gentlemen, we do want your advice in every problem that comes before us. We want it most insistently on all the great questions of industrial advance, which are of high importance to India at this particular juncture of her history. We want your advice and help in questions of public health, in dealing with disease and in ameliorating the physical condition of the people. We want your psychology in what is possibly the most important and greatest of all our problems, the problem of education, and we want your help very particularly in the task of increasing the agricultural productivity of our land. In every one of these problems we have to thank science for the timely help that it has already given us.

It would probably be uncongenial to them if I attempted to express the indebtedness of this province to some of my own colleagues, such as Major Sprawson in his investigations in tubercular disease, or Mr. Leake in his enquiries into the cotton plant. I may, however, be permitted to express the indebtedness which we owe in this province to one institution that lies outside our borders, the great Research Institute at **Pusa,** worthily represented here to-day, which has laid its indelible mark of beneficence upon the welfare of our rural millions.

And now, ladies and gentlemen, I will not stand for another moment between you and the joys of the presidential address. I beg you once again respectfully to accept our greetings in Lucknow, our gratitude that you have selected it as your meeting place this year, and our hope that when your work is over, you will carry away some pleasant recollections of our fair city.''

PRESIDENTIAL ADDRESS

THE PLAINS OF NORTHERN INDIA AND THEIR RELATIONSHIP TO THE HIMALAYA MOUNTAINS.

By Colonel Sir Sidney G. Burrard, *K.C.S.I.*, *R.E.*, *F.R.S.*, *President of the Congress.*

Plates A and B.

When I learnt that the Committee of the Indian Science Congress had honoured me by electing me the President for the year and by asking me to give an address to this meeting, I decided to invite the attention of the Congress to the unsolved problems surrounding the formation of mountains. The scientific world is now divided into numerous branches of specialists following their own roads, but the study of mountains belongs to no specialist branch; it is not a road, but a junction of many roads, and geologists and astronomers, physicists and mathematicians, geographers and geodesists all meet at that junction for discussion. I have approached the question from the roads of geography and geodesy, and I will tell you the lessons I have learnt; I do not, however, ask you to believe that the problems are solved, for although I may be led to place certain geographical and geodetic conclusions before you, I realize that no solution will be satisfactory, unless it proves acceptable to geologists, physicists and mathematicians.

You may think it peculiar that I should be speaking about mountains at a place where only flat plains are to be seen, but I may remind you that to the north of these plains stand the greatest mountains of the Earth, and one of the most interesting of the problems under consideration is, what is the relationship of these plains to those mountains.

This is an outline map of the United Provinces; you will see that these Provinces have three geographical divisions; there is the Himalayan area to the north, there are the level plains in the centre, and there is the ancient table-land on the south.

These great plains in the centre have been formed of loose sediment brought down by the Ganges, Gogra and other rivers: a borehole was sunk at Lucknow 1,500 feet deep, but no rock bottom was reached.

This is a section across the United Provinces. If you compare the rocky area lying to the south of the plains with that lying to the north, you will find on the south a massive table-land; the geologists have shown that this table-land belongs to a very remote past. The mountains on the north are totally different; here the rocks have undergone continued compression, elevation, and disturbance throughout the tertiary period, and our earthquakes prove that these movements of the Earth's crust in the north of the United Provinces have not yet ceased.

I ask you to consider how does this ancient table-land join on to these younger mountains that are always suffering from movements in the crust? If we could dig out from the Gangetic trough all the silt deposited by the Himalayan rivers, what kind of rocky junction should we find under Lucknow?

The Contraction Theory.

A hundred years ago the accepted idea was that mountain ranges were due to the upward pressure of liquid lava and that their elevation had been caused by volcanic forces. But when geologists began to study the structure of rocks, they found that mountains had suffered from great horizontal compression which was evident from the folding of strata. This discovery led to the idea that mountains had been elevated not by vertical forces, but by horizontal forces which squeezed the rock upward. The wrinkling of the Earth's crust into mountains by horizontal forces was explained by the cooling of the

Earth: this is the well-known Contraction theory illustrated in this diagram; the Earth's interior is held to cool and to contract, and the outer crust is supposed to get too large for the shrinking core and to wrinkle.

About 1860 the observations of the plumb-line in these Provinces brought to light a most important and totally unexpected fact, namely that the Himalaya were not exercising an attraction at all commensurate with their bulk.

This instrument is a plumb-line. It is a simple weight suspended on a string, and it hangs under the influence of the attraction of the Earth which pulls it downwards: you know from mechanics, that if one force pulls this weight vertically and if another force pulls it horizontally, the weight will hang in a resultant direction inclined to the vertical. Sixty years ago the question had to be considered, how will a weight hang near the foot of the Himalaya: here there will be two forces; the Earth's mass will be pulling the weight vertically, and the mass of the Himalaya will pull it horizontally. You may think that the mass of the Himalaya is very small compared with that of the Earth; that is true, but we can measure by the stars very small angles of latitude and longitude, and the question was, Will the Himalaya deflect the plumb-line sufficiently to affect the observations of the Survey?

The plumb-line was observed at Kaliana, a village near Muzaffarnagar in the United Provinces, 60 miles from the foot of the mountains: the observers found that the Himalaya were exercising no appreciable attraction. Archdeacon Pratt, the mathematician, then calculated from the known dimensions of the Himalaya mass the attraction that the Himalaya should exercise. Geographical exploration has taught us more about the dimensions of the Himalaya and Tibet than Pratt knew, and Major Crosthwait has now revised his actual figures. By the theory of gravitation the plumb-line ought to be deflected at Kaliana 58 seconds towards the hills; it is not deflected at all. It hangs vertically. This discovery was the first contribution made by geodesy to the study of mountains. The discovery was this, that the Himalaya behaved as if they had no mass, as if they were an empty eggshell; they seemed to be made of rock, and yet they exercised no more attraction than air. From the Kaliana observations Pratt deduced his famous theory of mountain compensation: he explained the Kaliana mystery by assuming that the rocks underlying the mountains must be lighter and less dense than those underlying plains and oceans. The visible mountain masses, he said, are compensated by deficiencies of rock underneath them. This is the theory of Mountain Compensation.

The compensation of the Himalaya is not believed now to be exactly complete and perfect: they seem to be compensated to the extent of about 80 per cent; their total resultant mass is thus about $\frac{1}{5}$th only of their visible mass standing above sea-level. The discovery of mountain compensation struck a blow at all theories which attributed the elevation of mountains to any additional masses that had been pushed in from the sides. The elevation of mountains by subterranean lava squeezed in from the side had to be rejected because it gave to mountains additional mass; the wrinkling of the Earth's surface by lateral horizontal forces had to be rejected because it gave to mountains additional mass pushed in from the sides. As the Himalaya possess only $\frac{1}{5}$th of their apparent visible mass, I am led to suggest that the principal cause of their elevation has been the vertical expansion of the rocks underlying them, vertical expansion due to physical or chemical change. The name of Pratt and the name of Kaliana have now permanent places in the history of science, and in this city of the United Provinces it is only right that I should recall to you that the great theory of mountain compensation, since found true in every continent, had its origin in the United Provinces, and that its author lies buried in these Provinces at Ghazipur.

You will understand from this diagram that if the Earth's interior shrinks and if the outer crust is squeezed up into wrinkles like this, the mountains must possess much additional mass: the theory of compensation forbids such additional mass.

The contraction theory was gradually becoming discredited under the attacks of Fisher, Dutton and others, and it seemed some years ago to be moribund, when it was given a fresh lease of life by the publication and translation into several languages of Professor Suess's great work, *The Face of the Earth.* This work is a critical history of all past geographical, geological and geodetic research; the wealth of its detail, the courtesy of its criticisms have won for Suess's work universal admiration.

But from the geodetic point of view it is disappointing; it accepts the contraction theory in its entirety, and it rejects the theory of Mountain Compensation. Suess does not obscure the issue, as some writers do, by the indefinite adoption of contradictory theories; being quite clear in his own mind he is quite clear to his readers. He states that he does not believe in the compensation of mountains by underlying deficiencies of mass. Now the compensation theory has been found to be true in India, Europe and America: nowhere do mountains attract the plumb-line as the law of gravitation would lead us to expect. So you see that the geodesists are sharply opposed to the school of Suess. Now what is Suess's reason for rejecting the theory of mountain compensation? It is this: he states quite clearly, "mountain compensation is inconsistent with all geological observations." Whilst I admit that mountain compensation is inconsistent with certain geological theories, I do not believe that it is inconsistent with geological observations.

If the Himalaya had the uncompensated mass which they appear to have, and which the school of geologists who follow Suess ascribes to them, they would attract the waters of the Indian Ocean over India; the plains of Northern India would be a great sea; this sea would be 300 feet deep above Allahabad, 400 feet deep above Lucknow and Gorakhpur, and 800 feet deep above Pilibhit and Bahraich. Fortunately those mountains have not the power of attracting the Indian Ocean.

Mountain Flotation and Isostasy.

But if the theory of compensation has suffered at the hands of its opponents, it has suffered also from its friends. Pratt's theory of compensation has been stretched into a theory of flotation: an iceberg floats, because ice is lighter than water; an iceberg is compensated in the water by its relative deficiency of density; Sir George Airy, the Astronomer Royal, suggested that mountains were compensated because they were floating upon a heavy subterranean magma. Pratt never went as far as this; he merely said, "the mountains are compensated." Airy went further; he said, "the mountains are floating." Distinguished geologists, Fisher, Dutton, Oldham, have developed the idea of flotation.

The theory of flotation lays down that the mountains are supported in their present positions by hydrostatic pressure, just as an iceberg floats upon water. I have no time to discuss this theory at length, but I should like to point out to you that if an iceberg floats upon water, its weight must be compensated by underlying deficiencies of density: the theory of flotation does not state this with regard to mountains; it states the converse, viz., that as mountains are compensated they must be floating. The principle of hydrostatic pressure demands that if any mass is floating it must be compensated; it does not, however, follow that if a mass is compensated it must be floating. The theory of flotation is based upon the assumption that the compensation of mountains is complete and perfect; but we have not found complete compensation in India: the outer Himalaya are compensated to the extent of 80 per cent. An iceberg would not float, unless its compensation were exactly complete; the fact that mountain compensation is nowhere quite complete or perfect is a serious argument against flotation. This imperfection of compensation differentiates rock from water: it denotes rigidity. What I have been calling the theory of flotation is frequently called the theory of Isostasy. I have however purposely avoided using the word Isostasy, as its exact meaning is open to question. Isostasy is a condition of approximate equilibrium, not perfect equilibrium like the condition of flotation. Isostasy is a condition of compensation in a solid crust; it does not necessarily imply hydrostatic support, as flotation does. I therefore hesitate to apply the word Isostasy to the Flotation theory; for Isostasy can exist without flotation.[1]

Mountains Originate at Great Depths.

A very important work has been that of Mr. Hayford who has recently discussed the results of the plumb-line at a large number of stations in America. He has confirmed Pratt. Hayford has investigated the depth to which the deficiency of density underlying mountains goes down, and he has found that that depth is between 60 and 90 miles. That is to say, he has shown that the depth of subterranean compensation is very great compared with the height of mountains. The discovery that mountains originate from the great depth of 60 to 90 miles is the second important contribution of geodesy to this study; the first was compensation, the second is great depth.

Most books are written on the assumption that mountains are surface wrinkles and that their structure can be determined by examining surface rocks.

The Satpura range runs east and west south of the Narbada; the plateaux of Hazaribagh and Chota Nagpore are the eastward continuation of the Satpura range. A high authority has stated that the Hazaribagh and Chota Nagpore plateaux can have no real connection with the Satpura range, because they are formed of different rocks. But if we regard this range as rising from a depth of 75 miles, its elevation will be seen to be due to a deep-seated cause that has nothing to do with the surface rocks. One deep-seated cause has lifted up this range from the Narbada to Hazaribagh irrespective of the kind of rocks lying on the surface.

The Gangetic Trough.

I have now discussed the two principal theories of Himalayan elevation, the Contraction theory and the Flotation theory. Let us consider for one moment how this deep Gangetic trough is explained by these two theories. For a great number of years the Contraction theory ignored this trough; it was, I think, Professor Suess who first recognised that the trough had to be fitted into the Contraction theory. His explanation of it was this: as the Earth's interior contracts, the surface of Asia is wrinkled, the wrinkles get pushed south-

[1] The idea of flotation has arisen because the question of mountain-support has been given precedence of the question of mountain-elevation. Questions of support and maintenance should be subsidiary to questions of formation and origin. If mountains are due to the vertical expansion of rock, a theory of flotation is superfluous.

wards against the Indian table-land, and the rock surface of Northern India gets compressed into a downward bend between the mountains and the table-land. This explanation is not satisfactory: if the surface of Asia is being pushed southwards in wrinkles against the table-land, it is difficult to understand how it is that a deep trough borders the table-land. Why should the solid crust be bent downwards by a horizontal pressure from the north: if the crust is being pushed against this table-land, it should be heaped up all round it.

The explanation of the Gangetic trough that is supplied by the Flotation theory is this: the Earth's crust is likened to a floating raft: the more weight you place upon a raft, the deeper it sinks into water. The Ganges and Jumna and other rivers are continually depositing fresh sediment upon these plains, and the crust according to this theory continually sinks downwards by the weight of the sediment. When we see the massive rocks of Kaimur and Mirzapur supported easily by the crust, it is difficult to believe that it cannot support a thin layer of silt without yielding.

You will see from this chart, that the Ganges and Indus have filled up their trough with silt, but that the Tigris and Euphrates are behindhand; the Persian Gulf is an unfilled trough which will be filled in time.

Here is a chart of Japan, showing the Tuscarora deep, a long submarine trough; it is over 24,000 feet deep, and it is continued to the north-east by further troughs lying in front of the Kuriles and Aleutian Islands, and attaining depths of 28,000 feet. How then can it be argued that the Ganges trough has been created by the weight of its own silt, when we see that the Euphrates trough and the Japanese trough are unfilled. These troughs exist before the silt comes to them. The idea that the weight of silt causes subsidence arose, I think, from the fact that the places where silt is being deposited are frequently found to be subsiding. But the truth may be this: a river carries its silt to the lowest hole in the crust it can find; the lowest holes near continents are those where the crust is subsiding; rivers thus deposit their loads in places of crustal subsidence, but their loads do not cause the subsidence.

Southerly Deflections Prevail over the Ganges Plains.

Now let me tell you of the third discovery due to this plumb-line. The Survey found that at 60 miles from the hills this plumb-line hung vertically, and Pratt deduced the Theory of Mountain Compensation. But when the Survey began to extend their operations, a new phenomenon came to light, which caused great surprise. All over the United Provinces at distances exceeding 70 miles from the hills, this plumb-line was found to hang decisively away from the mountains ; at Fyzabad, Cawnpore, Benares, the plumb-line is deflected southwards : here at Lucknow it is deflected 9″ to the south. If the Himalaya were simply compensated, this plumb-line should be hanging at Lucknow exactly vertical ; if the mountains were not compensated, it should be deflected here about 50″ towards the north. But it is deflected 9″ towards the south. The observers were astonished to find that at places in sight of Himalayan peaks the plumb-line turned away from the mountain mass ; that at Amritsar in sight of the Dhauladhar snows it was deflected towards the low Punjab plains ; that at Multan in sight of the Takht-i-Suleiman mountains it was deflected towards the desert ; at Bombay it was deflected seawards away from the Western Ghats ; on the east coast of India it was deflected seawards away from the Eastern Ghats (Plate A).

The new lesson to be learnt from the plumb-line is this : a hidden subterranean channel of deficient density must be skirting the mountains of India. Here in North India is a wide zone of deficient density, of crustal attenuation ; it is the presence of this zone of deficiency that accounts for the southerly deflection of the plumb-line. What is the meaning of this zone ? How has it come into existence ?

If you look at this section (Plate B) the Earth's crust in these outer Himalaya has been compressed laterally : of this there is no doubt. The area between the snowy range and the foothills is a zone of crustal compression. And I suggest for your consideration that the Gangetic trough, this zone of deficiency, is a zone of tension in the crust. The crust has been stretched here and attenuated. Here you have a compression, and alongside is the tension. The tension is the complement of the compression. I have pointed out that the Himalaya mountains are largely, but not completely compensated by their underlying deficiencies of density : their compensation is however rendered complete by the presence of the Ganges trough ; if the Himalayan compression and the Gangetic tension are considered together, it will be found that there is no extra mass.

Geodesy thus teaches that the Gangetic trough and the Himalaya Mountains are parts of one whole. The Contraction theory and the Flotation theory both treat the Gangetic trough as though it were a secondary effect of Himalayan elevation. But this Gangetic trough may have been the first and the decisive event ; the Himalaya Mountains may have been a secondary effect, a sequel to the opening of the trough.

Hypothesis of a Rift.

I showed you on the evidence of the plumb-line that the Gangetic trough was a zone of crustal attenuation, a zone in which the Earth's crust was deficient in density. I then took one step forward and suggested that it was a zone of tension. I will now take another step forward and suggest to you that there has occurred an actual opening in the sub-crust, and that the outer crust has fallen in owing to the failure of its foundation: I suggest that the Ganges plains cover a great rift in the Earth's crust.

The Earth is a cooling globe; an increase of temperature occurs as we descend into mines; and this temperature gradient is a proof that the Earth is losing heat by conduction outwards. The discovery of radium has not affected the argument.

The smaller bodies of the solar system, the Moon and other satellites seem to be cold; the Earth has a cold exterior and a hot interior; the larger planets are believed still to display heated surfaces, whilst the Sun is still a globe of fire. The inferences are warranted that all the bodies of the solar system were hot at one time, and that the smaller have lost their heat. So I say that the Earth is a cooling body. The rock composing the crust and sub-crust is however a bad conductor, and the interior of the Earth will not shrink away from its crust, as has been assumed in the Contraction theory. The inner core of the Earth is in fact not losing heat appreciably. The outer shell was the first to lose its heat, then the shell below it, and the sub-crust is now losing its heat more quickly than the interior core. As the outer shells contract from cooling, they become too small for the core, and they crack. Supposing we had here a great globe of rock, red-hot throughout; how would it cool? Can you imagine it cooling in such a way that the core became too small for the outer shell, and the outer shell became wrinkled? No; the outer shell would cool first, and would crack.

The outer shell of the Earth was the first to crack millions of years ago: now a lower shell, the sub-crustal shell, is cracking. When a crack occurs in the sub-crust, parts of the upper crust fall in.

You will see that this Indus-Ganges trough has the appearance of a crack. And there are reasons for believing that these Himalaya have been split off from this ancient table-land and have been moved northwards and crumpled up into mountains. This Assam plateau is stated by geologists to resemble in its structure and rocks the Indian table-land; Assam has been split off and moved away.

Here are the Bengal coal-fields, and just opposite on the other side of the trough are the Sikkim coal-fields; and the coal in the two places is similar. The rocks of the outer Himalaya have been very much crushed, but they still bear a resemblance to the rocks of the Vindhyan table-land.

Here are the Arravalli mountains which end now at the

Delhi ridge; Mr. Middlemiss has found signs of a transverse strike in the Himalaya on a continuation of the Arravalli alignment.

Similarity also exists between the rocks in Cutch and those on the other side of the Indus in the hills of Sind.

From the Bay of Bengal to the Mediterranean.

Geologists have discovered that the ancient table-land of the Vindhyas and Deccan is a remnant of a much greater table-land that in very early ages included Africa and Arabia. Africa and Arabia and the Deccan table-land are in fact fragments of one extensive and ancient continent. Hitherto I have been considering the peculiar trough that skirts the northern edge of the Indian table-land. Let us now consider whether this trough is continued to the east or to the west.

On the east we find one of the great linear deeps off the coast of Java and Sumatra. It is 24,000 feet deep. In 1883 the Krakatoa eruption took place in the Sunda Straits. Great depths have also been discovered off the Nicobar Islands and earthquakes have occurred on the Chittagong coast. In continuation of the Gangetic trough we thus find in the Bay of Bengal a line of seismic activity, and of submarine deeps.

To the west of Karachi we see the Persian Gulf, and the plains of the Tigris-Euphrates. The plains of the Tigris-Euphrates are very similar to those of the Ganges: they consist of mud, sand and sediment lying in a long trough between the ancient table-land of Arabia and the mountains of Persia.

Further west we find the Euphrates trough is continued by the Mediterranean Sea, and the Mediterranean is bounded on the north by the Taurus mountains, by the Balkans, Carpathians, Appenines and Alps.

Throughout the whole distance from Calcutta to Sicily we see that the old table-land India-Arabia-Africa is bounded on the north by a long trough, and that this trough is in its turn bounded by the younger mountain ranges from the Himalaya to the Alps. Geologists have discovered that all these mountain ranges were elevated in the same era; they are all of the same age.

I submit for your consideration that the Ganges-Indus-Euphrates-Mediterranean trough is an indication at the Earth's surface of a rift in the sub-crust.

When we get as far west as Sicily, we reach a region of active volcanoes, Etna and Stromboli. Italian Geologists believe that Sicily has been separated from Africa by recent subsidences.

The Earthquake Record.

The whole zone from Java to Sicily has been visited by earthquakes throughout the historic period. And the recent earthquakes in Shillong, Dharmsala and Messina show that seismic activity is continuing in our time. This is in fact one of the zones of the Earth, along which earthquakes occur most frequently.

In the last 300 years 64 destructive earthquakes are known to have occurred in India[1]: there may have been others of which there is now no record. Of the 64 violent Indian Earthquakes 58 have occurred along the Indus-Ganges zone. These may be grouped as follows:—

Assam-Bengal..	20
Outer Himalayas ..	11
Northern Punjab and Kashmir	17
Southern margin of Gangetic plain	4
Cutch and Sind	6
Total	58

If we consider the whole zone from Bengal to Sicily, we find from Milne's catalogue that the numbers of destructive earthquakes since 1615 can be grouped as follows:—

India	58
Mesopotamia and Syria	28
Eastern Mediterranean	116
Italy	482

In the last 300 years a destructive earthquake has occurred in Northern India on an average once in every 5 or 6 years.

From Lob Nor to the Black Sea.

Let us now glance to the north of the long mountain zone that extends from China to France. You will see north of Tibet there is the large inland basin of Lob Nor; then here are the low-lying plains of the Oxus; then come the Caspian and Black Seas. Now all four of these depressions are believed to be subsidences of the Earth's crust. South of the line of mountains we see a long continuous trough: north of the line of mountains we find not a continuous trough, but a series of separate depressions. Now these depressions are separated from one another by fragments of mountain ranges which once ran parallel to the Himalayan-Alpine trends. Here you see the Pamirs. The high Pamir plateau consists of parallel ranges running east and west. The eastern and western continuations of the Pamir ranges seem to have foundered into the abyss, those on the east have fallen into Lob Nor, those on the west into the Oxus depression.

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1 Milne's Catalogue of Destructive Earthquakes.

Here again you will see that one of the chains of the Caucasus has foundered into the Caspian, and the western extensions of the Caucasus have fallen into the Black Sea.

Why are these mountain ranges collapsing? May it not be that the Earth's crust is cracking and these mountains are falling into the rifts?

THE BOMBAY COAST.

I must now invite your attention to the Bombay Coast. From the Tapti to Cape Comorin runs the range of mountains known as the Western Ghats. This range is parallel to the coast of India and about 40 miles inland; it rises suddenly with a steep scarp. The strata are almost as horizontal as when first laid down; they have never been compressed or folded.

The Survey has observed the plumb-line at different points along this coast; it is always deflected strongly towards the sea. To the west of Bombay and Mangalore there is the deep sea; and to the east there is a massive range over 4,000 feet high: yet the plumb-line will hang seawards. If the Western Ghats possessed the mass which they appear to possess and which the Suess school ascribes to them, then the Bombay plumb-line should be deflected 15 seconds towards them. If on the other hand the Western Ghats are compensated by deficiencies of mass underlying them in accordance with the compensation theories of Pratt and Hayford, then the plumb-line should hang vertically at Bombay. But the plumb-line takes neither of these courses: it hangs towards the sea. We have been puzzled for years by the plumb-line at Bombay; we used to think that the rock under the ocean must be so dense and heavy, that it was able to pull the plumb-lines towards the sea. Major Cowie, however, observed in the south of Kathiawar, and found that the plumb-line here had a strong landward deflection. The seaward deflections occur throughout the Bombay coast but not round Kathiawar. It is only quite recently that we have realized we have here at Bombay the same phenomenon as at Lucknow.

In Northern India the plumb-line will persist in hanging away from the visible mountains and at Bombay it takes the same course, and when I consider its constant seaward deflection I can only suggest to you, that there must be, between Bombay and the Western Ghats, a zone of subterranean deficiency, a zone of fracture and subsidence like that of the Gangetic plains.

The secret is hidden below the Earth's crust: you will see that the Ghats have been forced (possibly by underground fracture) into a decided curve just above Bombay harbour; it is significant that at this curve the Deccan Trap rises to its highest point, Kalsubai.

I suggest to you that a crack in the sub-crust has extended from Cape Comorin to Cambay, and that as this crack has occurred the Western Ghats have been elevated. The crack has been filled by masses of fallen rock and by alluvial deposits brought down by rivers.

Geologists have shown that this range consists, from latitude 20° to 16°, of the lavas of the Deccan, comparatively recent rocks, whilst from latitude 16° to 8° the range consists of ancient metamorphic rocks. The rocks of the northern part of the range are of a different age and structure and origin from the southern.

Nevertheless geodesists contend that this is one and the same range: the rocks composing it have had nothing to do with its elevation. The Western Ghats have been elevated after the Deccan lavas had become solidified into surface rocks. Their elevation has taken place in the Tertiary age.

Now I will turn to the Eastern Ghats (Plate A); at Madras and at Vizagapatam we find the plumb-line hanging towards the sea. Here we have the same phenomenon as we witnessed at Lucknow and at Bombay, the plumb-line turns away from the mountains. I will not repeat myself, but I suggest again that this coastal zone, like the western, covers a sub-crustal crack.

I told you just now that in the last 300 years there had been 64 destructive earthquakes in India: of these 58 had occurred along the Indus-Ganges trough. Where did the remaining six take place? Three of them occurred on the Bombay-Surat coast; the other three on the Madras coast. No destructive earthquakes are recorded as having occurred at Hyderabad, or at Bangalore, or at Nagpore.

The ancient table-land of India is in the shape of a triangle, but its two wings, Assam and Cutch, have been severed from the main body: this may have been due to the coast-line cracks.

Assam-Bengal has had 20 destructive earthquakes in the last 300 years, and though only 6 have been recorded in Cutch and Sind, yet this western fragment of the table-land is of seismic region. In 1819 Bhuj was destroyed and every town in Cutch was injured; numerous fissures were seen throughout the land. North of Sindhi a drop 16 feet deep and 50 miles long suddenly appeared on the plains which had hitherto been as level as the sea. On account of its sudden appearance across the old bed of the Indus it was named by the inhabitants the Allah Bund, and by this name it is now known in geography. It was due to the subsidence of a large area to the south.

Many of the destructive earthquakes of Sind have not been recorded in history, but the ruins of strong buildings with human bones buried below them are evidence of sudden destruction by earthquake.

THE DEPTH OF THE GANGETIC RIFT.

I have been describing zones of deficiency and have suggested that they are cracks in the sub-crust. I have now the task of discussing the possible depths of these cracks.

By the depth of the Gangetic rift I do not mean merely the depth of the loose sediment: I do not mean the depth at which solid rock is first met with. If a rift has extended to a considerable depth, it may in its lower portion have become filled by solid rock that has fallen in from the sides, or by volcanic eruptions. Even if the Ganges sediment continues down to a depth of some miles, it may itself become consolidated by pressure and heat.

I define the depth of the rift as follows: it is that depth at which the rocks under the Ganges plains are similar to rocks at the same depth under the table-land There may be a solid floor to the Gangetic trough at a depth of 6 miles under Gorakhpur, but if the rocks which are deeper than 6 miles under Gorakhpur are different from and lighter than the rocks of the same depth under the Vindhyan plateau, the solid floor is not the bottom of the rift. When a crack occurs, volcanic eruptions are to be expected, and although there are no volcanic cones rising now from the trough of the Ganges, there probably were at one time. Dr. Pilgrim has discovered that there was great volcanic activity in the Persian Gulf at one time and that the islands now existing in the Gulf are isolated volcanic peaks. There exists also an old volcanic region in the Syrian desert between Baghdad and Damascus.

In considering the depth of the Gangetic rift we must appeal firstly to geodesy, and then to seismology. Now geodesy tells us that the compensation of the Himalaya (*i.e.*, the root of the Himalaya) extends downwards to a great depth: Mr. Hayford estimates 75 miles. We do not contend, and Mr. Hayford does not contend, that this value of depth is proved. The depth may be 60 miles: it is I think of that order. Geodesy says that the depth is great. I regard the Gangetic Plains and the Himalayan range to be the two parts of one whole; I believe that they have originated together, and if the depth of Himalayan compensation extends down to 60 miles, then I think that the Gangetic rift may extend down to that depth also.

Now let us turn to seismology: seismologists are able to form rough estimates of the depths of earthquakes. The earthquakes that visit Northern India seem generally to be most violent at places in the outer hills, such as Dharmsala, Katmandu, Shillong. But the line of fracture that occurs in the sub-crust at an earthquake may not be vertically under the place which suffers most. If for example a fracture in the sub-crust occurred at 60 miles depth under Gorakhpur, the hills to the north might be raised, and this elevation, though a secondary effect, might do more damage at Katmandu than the earthquake itself could do at Gorakhpur, which is protected by some miles of soft blanket of sediment underneath. In the Dharmsala earthquake Middlemiss estimated its depth to be between 12 and 40 miles. Middlemiss's maximum value is not very different from the geodetic value.

It is an interesting question to consider whether a fissure in rocks could extend downwards to a great depth. From a place near the Indus in Kashmir it is possible to see a continuous wall of rock 4 miles in height, on the flank of Nanga Parbat. Mount Everest stands erect 5½ miles above sea-level; its summit stands firm and rigid 11 miles above the depths of the Bay of Bengal. We have therefore evidence that the materials of the crust are strong enough to admit of the continued existence of great differences in altitude.

But Mount Everest is standing in air, whereas a crack in the sub-crust becomes filled with rocks falling in and with fluid rock magma from below; and the walls of the crack thus get a support that Mount Everest does not possess. It seems to me quite possible that a crack such as I have described may have extended down to a depth of 60 miles by successive fractures at increasing depths, the opening being filled by falling material.

INTERNAL CAUSES OF MOUNTAIN ELEVATION.

I have shown you how zones of subsidence in the crust are bordered by mountains, and I have now to discuss the relationship of subsidence to elevation, of troughs to mountains. The Red Sea is a zone of fracture, and it is bordered on each side by a zone of elevation. But along the Bombay coast the zone of subsidence is bordered only on the one side by a zone of elevation. The sub-crustal crack from Surat to Cape Comorin has been accompanied by a vertical uplift of the Ghats, and I suggest for your consideration that the vertical force which elevated the Ghats was the expansion of the underlying rock due to physical or chemical change.

Mr. Hayden informs me that the specific gravity of the rock composing the Neilgherries varies from 2·67 to 3·03, that is 14 per cent, and that the rock of the Hazaribagh plateau varies from 2·5 to 3·1, 24 per cent.

The Western Ghats appear to have risen about 4000 feet. Now we know that the Western Ghats are largely compensated by underlying deficiency of density: if the compensation of the Western Ghats extends downwards to a depth of 60 miles, then an expansion of two per cent would be more than sufficient to account for the elevation of the Ghats. Mr. Hayden finds variations of 14 and of 24 per cent in the densities of surface rocks, and yet an expansion of only two per cent would account for both the elevation and the compensation of the Ghats. Geodetic observations show that the compensation is not perfect, and that the Ghats contain an amount of rock in slight excess of the normal crust: the vertical expansion of rock must thus have been accompanied by a slight horizontal compression insufficient to fold the surface strata, but sufficient to account for the imperfection of the compensation.

The heterogeneous rocks composing the Earth's crust are continually undergoing changes of structure, known to geologists as metamorphism. At a depth of 30 miles the temperature is sufficiently high to melt all known rocks; but increase of pressure raises the melting point, and the increase of pressure underground may be sufficiently great to counteract the effects of the increase of temperature. So that at a depth of even 60 miles rocks may still be solid and rigid, as geodesy leads us to believe they are.

We have to imagine how deep-seated rocks, that have been buried for millions of years under high temperatures and enormous pressures, how they would behave, if a crack penetrating downwards from the Earth's surface reached and disturbed them. I suggest for your consideration that two cracks, opening one on the West Coast and one on the East Coast of India, have compressed the Indian Peninsula between them. This lateral pressure was insufficient to crumple the table-land; but may it not have been the exciting cause that led deep and ancient rocks to expand vertically and elevate the Deccan? Petrologists will be better able to discuss this question than I am.

The main ranges of the Himalaya are composed of granite; this granite has protruded upwards from below. I suggest that the protrusion of granite is due to expansion of rocks in the sub-crust. The great Himalayan range is 5 miles high; and the compensation of this range, that is, its underlying deficiency of density, is estimated to extend downwards to a depth of perhaps 75 miles. An underground expansion of 7 per cent would be sufficient to account for the elevation of the Himalaya.[1]

Many of the faults which intersect the Himalaya may, I think, be ascribed to the shearing, which must have ensued when certain areas of the crust were forced vertically upwards by the metamorphism of sub-crustal rock. Many distortions of

[1] If underlying deficiency of mass is greater than the excess of mass in a mountain, the plumb-line will be deflected away from the mountain. Over-compensation would therefore account for deflections *away* from mountains. But it would not account for tension or subsidence in the fore-deep. Pendulum observations in the outer Himalaya and at Ootacamund indicate not over-compensation but imperfect compensation.

surface strata may be ascribed to local variations in the vertical expansion of deep-seated rocks.

External Causes of Mountain Elevation.

The Western Ghats are as mountains very small compared to the great ranges that stretch from China to France; the former are an example of vertical elevation without any obvious horizontal compression of the surface; the latter exhibit both vertical elevation and considerable compression by lateral thrust. In the Western Ghats expansion of the subterranean rock seems to have uplifted the surface strata without disturbing the latter, in the Himalaya the subterranean rock has expanded to such an extent that it has burst through the surface rocks in the form of granite, and in its protrusions it has pushed aside the surface strata and helped to crumple the latter. The troughs skirting the Western and Eastern Ghats may have been caused by the mere cracking of the sub-crust from cooling. But the Indus-Ganges trough is so large, and the mountains to the north of it constitute so unique a protuberance that the idea arises that some external force must have pulled the Himalaya northwards from India, and must have torn into a great rent the original line of tension that had opened under the Ganges plains.

The Earth possesses a figure of equilibrium. If the Earth was at rest, its figure would be that of a perfect sphere: as it is rotating, the velocity of rotation has caused much extra rock to be heaped up round the equator: the diameter at the equator is 27 miles longer than the polar diameter.

Sir G. Darwin thought that the Earth's velocity of rotation was constantly being decreased by the Moon's attraction upon our oceans; he thought that the tides were tending to stop our rotation, just as the Earth's attraction has entirely stopped the Moon's rotation. If our rotation velocity is decreased, the figure of the Earth changes and becomes nearer and nearer to a sphere: water can flow from the equator to the poles at once, and the oceans can immediately assume the new form of surface suitable to the decreased rotation velocity. But a superfluity of rock would remain at the equator, and the straining of this towards the poles might cause cracks in the Earth's surface. I do not presume to say that this is the cause of the rent in the Earth's crust hidden below the Ganges plains. All I wish to point out is that these mountains appear, as if they had been pulled northwards out of the Ganges-Euphrates-Mediterranean rent, and I show you some reasons for believing that the Earth's figure may have undergone deformations. The astronomical cause of these deformations is hidden in the past history of the Earth. In the Permian era an ice age occurred in equatorial regions; if the Earth's rotation velocity were to decrease considerably now, Southern India and equatorial Africa would stand out as rock protuberances high above the ocean, and would exhibit snow and glaciers.

Every year the Earth is bombarded by swarms of small meteors; is it not possible that at certain times in the distant past the Earth received larger meteoric masses than in the historic period, sufficiently large perhaps to upset the Earth's equilibrium by displacing its centre of gravity. Its figure would then be forced to undergo readjustments. If the Earth meets a swarm of meteors in space, and if some of them approach within its attraction, it seems possible that almost all the captured meteors may fall upon that hemisphere of the Earth which first meets the swarm, whilst the other hemisphere may receive very few. This would interfere with the Earth's balance.

Whilst something may occur in one age to cause movements of rock towards the pole, another cause may arise at a later date that will tend to oppose those movements. Not very long ago a great ice age occurred, and all Northern Europe and America were buried under ice: an immense volume of sea-water must then have been transferred from the equatorial oceans to the north pole: this may have disturbed the Earth's equilibrium and have displaced its centre of gravity.

In the same ice age the Himalaya and Tibet became capped with greater masses of snow and ice than they now carry. The glaciers that now end at 12,000 or 13,000 feet descended in the ice age to 5,000 feet. This increase in the weight of the Himalaya was an additional deformation of the Earth's figure of equlibrium.

I suggest to you that the great mountains from China to France have been due, firstly, to a line of fracture from Bengal to Sicily, and, secondly, to adjustments of the Earth's figure.

The Andes trend north and south; they are of the same age as the Himalaya. If the Earth's figure is undergoing deformation, and a rent is torn in the crust along an east to west line under the influence of forces seeking to restore equilibrium, it seems possible that secondary cracks might occur and that the Andes may be the result of one of them. The Andes are shown to scale on this chart: you will see that in length they are not very much less than the China to France ranges, but in breadth and mass they are relatively insignificant.

You will notice from this chart (8) the peculiar curve of the northern Tibetan border, concave on the east, convex on the west. This sinuous curve is reproduced in the north of Persia, and again in the Carpathians. The Persian ranges all have a trend from south-east to north-west except that the Caspian subsidence seems to have pushed rudely in from the north and forced the northern range into a sinuous curve. It is significant that at the point of the Caspian push stands the peak of Demavend, the highest point in all Persia. ***Elevation is the companion of subsidence.***[1] Similarly the Lob Nor subsidence appears to have squeezed Western Tibet into what resembles the neck of a bottle, and on the edge of this subsidence stand the highest peaks of the whole Pamir region. Just as the Deccan table-land was squeezed between the western and eastern coastal cracks, so has the Tibet table-land been squeezed between the cracks of Lob Nor and the Ganges.

The conclusions which I have ventured to submit to this meeting may be summarised as follows:—

(1) The fundamental cause of both elevation and subsidence is the occurrence of a crack in the sub-crust.

(2) Mountains are compensated by underlying deficiencies of matter.

(3) Mountains have risen out of the crust from a great depth, possibly 60 miles.

(4) Mountains owe their elevation mainly to the vertical expansion of subjacent rock.

I have now had the great privilege of placing certain problems before you. My endeavour has been to point out to this Congress, and especially to its younger members, the many scientific secrets that are lying hidden under the plains of Northern India.

ABSTRACTS OF PAPERS COMMUNICATED TO THE CONGRESS.

Section of Agriculture and Applied Science.

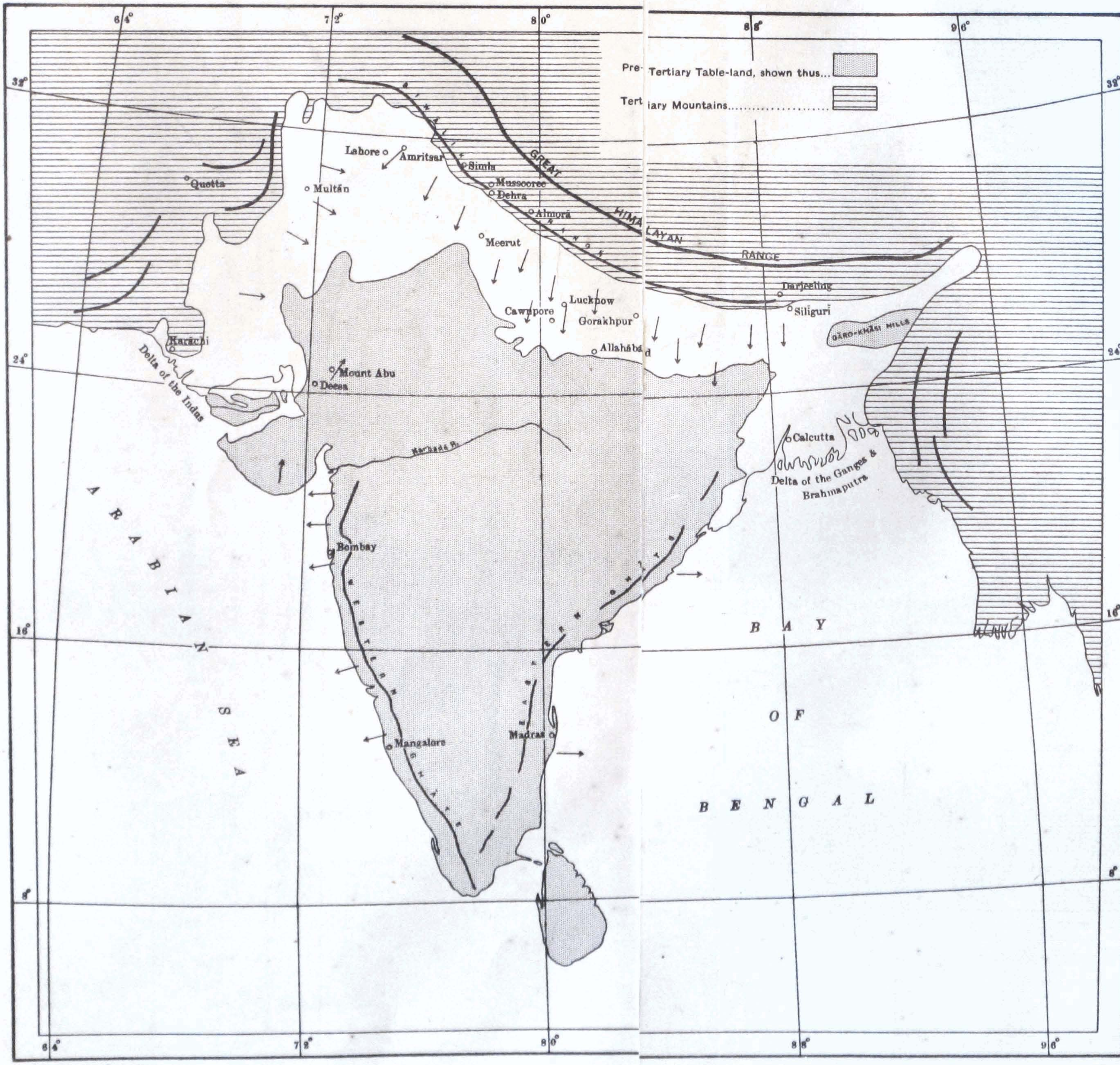
(*Chairman.*—Mr. Bernard Coventry, *C.I.E., Agricultural Adviser to the Government of India and Director of the Pusa Agricultural Research Institute.*)

Education in its relation to Agriculture[2].—*By* Bernard Coventry, *C.I.E.*

The population of British India comprises over 255 million souls. Of this vast multitude 80 per cent or over 200 millions, that is to say, 4 in every 5 are dependent on agriculture. Any educational system therefore which does not take into consideration the relationship it should bear to agriculture is likely to be at a disadvantage. Out of the whole population, 7½ millions or about 3 per cent are scholars, though 15 per cent or

[1] See "Sketch of the Geography and Geology of the Himalaya Mountains and Tibet," page 160. See also Records of the Survey of India, Vol. IV, page 3, "Note on the discovery of the peak of Namcha Barwa."

[2] This paper will be published *in extenso* in the Congress number of the Agricultural Journal of India.



NOTE.

The arrows show the directions in which the plumb-lines are deflected.
The thick black lines show the principal mountain-ranges.