, in the Kuling series of Kashmir.

Part 2.—Notes on the earthquake of 31st December 1881. On the microscopic structure of some Himalayan granites and gneissose granites. Report on the Choi coal exploration. On the re-discovery of certain localities for fossils in the Siwalik beds. On some of the mineral resources of the Andaman Islands in the neighbourhood of Port Blair. The intertrappean beds in the Deccan and the Laramie group in western North America.

Part 3.—On the microscopic structure of some Arvali rocks. Section along the Indus from the Peshawar Valley to the Salt-range. On the selection of sites for borings in the Raigarh-Hingir coal-field (first notice). Note on lignite near Raipore, Central Provinces. The Turquoise mines of Nishâpûr, Khorassan. Notice of a further fiery eruption from the Minbyin mud volcano of Cheduba Island, Arakan. Report on the Langrin coal-field, South-west Khasia Hills. Additional notes on the Umaria coal-field.

Part 4.—On the Geology of part of the Gangasulan pargana of British Garhwal. On fragments of slates and schists imbedded in the gneissose granite and granite of the North-west Himalayas. On the geology of the Takht-i-Suleiman. On the smooth-water anchorages of the Travancore coast. On auriferous sands of the Subansiri river, Pondicherry lignite, and Phosphatic rocks at Musuri. Work at the Billa Surgam caves.

VOL. XVIII, 1885.

Part 1.—Annual report for 1884. On the country between the Singareni coal-field and the Kistna river. Geological sketch of the country between the Singareni coal-field and Hyderabad. On coal and limestone in the Doigrung river, near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field-notes.

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VOL. XIX, 1886.

Part 1.—Annual report for 1885. On the International Geological Congress of Berlin. On some Palæozoic Fossils recently collected by Dr. H. Warth, in the Olive group of the Salt-range. On the correlation of the Indian and Australian coal-bearing beds. Afghan and Persian Field notes. On the section from Simla to Wangtu, and on the petrological character of the Amphibolites and Quartz-Diorites of the Sutlej valley.

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Part 3.—Geological sketch of the Vizagapatam district, Madras. Preliminary note on the geology of Northern Jesalmer. On the microscopic structure of some specimens of the Malani rocks of the Arvali region. On the Malanjkhandi copper-ore in the Balaghat district, C. P.

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VOL. XX, 1887.

Part 1.—Annual report for 1886. Field-notes from Afghanistan: No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traverse through Jaunsar-Bawar and Tiri-Garhwal. On the geology of the Garo Hills. On some Indian image-stones. On soundings recently taken off Barren Island and Narcondam. On a character of the Talchir boulder-beds. Analysis of Phosphatic Nodules from the Salt-range, Punjab.

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Part 3.—The retirement of Mr. Medlicott. Notice of J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of the Lower Himalaya, Garhwal, and Kumaun, Section I. Preliminary sketch of the geology of Simla and Jutogh. Note on the 'Lalitpur' meteorite.

Part 4.—Note on some points in Himalayan geology. Crystalline and metamorphic rocks of the Lower Himalaya, Garhwal, and Kumaun, Section II. The iron industry of the western portion of the district of Raipur. Notes on Upper Burma. Boring exploration in the Chhattisgarh coal-fields. (Second notice.) Some remarks on Pressure Metamorphism, with reference to the foliation of the Himalayan Gneissose-Granite. A list and index of papers on Himalayan Geology and Microscopic Petrology, published in the preceding volumes of the Records of the Geological Survey of India.

VOL. XXI, 1888.

Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of the Lower Himalaya Garhwal, and Kumaun, Section III. The Birds'-nest or Elephant Island, Mergui Archipelago. Memorandum on the results of an exploration of Jessalmer, with a view to the discovery of coal. A facetted pebble from the boulder bed ('speckled sandstone') of Mount Chel in the Salt-range in the Punjab. Examination of nodular stones obtained by trawling off Colombo.

Part 2.—Award of the Wollaston Gold Medal, Geological Society of London, 1888. The Dharwar System, the chief auriferous rock series in South India. On the Igneous rocks of the districts of Raipur and Balaghat, Central Provinces. On the Sangar Marg and Mehowgale coal-fields, Kashmir.

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VOL. XXII, 1889.

Part 1.—Annual report for 1888. The Dharwar System, the chief auriferous rock-series in South India. (Second notice.) On the Wajra Karur diamonds, and on M. Chaper's alleged discovery of diamonds in pegmatite near that place. On the generic position of the so-called Plesiosaurus Indicus. On flexible sandstone or Itacolumite, with special reference to its nature and mode of occurrence in India, and the cause of its flexibility. On Siwalik and Narbada Chelonia.

Part 2.—Note on Indian Steatite. Distorted pebbles in the Siwalik conglomerate. 'The Carboniferous Glacial Period.' Notes on Dr. W. Waagen's 'Carboniferous Glacial Period.' On the oil-fields of Twingoung and Beme, Burma. The gypsum of the Nehal Nadi, Kumaun. On some of the materials for pottery obtainable in the neighbourhood of Jabalpur and of Umaria.

Part 3.—Abstract report on the coal outcrops in the Sharigh Valley, Baluchistan. On the discovery of Trilobites by Dr. H. Warth in the Neobolus beds of the Salt-range. Geological notes. On the Cherra Poonjee coal-field, in the Khasia Hills. On a Cobaltiferous Matt from Nepál. The President of the Geological Society of London on the International Geological Congress of 1888. Tin-mining in Mergui district.

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VOL. XXIII, 1890.

Part 1.—Annual report for 1889. On the Lakadong coal-fields, Jaintia Hills. On the Pectoral and pelvic girdles and skull of the Indian Dicynodonts. On certain vertebrate remains from the Nagpur district (with description of a fish-skull). Crystalline and metamorphic rocks of the Lower Himalayas, Garhwál and Kumaun, Section IV. On the bivalves of the Olive-group, Salt-range. On the mud-banks of the Travancore coast.

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Part 3.—On the Geology and Economic Resources of the Country adjoining the Sind-Pishin Railway between Sharigh and Spintangi, and of the country between it and Khattan (with a map). Report of a Journey through India in the winter of 1888-89, by Dr. Johannes Walther, translated from the German, by R. Bruce Foote. On the Coal-fields of Lairungao, Maosandram, and Mao-be-lar-kar, in the Khasi Hills (with 3 plans). Further Note on Indian Steatite. Provisional Index of the Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in the Indian Empire (continued from p. 286, Vol. XXII).

Part 4.—Geological sketch of Naini Tal; with some remarks on the natural conditions governing mountain slopes (with a map and plate). Notes on some Fossil Indian Bird Bones. The Darjiling Coal between the Lisu and the Ramthi rivers, explored during season 1890-91 (with a map). The Basic Eruptive Rocks of the Kadapah Area. The Deep Boring at Lucknow. Preliminary Note on the Coal Seam of the Dore Ravine, Hazara (with two plates).

VOL. XXIV, 1891.

Part 1.—Annual report for 1890. On the Geology of the Salt-range of the Punjab, with a re-considered theory of the Origin and Age of the Salt Marl (with five plates). On Veins of Graphite in decomposed Gneiss (Laterite) in Ceylon. Extracts from the Journal of a trip to the Glaciers of the Kabru, Pandim, &c. The Salts of the Sambhar Lake in Rajputana, and of the Saline efflorescence called 'Reh' from Aligarh in the North-Western Provinces. Analysis of Dolomite from the Salt-range, Punjab.

Part 2.—Preliminary Report on the Oil locality near Moghal Kot, in the Sherání country, Suleiman Hills. On Mineral Oil from the Suleiman Hills. Note on the Geology of the Lushai Hills. Report on the Coal-fields in the Northern Shan States. Note on the reported Namsèka Ruby-mine in the Mainglôn State. Note on the Tourmaline (Schorl) Mines in the Mainglôn State. Note on a Salt-spring near Bawgyo, Thibaw State.

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Part 4.—On a Collection of Mammalian Bones from Mongolia. Further note on the Darjiling Coal Exploration. Notes on the Geology and Mineral Resources of Sikkim (with a map). Chemical and Physical notes on Rocks from the Salt-range, Punjab (with two plates).

VOL. XXV, 1892.

Part 1.—Annual report for 1891. Report *on the* Geology *of* Thal Chotiáli *and part of the* Mari country (with a map and 5 plates). Petrological Notes *on the* Boulder-bed *of the* Salt-range, Punjáb, Subrecent *and* Recent Deposits *of the valley plains of* Quetta, Pishin and the Dasht-i-Bedaolat; *with appendices on the* Chamans *of* Quetta; *and the* Artesian water-supply *of* Quetta *and* Pishin (with one plate).

Part 2.—Geology *of the* Saféd Kóh (with 2 plates of sections). Report *on a* Survey *of the* Jherria Coal-field (with a map and 3 section plates) (*out of print.*)

Part 3.—*Note on the* Locality *of* Indian Tscheffkinite. Geological Sketch *of the* country north of Bhamo. Preliminary Report *on the* economic resources *of the* Amber *and* Jade mines area *in* Upper Burma. Preliminary Report *on the* Iron-Ores *and* Iron-Industries *of the* Salem District. *On the* Occurrence *of* Riebeckite *in* India. Coal *on the* Great Tenasserim River, Mergui District, Lower Burma.

Part 4.—Report *on the* Oil-Springs *at* Moghal Kot *in the* Shirani Hills (with 2 plates). Second Note *on* Mineral Oil *from the* Suleiman Hills. *On a* New Fossil, Amber-like Resin *occurring in* Burma. Preliminary notice *on the* Triassic Deposits *of the* Salt-range.

Vol. XXVI, 1893.

Part 1.—Annual report for 1892. Notes *on the* Central Himalayas (with map and plate). Note *on the occurrence of* Jadeite *in* Upper Burma (with a map). On *the* occurrence *of* Burmite, *a new* Fossil Resin *from* Upper Burma. Report *on the* Prospecting Operations, Mergui District, 1891-92.

Part 2.—Notes *on the* earthquake *in* Baluchistán *on the* 20th December 1892 (with 2 plates). Further Note *on* Burmite, *a new amber-like fossil resin from* Upper Burma. Note *on the* Alluvial deposits *and* Subterranean water-supply *of* Rangoon (with a map).

Part 3.—On the Geology *of the* Sherani Hills (with maps and plates). On Carboniferous Fossils *from* Tenasserim (with 1 plate). *On* a deep Boring *at* Chandernagore. Note *on* Granite *in the districts of* Tavoy *and* Mergui (with a plate).

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Vol. XXVII, 1894.

Part 1.—Annual report for 1893. Report *on the* Bhaganwala Coal-field, Salt-range, Punjab (with map and 2 plates).

Part 2.—Note *on the* Chemical qualities of petroleum *from* Burma. Note *on the* Singareni Coal-field, Hyderabad (Deccan) (with map and 3 plates of sections). Report *on the* Gohna Landslip, Garhwal (with 5 plates and 2 maps).

Part 3.—*On the* Cambrian Formation *of the* Eastern Salt-range (with a plate). The Giridih (Karharbari) Coal-field, *with notes on the* labour and methods of working (with 2 maps and 8 plates of sections). *On the* Occurrence of Chipped (?) Flints *in the* Upper Miocene of Burma (with a plate). Note *on the* Occurrence *of* Velates Schmideliana, Chemn., *and* Provelates grandis, Sow. *sp.*, *in the* Tertiary Formation *of* India *and* Burma (with 2 plates).

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Vol. XXVIII, 1895.

Part 1.—Annual report for 1894. *Cretaceous Formation of Pondicherry. Some* early allusions *to* Barren Island; *with a few remarks thereon.* Bibliography *of* Barren Island *and* Narcondam, *from* 1884 *to* 1894; *with some remarks.*

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Vol. XXIX, 1896.

Part 1.—Annual report for 1895. *On the Acicular inclusions in Indian Garnets. On the Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks* (with 1 plate).

Part 2.—*Notes on the* Ultra-basic rocks *and* derived minerals *of the* Chalk (Magnesite) hills, *and other localities near* Salem, Madras (with 2—6 plates). *Preliminary notes on some* Corundum localities *in the* Salem and Coimbatore districts, Madras (with 7—9 plates). *On the occurrence of* Corundum *and* Kyanite *in the* Manbhum district, Bengal. *On the papers by* Dr. Kossmat and Dr. Kurtz, *and on the ancient Geography of "Gondwana-land." Note from the Geological Survey of India.*

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Part 4.—Report *on the* Steatite mines, Minbu District, Burma. Further notes *on the* Lower Vindhyan (Sub-Kaimur) area *of the* Sone Valley, Rewah. *Notes from the Geological Survey of India.*

VOL. XXX, 1897.

Part 1.—Annual Report for 1896. *On* some Norite *and* associated Basic Dykes *and* Lava-flows *in* Southern India (with plates I to II). *The reference of the genus* Vertebraria. *On a* Plant of Glossopteris with part of the rhisome attached, *and on the* structure of Vertebraria (with plates III to V).

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NOTE.—*The Records ceased to be published from the 1st January 1898.*

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