PUBLICATIONS of the INDIAN GEOLOGICAL SURVEY

bearing on the Himalayas, etc., etc.

Vol.I.

C O N T E N T S.

MEMOIRS

of

THE GEOLOGICAL SURVEY of INDIA.

Volume XXIV, Part 2.

MIDDLEMISS:

PHYSICAL GEOLOGY of the SUB-HIMALAYA

of

GARHWAL and KUMAON.

GEOLOGICAL SURVEY of INDIA.

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Published by order of His Excellency the Governor General of India in Council.

CALCUTTA:
SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY
AND BY ALL BOOKSELLERS;
LONDON: KEGAN, PAUL, TRENCH, TRÜBNER & Co.

MDCCCXC.

CALCUTTA:
PRINTED BY THE SUPERINTENDENT OF GOVERNMENT PRINTING, INDIA.
1890.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

PHYSICAL GEOLOGY *of the* SUB-HIMALAYA *of* GARHWÁL *and* KUMAUN, *by* C. S. MIDDLEMISS, B.A. (Cantab.), *Geological Survey of India.*

CHAPTER I.

INTRODUCTORY.

Subject of this work.

The subject of this memoir is one which has already been treated of many years ago by Mr. Medlicott (late Director of the Geological Survey of India), in his description of the country between the Ganges and the Ravee.[1] The present work will have answered all anticipations if it come to be regarded as a continuation, along the mountain-foot of British Garhwál and Kumaun, of Mr. Medlicott's labours further north-west.

Geological structure of Sub-Himalayan zone simple compared with that of Himalayan, and treated separately.

During the four and a half working seasons which I have spent in the Himalaya, I have gradually been led to the conclusion that the great break between what is known as the Sub-Himalayan system, and the crystalline and metamorphic groups, is one which makes it eminently advisable to treat the two separately, in any finished written account of them. It has also become plain that if close work on the one-inch scale is to be done over the vast regions embraced by the outer and central Himalaya; and if that

[1] Mem. III, G. S. I.

work is to be brought into a form suitable to the requirements of modern scientific thought; it will take a considerable time to collect the material in the field, and to work it up into a homogeneous whole. Such papers on the subject as I have hitherto contributed to the "Records" of the Geological Survey deal with isolated areas; and it will only be by continually adding to these that the way can be prepared for a thorough digest of the whole region. In the meantime, it seemed to me that the comparatively simple Sub-Himalayan zone need not wait until all the difficulties which surround the older hills like a great cloud were dissipated. Moreover, in any case, it would have seemed advisable to me to describe the Sub-Himalayan zone first, whether the whole were combined in one book or not; because, just as the physical aspect of these hills suggests a stepping-stone from the plains to the lower parts of the main range, so does their geology prepare us, or carry us, step by step, to an understanding of the great geological problems sealed up in those mountain strongholds.

Previous writers.

In the year 1864 Mr. Medlicott produced his memoir "On the Geological Structure and Relations of the Southern Portion of the Himalayan Range between the Rivers Ganges and Ravee." In that book he devoted most space to the Sub-Himalayan zone; supplementing the palæontological researches of Cautley, Falconer, and D'Archiac and Haime, by putting the lithology and stratigraphy of the investigated area on a sound basis of observed fact. Besides this, he was the first to attempt a classification of the older Himalayan rocks. Finally, he considered the whole of the Himalayan and Sub-Himalayan groups, individually and together, with regard to the *rôle* they have played in the general structure and history of the mountain-range. That book, therefore, will very naturally form a constant subject of reference; more so, indeed, than the works and papers of other writers on adjoining areas,—*e.g.* Stoliczka, Lydekker, W. T. Blanford, R. D. Oldham, McMahon. As for the authors, Herbert and Strachey, who came before Medlicott, their results have been criticised by the latter in his quoted memoir, and so need not be referred to again.

New features in this work due to better maps.

As stated above, the present work aims at being an extension in a south-easterly direction of the geological operations described in that memoir. Owing to the possession of better maps, it has been possible to accomplish this in more detail than was possible in 1864. Much of the ground herein covered has been topographically surveyed by the Forest Survey, on a scale of 4 inches to the mile. These maps leave nothing to be desired, and are invaluable in a country of dense jungle and few landmarks, such as the Sub-Himalayan tract. Wherever I have been able to use them, I have been constantly reminded of the debt of obligation the geologist owes to the conscientious map-maker. The 1-inch maps of the Trigonometrical Survey are available for the whole of Garhwál and Kumaun; and I have worked with them in the field, wherever the larger ones were not yet published. For the coloured maps accompanying this work, I have been compelled to be content with the ¼ inch atlas sheets; which are reduced from the 1-inch maps. Though very good as a whole, their accuracy is not to be depended upon in the intricate wooded districts. The chief features of novelty, therefore, that I would claim for this book, in advance of Mr. Medlicott's, are connected with the closer and more accurate delineation of the geology rendered possible by these better maps; together with such amplifications and modifications of that author's theory of the Sub-Himalaya as have been brought to light by the foregoing advantages in a tract of country naturally endowed with clear and convincing sections.

Popular misconceptions as to the upheaval of the Himalaya.

Even without any new features whatever, I should have very little hesitation in placing the results of my work before the public, inasmuch as there is perhaps no geological structure so greatly misunderstood by many English geologists as the Himalaya. In the face of Mr. Medlicott's writings, it is not easy to understand why this is so; and I can only partially account for it by the consideration that, like Darwin, Mr. Medlicott is a difficult writer, who requires following

through an argument with the closest attention and often reading several times before his full meaning is grasped.

As an instance of the misconceptions prevailing, Dr. Geikie[1] writes, speaking of the Siwaliks, or younger tertiaries: "They have "been involved in the last colossal movements whereby the Himalaya "have been upheaved;" whereas Mr. Medlicott, in enumerating the principal conclusions to which he was led by the study of the Himalaya, writes[2] "the Himalayan mountain-area was defined before "the deposition of the Sabathu nummulitic rocks" [or older Tertiaries]. It is true that in later remarks made in the *Manual of the Geology of India*,[3] he has qualified this statement to a certain extent by urging that all special Himalayan disturbance was altogether post-eocene [post-nummulitic]; but he again qualifies this, as regards an earlier pre-nummulitic state of Himalayan elevation, which he likens to a simple protuberance (*bossellement*), or warp, and which he declares to have been considerable, though probably unplicated. The first of these qualifications, however,—namely, that all special Himalayan disturbance was altogether post-eocene,—is misleading if read loosely. The reader is apt to go away with the belief that Mr. Medlicott thereby meant that the Himalayan range, as a great mountain barrier, was undeveloped at that time: he used the words special Himalayan *disturbance;* but apparently he has been understood by Dr. Geikie to mean special Himalayan *upheaval*—a very different thing. Unfortunately, in making that statement, the former author was trusting largely to the section across the Lapri and Sangar-Marg ridges in the Jamu area[4]; where a manifest uniformity in lie between the nummulitics and the Great Limestone (the probable equivalent of the Król limestone) gave a strong presumption in favour of the belief that the Himalayan rocks were undisturbed before the deposition of the nummulitics. But it is

[1] Text-book of Geology, p. 879, 1st edn., 1882.
[2] Mem. G. S. I., Vol. III, p. 174.
[3] P. 569.
[4] He also mentions the section of the Sabathu rocks in the Simla area; but the disturbances of all the strata there are so extreme that I cannot regard the evidence of conformability as sufficiently conclusive.

evident that that belief depends on the assimilation of the Great Limestone as conformable with the still older rocks,—namely, the palæozoic slates and schists, which occupy much of the higher Himalayan range. Herein, I shall subsequently show reason for differing from Mr. Medlicott: it will be made clear that the nummulitics, though in many places lying in the same state of disturbance as rocks of probably mesozoic age, which in turn are equally disturbed, with a great or massive limestone formation coming beneath them, are probably merely the uppermost beds of a zone of formations which must be regarded as young, compared with most of the great Himalayan range itself. That is to say, I shall introduce behind the Siwalik and Nahan rocks (upper tertiary) a disturbance zone, composed in ascending order of massive limestone, Tál (mesozoic), and nummulitics, which bear the same relation to the older slates and schists that the Siwaliks bear to them. The matter, in a word, is this: Mr. Medlicott supposed the Great Limestone of the Jamu area to be palæozoic; and therefore the nummulitics, which were thrown into folds with it, give a tertiary date to the disturbance of the whole *palæozoic* rocks of the Himalaya. I myself (in agreement with Mr. Lydekker) by showing the massive limestone to be more probably of mesozoic age, and divided sharply from the still older slates and schists, merely give a post-nummulitic date to the disturbance of this zone of *mesozoic* age; leaving the question of the still older palæozoic rocks very much where it was before.[1]

The conclusions to which I am led by independent exploration are in entire agreement with Mr. Medlicott's original statement in the memoir, save that I would go further. I believe that, if we could have been present in Siwalik times,—nay, even in Nahan or nummulitic times,—we should have seen the Himalayan range in all its might standing up very much as it does now.

[1] From one remark in his memoir Mr. Medlicott would seem to have once leaned towards this view. At page 170 he says: "From this point of view there are many reasons for associating the calcareo-shaly band, which I have described as the Krol group, with the younger rather than with the older strata."

A similar misconception is to be found in Mr. Mellard Reade's "Origin of Mountain Ranges," a more recent publication. He says:[1] "The Himalaya, the Andes, the Alps, and the mountains of the Cau-"casus have been to the larger extent upheaved in tertiary times;" and further on,[2] referring to India, he makes the startling announcement that "The tertiary [system] alone, measuring 30,000 feet, has "been upheaved and carved by denudation into the greatest mountain "system of the globe,—the Himalaya." To say that the mountains of Wales and the Lake District were carved out of post-tertiary glacial deposits, would have a relatively greater basis of credibility than the statement in question; for those glacial and palæozoic rocks are less unequal, in height and ratio of distribution, than are the tertiary and the Himalayan rocks in India. I shall have further remarks to make on this head in the body of the work.

An impartial view solicited.

These instances show how hard it is to break down an ancient prejudice. For a long time, the fact that the youngest Siwalik conglomerates seemed to share in the same folds which the oldest Himalayan rocks have shared in, convinced the geological world that the date of the upheaval of the whole Himalayan range was quite modern; and this belief, once engendered, has steadily gone on propagating itself in spite of later research. If, in the following pages, I can do something towards bringing about a more reasonable and impartial view of the case, I shall be content.

The material for this memoir has been collected mainly during the months of January, February, and March 1887; January, February, March, and April 1888; and January, February, and March 1889. As having had something to do with preparing the way for a geological exploration of this region, I may mention that, on first joining the Survey at the close of 1883, I accompanied Mr. R. D. Oldham over portions of the Siwalik range and the Dehra Dún, by which means I was able to see a part of the area described by Mr. Medlicott.

[1] Chap. V, page 29.
[2] P. 73.

CHAPTER II.

SCENERY AND SUPERFICIAL ASPECTS OF THE COUNTRY; ITS FLORA AND FAUNA.

Definition of the Sub-Himalayan zone.

Between the Ganges at Hardwár, and the western frontier of Nepál, stretches the tract of country to be described in the sequel. It is some 130 miles long, and varies from 6 to 14 miles in width. It is composed of low hills and shallow valleys, and rises sometimes abruptly and sometimes gradually, from the great alluvial plains on the south; and merges more or less imperceptibly on the north into the elevated country of the outer Himalaya. Geologically, it is known as the Sub-Himalayan zone, being composed of tertiary rocks; and is continuous with that of the same age and formation trending in the opposite direction from Hardwár, comprehended in Mr. Medlicott's memoir. Its surface features are very characteristic of the zone of which it is a continuation,—that is to say, the hills are low and flowing, they seldom rise to any great height above 3,000 feet, and they are distinguished by the presence of several beautiful, flat, longitudinal valleys, known as dúns, some of which bear a strong resemblance on a small scale to the Dehra Dún north-west of Hardwár.

Its magnificent forest scenery compared with the higher Himalaya.

On first visiting this country one is much struck by the beauty and luxuriance of the forest scenery. It is true, there are none of those sublime sights which one meets with in the higher Himalaya. It is impossible from any one height to take an extensive survey over range beyond range of purple peaks, or across the harsher black and white pinnacles of the snowy range: the view is much more confined, and the eye bewildered by the labyrinth of small wooded knolls. But there is a softer beauty of a different order to be found here, for which the traveller in the higher hills may seek in vain. The flora is sub-tropical, and gives an aspect of richness and bursting vegetable life to the scene, as well as naturally increasing its brilliance by the vivid greens. As is characteristic of these hot and

moist regions, there are no flowers, except a few large ones flaming here and there. Nature is too full of life to need such artificial aids to fertilization.

It is rather the forms of the forest elements which give the charm. A thick grove of Sál trees (*Shorea robusta*), covering a flat chaor,[1] is a magnificent sight in itself, even though its primeval maze of climbers, &c., has fallen before the conserving care of the Forest Department. But when broken country is reached,—when the flat plateau gives way to the steep scarp, or steady slope down to the river bed,—the varying conditions offer many other trees a home, whose striking forms have a strong individuality of their own, such as the Bamboo, the Cotton-tree (*Bombax malabaricum*), the red-tinted Bákl[i] (*Anogeissus latifolia*), and the great thorny jungles (*Acacia*) of the alluvial flats and dry river-beds. They harmonise well with the ever-changing panorama of winding river-bed, of naked ochre-tinted cliffs and deep pools, of softly-swelling slopes, or of jagged mural scarps rising one behind the other. Sometimes in wandering through this region a deep gorge is reached with bare rock below and festoons of tangled creepers and shrubs above, shutting out the sky. And when, after leaving this array of miniature crags, peaks, and precipices, the dún itself is entered, the sight is rested as it falls on the gently undulating plain, which, expanding in all directions in a sea of Sál forest, dies away at its margin into a thousand slightly-inclined slopes, ultimately steepening and ending either in the serrated peaks of the Siwalik ridge to the south, or in the mountain-foot of the greater Himalaya to the north.

Climate: Government forest.

The Sub-Himalayan zone is visited by a heavy monsoon, during June, July, and August, and has an annual rainfall exceeding 60 inches; it therefore forms part of a climatic zone which is one with that of Bengal and the coast of Burma. In consequence of these favourable conditions, it supports dense forests, rich in a few species of very valuable trees. Nearly all

[1] A *chaor* is a level or gently sloping bit of ground, generally elevated above the neighbouring drainage lines.

the Sub-Himalayan forests are under Government, and yield a large revenue to the State. They are managed directly by the Forest Department, which looks after the maintenance and working of them.

The Sál tree.

The principal tree which thrives in this area is the Sál (*Shorea robusta*). It is a large tree, with broad, shining leaves, and allied to the Copal (*Vateria indica*) and the Lac-tree (*Shorea laccifera*) of West India and Mysore, respectively. It is also of the same family as the Wood-oil trees (*Dipterocarpus*) of Burma, and the Camphor-tree of Sumatra and Borneo. It ranges everywhere from the plains immediately at the foot of the hills up to heights averaging 3,000 feet. It sometimes forms almost pure forests, which grow with great vigour on the light sandy soils of these hills; but more often it is mixed with several other less valuable trees. On wide open chaors, either flat or gently sloping, but still out of reach of the river floods, it flourishes; but it shuns clayey ill-drained soils and steep country, and at great heights it becomes useless as timber. The wood of the Sál is very durable, though taking a long time to season, and apt to split and warp. It is largely used for building purposes and for railway sleepers. From a commercial point of view, it is *the* useful tree of the Sub-Himalayan zone, and supplies the place of the Teak of Burma and the Deodar of the higher Himalaya.

The Sissoo and the Khair.

Just as the dark shining green of the Sál is the most conspicuous object on the flatter slopes and chaors, so the dry river-beds, wherever they possess low banks and islands composed of hardly-reclaimed recent gravel and alluvium, give us the well-known forms of the Sissoo or Shisham (*Dalbergia Sissoo*) and the thorny Khair (*Acacia Catechu*). Unlike the Sál, which is never quite leafless, these trees are bare and brown during the cold-weather months, causing the white stony stream-beds to have a death-like, forsaken appearance. But in March and April they all burst into leaf, and light up the islands and banks with a pale-green tint, which contrasts strongly with the sombre colour of the dark Sál forest above and with the bright-red flowers of the Dhák-

tree (*Butea frondosa*), which is then in bloom. The wood of the Sissoo is valuable for its strength and elasticity, and is used for carriages, camel-saddles, and agricultural implements. It is also a beautiful furniture wood. The Khair is a very hard wood, and was formerly used for sugar mills, but is now superseded by iron in this respect. It is principally useful for making catechu, which is employed in dyeing and tanning, and also medicinally as an astringent. In ravines and damp places among the Sál covered hills grow the Soanjna (*Moringa pterygosperma*) and the Jáman (*Eugenia jambolana*).

The Bamboo.

Another special feature of the Sub-Himalayan zone is the Bamboo (*Dendrocalamus strictus*), which takes the place of *Bambusa* of South India. Its feathery foliage adds a graceful appearance to the drier and more stony low ground and hollows at the foot of the hills, where it is generally to be met with, though it also extends up the hill-slopes themselves, preferring those with a southern aspect. Its uses are proverbial, and next to the Sál tree it is the most important product of these forests. It is easily cut and carried away, needing but an axe to shape it. The sale of it brings a large revenue to the Forest Department: the average annual amount realised during the years 1881-1886, in the Ganges Division of forests alone, was ₹32,984.[1]

Other useful woods.

There are a number of other forest trees, which are found in certain places amongst the Sál, and are worth mentioning here as being useful woods. The principal are Sain (*Terminalia tomentosa*), which may be considered as the complement of Sál, since it favours a clayey soil, whilst the latter will not thrive on a stiff soil. It is largely used as fuel, for building purposes, for making potash, and the leaves are eaten by the tussah silkworm. Gosam or Kusam (*Schleichera trijuga*), which also affects clayey soil, and is remarkable for its hardness, and is made into sugar-crushers, rollers, harrow-teeth, ploughs, &c. Hair (*Termi-*

1 See Working-Plan of Ganges Working Circle (Forests), p. 31, by N. Hearle, Deputy Conservator of Forests.

nalia chebula), the wood of which is valuable, and the dried fruits are the Black myrobalans of commerce; Bákli (*Anogeissus latifolia*) abundant in hilly parts and nearly always restricted to southern slopes. On account of its hardness it is extensively used for furniture, agricultural implements, ship-building, and it is also used as fuel. Sándan (*Ougeinia dalbergioides*), abundant on hot, dry slopes, and ascending to 5,000 feet in some places; a useful wood of the same character as the last. Tendu or the Ebony tree (*Diospyros*), found on hilly exposed tracts; a beautiful furniture wood. Toon (*Cedrela Toona*), rare, in damp shady valleys only. This is also a highly-prized furniture wood; it is also lopped for cattle; the bark is a powerful astringent, and from the flowers a yellowish dye is made. Riuna (*Mallotus phillipinensis*), a large shrub with a deep red fruit, the size of a holly berry, is a common sight in these hills. The red dust covering the fruit is used principally as a dye.

Among these trees in the natural forest, the climbers Máljan (*Bauhinia Vahlii*) and Gauj (*Milletia auriculata*) are frequently conspicuous; but as they do much damage, by smothering the trees to which they cling, they are destroyed in the reserved parts.

There is perhaps no more characteristic feature among these forests than that afforded by the Haldu, the Pipal, and the Semal. The two former generally grow solitarily or in small clumps, in low flat country, by the banks of streams or at the foot of the hills. The Haldu (*Adina cordifolia*) is a useful shade tree, and is also of value for its wood. It is common in the Bhábar country, and gives the name to the villages Haldwáni, Haldukháta, Halduwála, &c. This tree is said by Mr. Hearle to be dying out in the Ganges Division of forests, as no young trees are to be found thriving. Further east, however, this does not seem to be the case. The Pipal (*Ficus religiosa* and *F. cordifolia*), being sacred to the Hindus, is planted by them near villages and shrines, though it also grows wild. Both the last two trees form magnificent spectacles when full-grown, as they attain to the great size of 80 to 90 feet. The ground near one is commonly chosen as a camping-ground, for the sake of the shelter it affords. Another

large tree is the Semal (*Bombax malabaricum*), or cotton tree, which rises to the height of 150 feet, with a tall, straight, buttressed stem. It is a marked feature in the landscape in the cold weather, when it is leafless, but covered with large scarlet flowers. The wood, on account of its lightness and resistance to water, is used for boats, well-curbs, &c. The cotton is gathered from the unripe fruit, and used to stuff pillows, &c.

The wild mango (*Mangifera indica*), though not as marked a feature as the cultivated variety of the plains, is however found in a few places. It is chiefly of value for the fruit it yields under cultivation.

An undergrowth of the common *Adatoda justitia*, of *Zizyphus* of several species, and of many other shrubs covers much of the low country, along with the Munj or Elephant-grass (*Saccharum sara*), which grows to great heights; while Bábar-grass (*Spodiopogon angustifolia* and *Eriophorum comosum*) is found on the hillsides and is largely employed in making cordage and paper.

The preservation in a luxurious condition of these forests entails a great deal of labour on the part of the Forest Department. The great enemy dreaded during the hot months is fire, when the long dry grass and Sál leaves, and the dead and small timber, is such as to enable it to spread with extreme rapidity, destroying seeds and seedlings, laying bare the ground, and interfering with the natural decay of leaves, &c., into the nitrates which manure the soil. The rapid production of ash by burning leaves it in a thick superficial layer, which is carried away by the first rain, instead of fertilising the ground *in situ*, besides exposing the soil to the direct rays of the sun. Wild elephants are a great source of loss to the bamboos and young Sál, of which they are inordinately fond. There are also numerous insect-pests, such as the formidable stag beetle and the white-ant,[1] against which little can be done, save the preservation of the smaller birds by reducing the numbers of the birds of prey.

[1] It is a question, however, whether the function of the white-ant in turning up the soil is not, in some measure, a compensation.

What is the relation, if any, between the geological formation of the Sub-Himalayan zone and the covering of forests? This is a difficult question to answer directly, because so many secondary results follow on a certain rock-structure, that it is often more probable that the favoured trees depend rather on these secondary results or on the aspect of the hill slopes than on the primary structural causes. A comparison of the stock maps (which have been kindly lent me by the Forest Department) with my own geological maps, is to a large extent disappointing; the stratigraphical zones do not, at the first blush, seem to show much resemblance to the different stock areas. Large portions of the Pátli dún, for instance, are composed of Siwalik conglomerate, and these are covered with a growth of fine young Sál. But the Chokhamb and Kotri dúns, where the conglomerate is absent, have also many fine Sál forests. So that the particular petrological constitution of any part of the sub-Himalaya, varying but slightly in its chemical elements and state of solidity from its neighouring zones of tertiary age, does not seem to be a very important factor in determining the nature of the stock. In some measure this is what we should expect, for, as will be seen in the following chapter, the several rock stages of the Sub-Himalayan formations being very much alike in their general facies and in the ultimate material into which they can be reduced, produce, of necessity, a very similar soil under like conditions of drainage and aspect. The following generalizations seem to hold to a certain extent; though numberless modifications, dependent on those natural and more superficial causes which I need not stop to mention, have great prominence :—

(1) The northern limit of the Tertiary zone is practically the limit of the Sál tree, and therefore of the reserved forests of this region. This geological boundary is a very important and marked one, and seems to have a real and direct effect on the prevailing forest species.

(2) The Middle Siwalik sand-rock[1] generally forms low undulat-

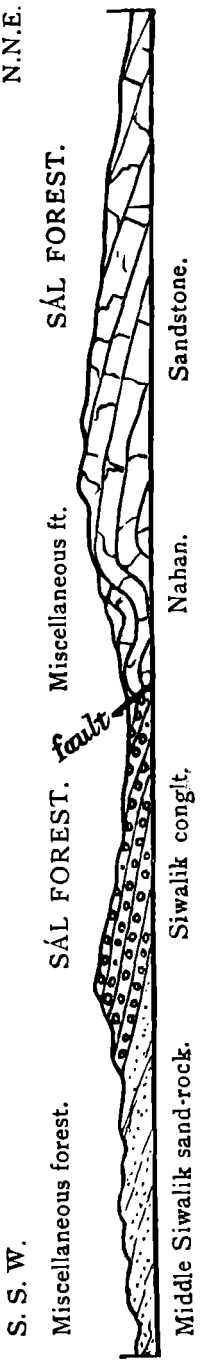
[1] See Chap. III,—Petrology.

ing country, and towards the plains supports a miscellaneous jungle. A good example of this is seen between Rámnagar and Kálagarh, on the plainward parts of the hills.

(3) Wherever the dip of the strata is low, 10° to 30°, and down hill (which generally coincides with a northern aspect), the Sál, tree has flourished far above any other tree. Obviously, however, the coincidence referred to in brackets may, after all, be the vital reason.

(4) All escarpments and sloping country, with dips towards the hill, support a miscellaneous jungle. This may be due, however, to secondary causes, arising partly from the more varied secondary slopes and ridges into which such a structure weathers, and partly because of their facing south.

Thus, in a section such as on the margin, we should find the forest disposed as marked :—



(5) All surface-gravels, dry river-beds, and shingle islands, which are constantly liable to change, to being washed away and re-made lower down, only support the Khair, the Sissoo or Shisham, and sometimes bamboos.

Rivers.

The country is well watered by four large rivers, the Ganges, the Rámganga, the Kosi, and the Sárda; and by numerous smaller rivers and streams of some importance. The Rámganga and the Kosi both rise in the higher Himalayan zone, but their waters are not fed by perennial snow.

The Ganges, and the Sárda, on the other hand, have their several affluents originating in the great central chain of the Himalaya, and melting glaciers and snow-fields go to form their icy streams. Whilst these two large rivers cut straight through the Sub-Himalayan zone without swerving, the two former rivers each take a considerable turn on entering it,—the Kosi very notably between Okaldhúnga and Mohán, and the Rámganga in its traverse along the Pátli dún. The distinction in this respect seems to be due partly to the greater strength of the current in the case of the Ganges, which enabled it to cut through the advancing flexure wave of the Siwalik rocks, whilst, of the other two rivers, the Kosi was successfully turned for some way by a similar flexure in the Nahan rocks, and the Rámganga by one in the Siwaliks; partly the difference may be due to a fault along the Ganges where it escapes through the Sub-Himalayan range—a fault due to great lateral wrenching of the strata as they inbay in a direction up the present Ganges bed. The Gola, Nandhaur, and Ladhia rivers come next in importance; and they all show at some point of their course in the Sub-Himalaya a longitudinal diversion of their waters following the axes of folds. Of the streams which rise in the Sub-Himalayan zone itself, the Sona and the Peláni (Paláine) both fall into the Rámganga. They and the Kalaunia are the most characteristic of the younger rivers of this zone, which are more than mere torrents. Their waters are pure and sweet; and they meander with much twisting and recurving upon themselves, in a way quite unlike the streams and rivers of the higher Himalaya, which run a more direct course. Many of these Sub-Himalayan streams carry down with them a meagre quantity of gold, which is washed in a small way during the rains.

The periodical monsoon to which India is subject necessarily causes a great and rapid increase in the volume of water carried down by these rivers at that time of the year. Hence what is but a mere trickle of water amongst vast beds of shingle during the cold weather, becomes a broad and mighty torrent when the rains have fairly set in. Snow-fed rivers, such as the Ganges and the Sárda, in addition have their waters very much discoloured by the melting of the glaciers as

soon as the hot months commence, and long before such rivers as the Kosi and Rámganga become tinged with mud from the monsoon which follows.

Fauna.

A tropical country, possessed of all these advantages of forest and flood, of secluded valleys and hidden gorges, cannot but be rich in animal life, and especially in the larger mammalia. The Sub-Himalayan zone is verily a paradise for the sportsman. There is every style of country in miniature; abundant cover, afforded by the system of reserving the forests; and every other inducement that would tempt the largest and fiercest of wild animals to make it their home. In addition, it is a sort of meeting-ground for the fauna of the hills and the plains; which, by its variety of surface features, can accommodate both. It is of interest to geologists and naturalists, as bearing on the distribution of animals in time and space, to reflect that, during the ages when the Sub-Himalayan rocks were deposited, there flourished a large and fierce group of mammalia, whole families and genera of which are now extinct; and that this portion of the earth still affords refuge for the few representative descendants of those mammalia, which exist at the present day.

A brief epitome of the more important and larger animals must here suffice. The Asiatic Elephant (*Euelephas indicus*) is thoroughly at home among the Siwalik hills, where food and seclusion are at his command. As shooting this animal is forbidden, except in certain cases, the reserved forests have become a sort of elephant preserve, which is drawn upon every few years, when fresh supplies of tame elephants are wanted by Government. They are caught by being driven into deep sóts (stream beds), having only one outlet. If they offer resistance, they are reduced to a state of submission by special fighting elephants, and then secured by ropes in the ordinary way. Of the carnivora, the Tiger (*Felis tigris*) regularly inhabits the flatter portions of the country, especially the dúns and the deep sóts which run up into the hills from the dúns. It is also very numerous just at the foot of the Siwalik hills and downwards to the Terai. The Panther and Leopard (*Felis pardus*) occupy the hillsides, and prey upon

smaller animals; but they are seldom found in the dúns, doubtless because they recognise that the tiger has the monopoly of the flatter parts. The Wild Dog (*Cuon rutilans*) scours much of this zone in packs, slaying large numbers of deer, especially females and young ones. The Indian Black Bear, or Sloth Bear (*Ursus labiatus*) is common. Being an inhabitant of the plains it does not ascend very high. The Himalayan Black Bear (*Ursus tibetanus*) is often to be met with in these lower hills, though its more natural country is higher up in the Himalaya, in the region of the oak trees upon which it feeds. The Indian Wild Boar (*Sus indicus*) is fairly numerous. The Nilgao (*Portax pictus*), or blue bull, is only very occasionally met with in the flatter dúns; its natural home being below in the Bhábar country and the Terai. None of the antelopes or gazelles, except the four-horned antelope (*Tetraceros quadricornis*) are to be found in this zone. They need the unfettered freedom of the wide plains to live naturally. The genus *Capra* belongs entirely to the higher parts near the snows, and to Tibet. The Serow (*Nemorhœdus bubalinus*) is, however, a common sight on the bare and steeper scarps and precipices of the Sub-Himalayan zone, whilst the Gooral (*Nemorhœdus goral*) is extremely common in similar localities. Of the family *cervidae* this zone has a lavish display so far as number go. The most plentiful species is the spotted deer (*Cervus axis*) which inhabits all the dúns, the country at the foot of the hills and the flatter chaors. It loves to bury itself in the deep sál forests during the hot part of the day, and to wander in herds among the long grass of the plains and dúns at early morning and evening. The Sámbar, or Jerao (*Cervus aristotelis*), on the other hand, frequents the more hilly country, although it is a larger animal than the spotted deer. It ranges for some distance into the higher Himalaya, preferring steep ridges and deep wooded glens to the more open country, except in the cold weather, when it may be found in the dúns and Bhábar country. Along with it, in similar situations, is to be found the Barking-deer (*Cervulus muntjac*), a small red deer. Another small animal, the Hog-deer (*Cervus porcinus*) is a common accompaniment to most of

the marshy stream-beds, whose waters flow longitudinally with the geological strike of the country.

The larger rivers of this zone are full of fish; the chief of which are the Máhseer or Indian Carp (*Barbus tor*), and the Indian Trout (*Barilius bola*). A species of *Labeo* is very common in the Peláni R. There are also fresh-water Tortoises, Crocodiles, and Otters in the Ganges and Rámganga.

Malaria.

Although nature has fitted out these jungles with every requisite for the brute creation, the human inhabitants are not so well off. The unsurpassed loveliness of the country, its crystal waters and brilliant skies, would lead a casual traveller in the cold weather to imagine that no more desirable spot to dwell in could be found. And this is true, in a large measure, for the winter months of the year. But in the hot and rainy seasons, especially during May, June, July and August, the climate is one of the most deadly in India. Malaria then stalks through these jungles, and a native's life is not worth much (I am told) after three years' experience in them. In this respect it is said to contrast unfavourably even with Assam.

CHAPTER III.

PETROLOGY.

Classification and scope.

It will be well, at the outset of this chapter, to give the classification of the Sub-Himalayan system[1] inaugurated by Mr. Medlicott; and to indicate, by a parallel table, the formations which are represented in this district. The following is Mr. Medlicott's classification:—

Sub-Himalayan System.	Siwalik Series	Upper. Middle. Lower (Nahan).
	Sirmúr Series	Upper (Kasauli). Middle (Dagshai). Lower (Sabáthu: nummulitic).

[1] So far as possible I have made use of the stratigraphical and chronological terms recommended at the Bologna International Geological Congress. Thus, in descending order of magnitude—

Stage = Age.	System = Period.
Series = Epoch.	Group = Era.

The Upper, and a portion of the Middle Sirmúrs, are not represented in this district; we therefore have—

Sub-Himalayan System.	Siwalik Series . .	Upper. Middle. Lower (Nahan).
	Sirmúr Series . .	Middle (Dagshai) in part. Lower (Sabáthu : nummulitic).

As equivalent terms, I shall make use of the following, which depend for their nomenclature on the character of the composing rock :—

Siwalik conglomerate	=	U. Siwalik.
Sand-rock stage	=	M. Siwalik.
Nahan sandstone	=	L. Siwalik.
Nummulitics	=	M. Sirmúr (in part). L. Sirmúr.

It will be seen from this that the geological succession is a simple one. It is even simpler in the *de facto* Sub-Himalayan zone, as defined by Mr. Medlicott; for, as explained by that author, the nummulitics lie in a zone among older Himalayan rocks, some distance above the main boundary fault which divides the Sub-Himalayan from the Himalayan country. For several reasons, therefore, I shall only describe in detail the rock series as found occurring actually in the Sub-Himalayan zone. I have been led to do this partly from the fact that the large-scale Forest maps do not, in the majority of cases, extend beyond the Sub-Himalayan zone; and partly because the nummulitics, in this part of the country, are in the form of a very thin band, and appear so constantly in a regular succession upon a set of mesozoic formations, that it would be absurd to describe the one without the others. The nummulitics will, therefore, be left for subsequent delineation along with the Himalayan formations. This decision will not interfere with my taking any one individual section, such as that along the Peláni R., and discussing it, even as far as the metamorphic rocks, for the purpose of illustrating the relations of the Sub-Himalayan to the older rocks. Such sections will, however, merely be illustrative, and not exhaustive.

The description of the individual formations of the Sub-Himalayan tract, from a petrological point of view, is sufficiently easy. There

is a certain sequence in these Upper Tertiary strata, never departed from, without a fault, or thrust-plane, being evident. But the several members of the sequence, though of minor interest in themselves, become absorbing when regarded as the parts of a puzzle; which, if put together rightly, will initiate us in the mysterious workings of those elevatory powers, whereby band after band of rocks have been won from the oblivion of the plains and added to the achievements of the Himalaya; or they may be looked upon as an alphabet, or key, that will enable us to read this last volume of geological history, which, written in a strange language, now lies open before us.

Recent formations.

The superficial deposits of Recent age may be disposed of in a word or two. They consist of banks of coarse gravel and torrent-boulders, generally mixed with ferruginous sand or clay, which line the margins of many of the larger streams and rivers, and cover great portions of the dúns and level chaors. In one or two localities about Chúna Khán and Madan Bhíl, and in the more eastern portions of the Kotah dún, where the streams carry much lime in solution, there are some beds of very pure calcareous tufa, interstratified with gravel banks and sandy clays. The streams which emerge from the Kotah dún, at its eastern limit, cut through escarpments of the Siwalik conglomerate, often by a series of falls, or steps of calcareous tufa, one of which at Madan Bhíl is about 50 feet high. The stream-beds are sometimes filled with huge weathered blocks of this tufa, of pale grey or dirty-white colour, and of an appearance akin to that of scoriaceous lava. Impressions of land-shells and plants are frequently found in them. In the Nehál Nadi,[1] south of Naini Tál, there are also superficial deposits of gypsum[2] of considerable extent. Re-made beds of the Nahan shales, sloping down the sides of the gorge a little south of the old Nehálpur bridge (now gone), contain three or four beds of gypsum in irregular lumpy

[1] Nadi = small stream, in size between a river and a mountain-torrent. In future "Nadi" will be written "N."

[2] Briefly mentioned in the Manual of the Geology of India, Part III, p. 454. See also a paper by myself (Records G. S. I, Vol. XXII, p. 137) in which I estimate the available amount at 37,400 tons.

masses. It is white, micro-crystalline, and very soft. It is forming at the present day in some places, and is evidently the joint product of the sulphur-springs and the massive limestone that are plentiful near Naini Tál. There is hardly a sufficient quantity to go far as an artificial fertilizer for the soil, for which purpose it is in some request; but for making selenitic mortar for building and canal-works (as strongly advocated by Colonel Thomason, R.E.) there is practically an unlimited supply for local uses, obtainable at little cost.

Wherever the Siwalik conglomerate flattens out into a gentle anticlinal or synclinal, the division between the Recent and Siwalik deposits cannot be made on petrological grounds, especially when the Recent gravels have been cemented and hardened by the deposition of lime. The gravels on the plainward edge of the hills forming the Bhábar, and the alluvium of the plains, also come under this heading; but they lie outside the pale of this memoir.

No glacial beds.

I have met with no deposits of material, angular, or otherwise suggestive of the agency of ice. It would indeed be strange if glacial conditions had prevailed during the Recent period in this part of India. Some angular conglomerates in the Nehál N. and in the Gola R. near Amratpúr, which cling to the hillsides, are no doubt scree-material. They resemble similar deposits in the Dehra Dún, near Rájpur, which present somewhat the appearance of a boulder bed, but are more probably an accumulation of scree-material: the ridge up to Masúri hill-station, which rises very steeply above these deposits, would constitute a *vera causa* for the accumulation of such angular débris in that locality.[1]

Siwalik conglomerate: U. Siwalik.

The Siwalik conglomerate, in the majority of cases, is found to be sharply marked off from the Recent deposits by a very distinct uncorformability, except in

[1] Connected with the glacial question, the presence of very distinct ancient moraines (two lateral and a terminal), a few miles south of the present Kedarnáth glacier, and some hundreds of feet below it, show very clearly the limits within which the glacier has contracted during the Recent period. Major-General McMahon (Rec. G. S. I., Vol. XII, p. 68) gives similar evidence from observations made by him during a tour through Hangrang and Spiti.

such cases as I have mentioned, in some of the dúns, and wherever the former are comparatively undisturbed. These exceptions, however, give a reasonable colour to the supposition that there was never a continuous unconformability between the Recent material, now in the process of forming, and that of the uppermost Siwaliks. Notably in the Pátli dún, and in the Kotah dún at its eastern end, is it impossible to separate the one from the other; and I am inclined to think that this is somewhat of, or very nearly, a real sequence, rather than a deceptive conformability.

The Siwalik conglomerate is composed of much the same material as forms the present stream-beds. Very seldom it is somewhat angular, but generally it is well rounded. The pebbles are of large size, chiefly of Himalayan rocks, and with a considerable admixture of earthy sand, of buff or dark yellow colour. Near Dhanaor Chaor on the Nandhaur R. there occur Siwalik conglomerates, often vertical and almost entirely composed of large blocks of Nahan sandstone. Many clay and loamy bands, of brown and yellow colours, are interbedded with the ordinary conglomerate. The latter increase in quantity low down in the formation, and are often studded here and there with pebbles. False bedding is very common; and the rock is hardened in places by a deposit of lime between the pebbles. Over the area in which I have worked, I have seen very little horizontal variation in the material forming the conglomerate. An attempt to establish a difference between the pebbles at the E. and W. extremities failed, with the exception that in E. Kumaun the presence of large numbers of well-preserved granite and trap pebbles is clearly due to the existence of the parent-rocks immediately north of the sub-Himalayan zone. Seeing that their general source must have been the higher Himalayan range, and that lateral uniformity is the chief thing noticeable in that range, so far as its composition goes, this is exactly what we should expect. The following is a list of the commoner pebbles, between many of which innumerable passage-forms exist:—

Himalayan rocks	Purple and white and grey quartzite	most common.
	Purple and grey slate	common.

Himalayan rocks	Purple and greenish gritty quartzites	common.
	Fine conglomerates	do.
	Lydian stone	rare.
	Decomposed greenstone	do.
	Vein quartz	common.
	Well-preserved trap	common locally.
	Ditto granite	do.
Older Tertiary	Soft, brown and pepper-and-salt sandstone (Nahan)	common locally.
	Greenish-grey shales	rather common.
	Ochre and dark brown shales	do.

The above gives a fairly accurate general idea of the composition of the pebbles. This is all that is necessary here; for to detail the composition of every pebble would be to describe prematurely the petrology of the whole of the higher Himalayan range.

A very constant character of the conglomerate is the alternations of coarse and fine bands, and of sandy, loamy and clay beds with it. Only in the Kotah dún, and at a few places near Dúrgapipal, where outliers on the Himalayan rocks occur, is there any rapid, radical change in the nature of the conglomerate. It is there seen to be very angular, and composed of the particular rocks immediately in the vicinity. There is some doubt, however, as to whether all these should be classed with the Siwaliks, or with the superficial Recent accumulations. More probably they represent those intermediate strata which, as already indicated, blend, though in an imperfect way, the Siwalik with the Recent period.

As a whole, the Siwalik conglomerate may be said to be more ferruginous, and to be composed of larger and coarser material in its upper part, than at lower horizons. In the lower beds, the sandy-clay partings become more frequent, and the material of the conglomerate finer, though different-sized pebble-beds alternate as before.

In numberless sections there is seen to be a petrological passage from the conglomerate down into the stage next to be described. I think this passage to be a real one, indicative of a gradual though decided change of conditions at the time of its deposition; but, as other observers in the country further north-west have found local unconformabilities in it, I shall have to refer to the subject again later

on. The Siwalik conglomerate usually interbeds itself rapidly, but still gradually, with the sand-rock below.

The thickness of the Siwalik conglomerate is very variable, according as the locality is near to or distant from a large river. A calculation across the ridge south of the Pátli dún, along the line of the Gaujpáni Rau, gives a thickness of 2,970 feet; or a little over half a mile. Mr. Medlicott mentions[1] that in some localities, in the country further north-west, the conglomerates are at least 5,000 feet thick.

Sand-rock stage.

Although the previous formation passes down into the M. Siwalik, or sand-rock stage, the latter is sufficiently well-marked off from the former, through its main thickness, to warrant a separate description. Previous writers on the Sub-Himalayan zone have been unanimous in naming its representative elsewhere a soft sandstone. That it passes down into soft sandstone and shales, undistinguishable from the Nahans, I shall show later on; but, seeing that there is a large thickness having the characteristics of a sand-rock, rather than a sandstone, besides possessing other peculiarities, I think it not unnecessary to give this division of the Siwaliks the above name of the sand-rock stage. The passage of it down into the Nahans was a moot question when Mr. Medlicott wrote his book. It is entirely owing to the clearer nature of the sections, which are easy to read in the districts covered by this memoir, that I can make this statement so confidently and without reserve. But, although the passage is undoubted, the gradations are rapid; so that there can only be a very small zone which is doubtfully the one or the other. Hence the mapping of the boundary, though in a sense arbitrary, is not so to any great extent. A very little way on each side of the boundary, the material is distinctly sand-rock on one side, and sandstone on the other. A simple and practical distinction between the two is, that while the sand-rock crumbles under the hammer and refuses to make a coherent rock speci-

[1] Manual of the Geology of India, Pt. I, p. 536.

men, the sandstone, however soft, can always be trimmed into a solid block. For this reason the one is useless, and the other useful, for building purposes.

In the main, the sand-rock is a pure, micaceous, slightly ferruginous, and sometimes felspathic, sand as to its basis. It is of sugary texture, and without jointing or other divisional planes. Pale ochre colours generally prevail ; but a banded coloration is more common, in which the former are associated with pale blue greys, chocolate browns and pale purplish tints. Sometimes the rock weathers white and sometimes pepper-and-salt colour. Reddish brown clays are freely interstratified, and grey clays and loams are very prevalent in its uppermost layers. It is said by Mr. Medlicott to resemble the Swiss molasse in texture and composition. A characteristic feature of the sand-rock is the presence of numerous nodular layers, apparently of the nature of concretions. They are sometimes massed into a thin tabular layer, and they vary in thickness from a few inches up to two feet. Their surfaces are wavy and mammillated, owing to the concretionary action round different centres interfering and mingling the one with another. These layers become so hard as to ring unmistakeably under the hammer, and to stand out in relief in the river-bed and scarp. They are sometimes broken up into distinct masses of remarkably spherical shapes, like the concretions in the lower Kelloway rock of the north of England. Not unfrequently they appear in grotesque forms like flints. Occasionally, as in the Peláni R., they become so like flattened pebbles, in their distinctness from the rock matrix, that one may be easily deceived by them. In the Rámganga R., among Nahan sandstones, some two or three miles from Kálagarh, there are similar concretions which I may notice here. They are a foot or more in diameter, and of a different colour to the rest of the rock. Their appearance is, in fact, that of stray boulders scattered in a finer matrix. I was fairly misled by them at first; but a search for scratchings and groovings proved that the bedding of the supposed boulders always coincided with the bedding of the sandstone in which they lay. In every one of thirty or forty cases

that I examined, this held good, and was a satisfactory proof that they were merely concretions, and not transported blocks.

There are two sorts of pebble-beds, or fine conglomerates, occurring in the sand-rock formation. None, except in the upper parts where it is passing into the Siwalik conglomerate, have any predominating effect over much of the area covered by this memoir, though an exception will be noted hereafter. Their pebbles are always small and insignificant, and of a different composition to those of the U. Siwalik stage. One kind consists of thin strings of white quartz pebbles three-fourths of an inch long. Thin layers of irony concretions sometimes accompany these pebbles, and give a dark-brownish appearance to the rock. The other kind of conglomerate is made up of rolled clay balls. They are often scattered sparsely through a sandy matrix; but in other places they become more crowded, and make up the so-called clay-conglomerates, similar to those described by Cautley in the Kálawala Rau. These beds may easily be confounded with the nodular clays which are frequently interstratified with the ordinary sand-rock. The latter, however, are quite distinct. The clay pebbles are brownish ochre, and sometimes Indian yellow coloured, and so soft as to be scratched by the finger nail. Sometimes a few brown sandstone pebbles are mixed with them.

Nests and strings of lignite and coaly material, bright, shining, and breaking cuboidally, are very common. They are very small, though occasionally a somewhat larger tree trunk has been fossilized, and given rise to unreasonable expectations of coal. Nothing resembling a seam is known. It may be as well to state therefore, at once, that there is not the slightest chance of finding workable coal in these hills.

The sand-rock formation, as a whole, is so soft that the country, wherever it crops out, is in a state of rapid disintegration. The southern portion of the Chándi hills is a good example of this decay of the hillsides, which there goes on at such a rate that the forests are unable to keep sufficient hold to thrive.

A good deal of the material of the sand-rock was examined by me, by means of washings and the microscope, in order to trace the origin of the gold which is obtained in many of the rivers. The pure kind was shown to be a fine-grained, pure sand, with a small amount of argillaceous material. Clear quartzes, in slightly-rounded grains, formed the bulk of the rock; white mica, in flakes, was very common; amethystine quartz was also numerous, together with some deeper red coloured fragments of cornelian and jasper; and a fair percentage of iron oxide (magnetite), in fine rounded grains, was always discernible.

In washing the material by hand, the mud and the mica flakes are the first to run away; the quartz forms up next on the edge of the plate; and last of all there is left a black border of magnetite. If gold had appeared in the washing, it would have been found next to the border of magnetite; for it is a similar black magnetite residue, among which the precious metal is found by the washers of the Sona N. Certain portions of the sand-rock are, in addition, rich in felspar in irregular grains, and black mica. The whole of the material of the rock is then much less rounded by water action. It is the magnetite and black mica which, mingling with the other constituents, give the rock in some places the speckled, or pepper-and-salt, appearance.

Taking the sand-rock stage altogether, we may say that the upper portion of it is largely composed of the sandy and loamy beds. The concretionary layers set in lower down; and lower still the fine quartzose conglomerates, and the clay conglomerates. The concretionary sandy layers, and the conglomerates, continue down to the base of the stage, and even pass into the upper beds of the Nahan sandstone.

The thickness of the sand-rock stage is very great; and appears sometimes to vary inversely as the thickness of the Siwalik conglomerate. For instance, there are 7,260 feet of the former, calculated along the Rámganga, from the Nahan boundary up to the Siwalik conglomerate; whilst in the Kotri N. the thickness of the corresponding band is 8,910 feet. It is true the northern boundary of the former

band is not quite a natural one, so that the thickness there should probably be a little more. On the other hand, the conglomerate, which begins to thin at the Rámganga, dwindles down to a scarcely recognisable bed in the Kotri N. Its northern edge is, however, a fault, though, as will be shown later on, it is improbable the conglomerate here was ever very thick. Should it be found true that the thickness of the sand-rock varies inversely as that of the conglomerate, we should probably have to regard the upper part of the former, in one locality, as contemporaneous with the lower part of the latter elsewhere.

Nahan sandstone.

The Lower Siwalik, or Nahan beds, as already mentioned, may be called sandstones; for they are, as a whole, much more indurated than the rocks of the sand-rock stage, although the two merge into one another conformably. The Nahan sandstone is generally of darker colour than the sand-rock, brownish and greenish-brown tints prevailing, with sometimes a bluish-grey. It is very micaceous, and occasionally felspathic. It is never so purely silicious as the sand-rock, but contains more earthy and secondary ferruginous products. Purple, dark reddish brown and greenish shales, finely laminated, are interbedded with it, especially at the lower horizons. It is possible that this preponderance of red shales in the lower parts indicates an incomplete passage into the uppermost Sirmúrs; but such a passage has never been actually proved in this region: that is to say, the lowermost Nahans never show the nummulitics underlying them in a normal section. There are some conglomerates similar to the clay conglomerates of the sand-rock, but they are generally more compact and more firmly aggregated. In the upper horizons there are also some concretionary layers of the same nature as, but less distinct than, those in the stage above. There are irony bands in some of the lower purple shales, which near Dechauri swell out into considerable beds of brown hematite. This was once worked, and smelted along with the Rámgarh iron ore brought down from the higher hills for the purpose. The absence of coal in the neighbourhood has rendered this unprofit-

able, notwithstanding the large supply of charcoal always available from the surrounding forests.

A very conspicuous difference between the sand-rock and the Nahan sandstone is that the latter is traversed by numerous joints, parallel and at right angles to the bedding planes. Thus, the rock splits with readiness into blocks and slabs. The jointing is more marked in the lowermost Nahans, and less in the uppermost.

The thickness of the Nahan sandstone canno be definitely estimated; because, in the first place, the base is nowhere seen, and, in the second place, the strata are folded in the typical zones with an unknown amount of fold-faulting. In the Peláni N. the middle Nahan sandstone zone is 4,950 feet thick, from the base of the sand-rock down to the anticlinal north of the Nahan-Siwalik boundary. The middle band in the Kotri river gives a visible thickness of 6,270 feet. Thus, we can only say that at least it is as thick as the latter value.

Whole of Siwalik series.

Regarding the whole of the Siwalik series, from the visible base of the Nahans up to the top of the Siwalik conglomerate, one is impressed by the aspect of a great conformable and connected formation, but one which must have taken a long epoch of time for its deposition. There are three standards by which one is able to infer that that epoch was of great duration. In the first place, the immense thickness of the deposits (which average at least 16,500 feet, or over three miles) render it impossible, except on some cataclysmic theory, that they could have been accumulated in a brief interval. Secondly, the difference in the consolidation of the rocks forming the lowest and highest beds in question (which difference is well seen in the Nahan and middle Siwalik stages), shows a great aging of the lowest members. Thirdly, the relative differences in the disturbance which has affected the lower and higher parts of the series, and which we shall see later on resulting in the apparent anomaly of marked unconformability between the uppermost and the lowermost beds with continuous conformability between consecutive stages, point in the same direction and argue a long epoch of time.

Sirmúr series, nummulitic stage.

Although, for reasons given above, the detailed description of the nummulitics will be left until the Himalayan group of formations can be taken in hand, I may make a few remarks about their petrology here for the sake of uniformity. They are characterised by being thinner bedded and less massive than any of the previously described formations. A pisolitic iron ore bed is found at the bottom of the series in some places, just as in the area examined by Mr. Medlicott. This passes upwards into grey, and sometimes slightly purple, shales and sandy beds; with earthy calcareous nodular beds, and other thin strings of purer dark blue-grey limestone, containing nummulites and other foraminifera, besides mollusca and fragmental vertebrate remains. Still higher in the stage, the rock becomes marked by more shales, the limestone dies out, and sombre purple, grey, and greenish-grey coloured shales take their place. Some few purple, gritty bands next come in, and suggest a beginning of the Dagshai stage in this locality. The whole of the Sirmúr series here exposed is very thin, becoming thinner as we travel east of the Ganges. A few hundred feet is the maximum attained.

CHAPTER IV.

DISTRIBUTION AND STRATIGRAPHY.

In describing the distribution of the different rock stages, it will be well to take separate portions of the Sub-Himalayan zone, bounded in a more or less natural way, and detail the geology of each. Certain considerations also make it advisable to begin in the middle of the region where the stratigraphical relations are the simplest, namely, the Kotah dún, and to travel in imagination west-north-west; taking up one after the other of the minor dúns and the intervening country until Hardwár is reached. After this the rest of the Sub-Himalayan country of East Kumaun will be gone over in the opposite direction as far as the Sárda R.

THE KOTAH DÚN.

The Kotah dún is about fourteen miles long, stretching in a direction N. W. and S. E., and lying to the east of Rámnagar. The plains at the foot of the dún are about 1,250 ft. above the level of the sea; whilst the dún as a whole may be regarded as a plateau, which has been elevated 750 ft. above the plains, and become crumpled as to its strata along its south-west border. The south-east portion of that border is merely an escarpment lower than the dún itself, whilst towards the N. W. it rises to the insignificant height of 300 ft. above the dún, forming a low range of hills separating the latter from the plains (see sections I, II, and III). On the north-east and east the dún is bounded by a series of spurs, running out from the main range of the Lower Himalaya. Towards the north-west, near the Kosi R., the dún comes to an end by the fusion of these spurs with the low bordering hills. The eastern portion of the dún is more or less cultivated, bright patches of green fields and small villages being scattered for some distance round about the deserted buildings of the Dechauri Iron Works. On the other side of the Dabka R., villages cease in the dún proper, and reserved forest takes their place. The Sub-Himalayan zone, however, is continued some way north of the dún, and is bounded by the usual reversed fault between the Nahan sandstone and the Himalayan slates. This divisional line will, in future, be called the main boundary fault, as named by Mr. Medlicott. It is remarkable for its constancy over the whole area treated of in this memoir, in which area it is always the northern limit of the Sub-Himalayan rocks, and the southern limit of the Himalayan slates, &c. The portion coloured on the map as Nahan sandstone, between the north edge of the dún and this main boundary, presents the ordinary characteristics of the Nahan rocks elsewhere, so far as its petrology goes, save that there is a strong band of brown earthy hematite 1¼ miles east of Dechauri, as already mentioned. These Nahan beds all dip N. E. or N. N. E., with a few ocal exceptions, at pretty uniform angles of between 40° and 60°. This position of dipping

towards older rocks is a normal one in the Sub-Himalayan zone, as all students of Himalayan geology will be aware. Its production has been accounted for in a variety of ways. Some observers see in it an entirely inverted state of the rocks; others would represent it as the effect of a gigantic fault; whilst others again throw doubt on the fault theory, and regard the main boundary as an original limit of deposition, complicated by crushing. It would be premature to discuss the subject here, more especially as, in the process of describing the country bit by bit, its full meaning will more clearly unfold itself. Whatever be the nature of this boundary, it has always claimed an important share of attention, as being the greatest master-feature of the south face of the Himalaya; inasmuch as it relentlessly divides in a natural way the Sub-Himalayan from the Himalayan region.

At the foot of the Nahan sandstone spurs the winding edge of the dún marks the in-coming of the great chaors, or plateaux, forming the Kotah dún. They are uniformly composed of slightly coherent coarse gravel, or torrent-boulder beds, and sandy clays, which lap round the eroded edges of the Nahan sandstone, just as the deposits of the plains lap round the edges of the still younger rocks. There is every reason for supposing the greater part of these beds to be uppermost Siwalik in age, the section being a parallel one to that at Simbuwala described in Mr. Medlicott's memoir (p. 111). At first sight, their level arrangement, as exhibited in some parts of the Dabka and the Baur (Bhaol)[1] rivers, inclines one to the only other belief tenable, namely, that they are still more recent gravels than the Siwalik, which might be expected to be found overlying unconformably the real Siwalik conglomerates. This idea was the first to obtrude itself on my mind. Detailed work, however, showed me the following excellent reasons for discarding it, and assimilating them with the Siwaliks, even though that assimilation should bring the top of the Upper Siwalik stage much higher in the scale than is commonly supposed, and within measurable distance of the Recent river

[1] Wherever names of villages and rivers differ, the first written in the text is the more correct or more modern one, and is so marked on the 4-inch Forest Survey maps; the name in brackets is that marked on the older 1-inch Trigonometrical Survey maps.

deposits:—(1) There is no unconformability visible between them and the undoubted Siwalik conglomerate forming the low range between the dún and the plains. (2) Slight sharp local flexures can be seen in them here and there. (3) Every gradation of dip, from the horizontal beds of the dún to the distinctly inclined strata of the range south-west of the dún, can be made out. (4) They cannot manifestly be imputed to any Recent river-bed. (5) Even where horizontal, they are of great thickness. (6) Wherever undoubted modern gravels can be seen covering certain portions of the dún their thickness is trivial, and the bed-rock can be nearly always made out underneath.

The detailed sections which follow will illustrate the stratigraphy of the Kotah dún, and establish the six propositions just enumerated.

Baur N. (Bhaol N). (1)

This river presents many shingly terraces, some overgrown with vegetation, which are manifestly of recent origin; whilst, on the other hand, still higher banks, sometimes in two or more steps, and rising 200 ft. above the present river-bed, mark the ancient levels of the river as it cut its way through the horizontal Upper Siwalik beds. From one end of the river to the other the Siwaliks are horizontal, save for a dip of not more than 3° S.W. near the ironworks. The river runs very nearly along the boundary between the dún and the higher Nahan hills. Sometimes it actually follows the boundary, and shows sections of the Nahan sandstone and purple shales with the conglomerate horizontally disposed against them, as against a cliff. In other parts, especially towards the south, the boundary is a little on the eastern side of the river. The conglomerate is generally, throughout this river section, hardened by calcareous infiltrations.

Dhúni gádh (Dhooni gádh, a few miles W. of Bhaol N.).

From a point near 1,510 ft. *bar.*[1] there are exposures of horizontal beds of the Siwalik conglomerate with the sandy clay basis, sometimes hardened. They continue horizontal down to a point due west of 1,556

[1] *Bar.*—Point on the Forest Maps fixed barometrically.

ft. *trig.*[1] Here there is a steep scarp on the left bank of the river showing a gradual inclination of the beds S.S.W. The increase of dip can be watched, step by step, as it gradually achieves the angle of 40°, which sinks again to 30° near where the stream issues into the plains. At several points along the river-bed Recent deposits of calcareous tufa are seen in small quantities, formed by a constant dripping of the water from the banks above.

Karar gádh (Ghoráni gádh, 1¼ miles further W.).

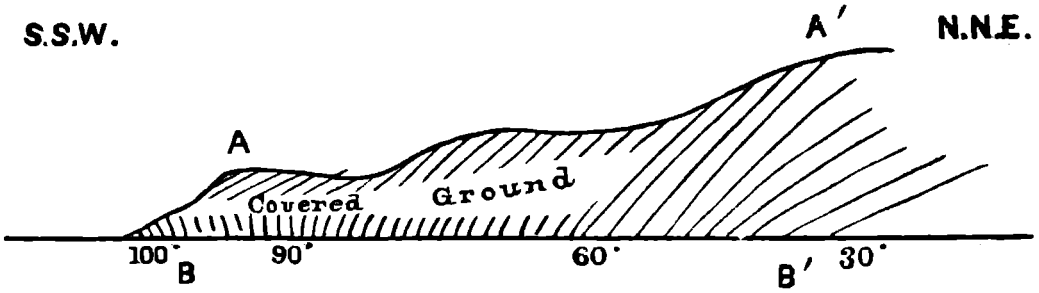
The upper reaches of this stream show horizontal conglomerates similar to those just mentioned. No deflexion from the horizontal can be detected with a level in the steep scarp near Okjálu páni, nor under Mania tila. This horizontality continues down stream until about ¾ mile of the outlet. Numerous good exposures then show a gradual bending over towards the S.S.W. and S. There is nothing that can be construed as an unconformability between the horizontal beds and the inclined ones; nor is there any distinction between the material forming either set of beds. The dip increases gradually, the increase being measurable degree by degree, until at the outlet by Komola the beds are vertical, striking E.—W. very nearly. For about two miles up this stream the left bank is flat and low, being covered with recent alluvium composed of fine clay, and with very numerous deposits of calcareous tufa.

Ladwa gádh (Larwa gádh, one mile further W.). (2)

Except for the last mile or so down stream, the conglomerates here are perfectly horizontal. A gradual dip S.S.W. then sets in until the vertical is reached and passed, and the dip is 100° S.S.W. (or 80° N.N.E. inverted). At the south entrance to this stream I very nearly made a mistake of interpretation, which is sufficiently instructive in itself to be mentioned. Just at the point where both sides of the stream rise into steep banks, the right bank for some distance shows inversion to the north, which gradually becomes vertical in 20 or 30 yards of exposure up stream. The cliff showing this is about 20 feet high, but the upper 15 feet are

[1] *Trig.*—Point on the Forest Maps fixed trigonometrically.

composed of horizontal Recent beds of gravel and clay, which seem to be sticking to the sides of the bank. A little south from this point I was astonished to see what appeared to be those upper gravels and clays dipping S.S.W. at an angle of 30°. The lower portion of the bank was here much obscured by talus, but at intervals I could still make out nearly vertical conglomerates just visible above the river-bed. I was immediately impressed by the belief that there must be here a set of inclined gravels and clays, of younger age than the Siwaliks, and superposed uncomformably upon them. I could see no way out of this interpretation for some time, until I worked up stream, when I made out the points illustrated below—



At A and B was the supposed unconformability between the inclined gravels A and nearly vertical Siwalik conglomerate B. But since A and A′ were continuous, B and B′ also continuous, and so also A′ and B′; we have (using = in the sense of conformable or of the same age)—

$$A = A'$$
$$B = B' = A'$$
$$\text{Therefore } A = B$$

I came to the conclusion, therefore, that the beds at A and B were of the same age. I then set to work with coolies to pick away the section. I was rewarded by finding the loosely aggregated gravels becoming firmer as the material was cut into, and by also finding the upper beds at A bend round rapidly to the vertical, and so become actually continuous with those at B. I have taken the pains to describe this carefully because it is an example in miniature of what

is so frequently seen in the higher Himalaya. I refer to the apparent flattening out of the dips on the hillsides, as contrasted with their steeper dips in the river beds. One more remark may be made with regard to the section. A and B contrast very much in hardness or degree of consolidation, B being much more solid than A; but the same was observed between A′ and B′ where the section was seen to be absolutely continuous. Probably much of this contrast may be imputed to the loosening of the material on the hillsides, due to percolation of rain-water, and a little to the hardening effect of the stream water carying lime in solution.

Horizontal accumulations of gravels, calcareous tufa, and alluvial clays cover the top of the cliffs on the east bank near the south end of the gádh. Still higher up the stream they form a barrier over which the water pours in a cascade. A confused mass of the tufa in large mis-shapen blocks fills in the stream-bed beneath the barrier. It is of pale grey or dirty white colour, much honeycombed and in appearance twisted like ropy lava.

Gothna gádh and Bhira páni (1¼ miles further W.) (3)

These streams show some few deposits of calcareous tufa with the Siwalik conglomerate beneath dipping at various angles S. W.

Sanáni gádh.

In the higher parts of this stream the conglomerates are horizontal, with a wide alluvial flat on the left bank, and some deposits of tufa. The latter increase in size and thickness towards the mouth of the stream, making many very picturesque cascades as the water descends from one level to another. About ¼ mile from the mouth there is a great fall into a widened basin with clean cut sides, which reveal the Siwalik conglomerate dipping at 70° and 80° S.S.W., and the Recent gravel and alluvium, with thick tufa beds, disposed horizontally upon them.

Chúna Khán. (4)

This is a steep cliff, or escarpment, fronting the plains, about 50 ft. in height, and having a mass of calcareous tufa deposited in shelves on the edges of the Siwalik conglomerate. The latter is inclined at 40° and 70° S.S.W. The tufa is largely quarried here for lime.

These form a wide river-bed and show to the south dips of 5° S. S. W. and dips of 5° and 8° N. N. E. further north, that is to say, a flat anticlinal is cut through. The northerly dip is coincident with the in-baying of the alluvium of the plains along the bed of the Dabka, which takes a wide turn to the west in this place. To the west of the Karkát N. there are left two islands of the Siwalik conglomerate; the near one of which is a flat anticlinal, with axis W.N.W. to E.S.E., and with steep dips on the south side close to the plains, and low dips on the north insensibly taking the conglomerate underneath the E.-W. reach of the Dabka N.

Dhauntia sót, Karkát N. and Káli gádh (stream between Pawalgarh and Belparao). (5)

From Pawalgarh (6) in a northerly direction, a continuous set of cliffs is exposed, showing the conglomerate scarcely consolidated, first with a slight dip towards the south as it recovers from the similarly slight dip to the north in the Karkát N. This quickly changes to horizontality, which is retained for about a mile, when another steady N.N.E. dip of 3° gradually begins and accumulates to as much as 7° at the point where the real dún is reached, north-east of the Kailkhúr (Kailakhoor) (7) hilly mass. The river-bed suddenly widens out here, and horizontal beds of conglomerate and more or less coherent gravels continue across the level expanse of the dún. It is therefore evident that the dún strata are but a portion of a wide, flat synclinal; whilst those exposed in the lower portion of the Dabka, where the low range of hills is cut through, are a portion of a wide, flat anticlinal. As the latter is traced further north-west to the Khichri N. (Kichulee N.) we shall see it increasing in steepness as the hills increase in size. At the same time more strata are brought into view, and we have an accumulated thickness of conglomerates and clays of sufficient magnitude and disturbance to completely negative the idea that they can belong to anything but the normal Upper Siwalik stage.

Dabka N.

On the north side of the Kotah dún, just where the Dabka N. emerges from the higher Nahan sandstone hills, there is a curious sharp monoclinal flexure in the conglomerate beds which takes them

up to an unconformable position on the top of typical Nahan shales and sandstone. The long stretch of perfectly horizontal beds exposed across the dún is rudely broken by this sharp bend; and if there were still any doubt as to whether the latter were Recent or Siwalik in age, I think the occurrence of this flexure would dispel it. (See section II.)

Still higher up the Dabka there are a few small outliers of the conglomerate, the northernmost of which is resting on Himalayan rocks. They are probably of younger age than the dún conglomerates; and, though I class them with the Siwaliks, they must be the uppermost of those beds, which probably link or merge them with the Recent deposits of the present rivers.

Khichri N. (Kichulee N.).

During the course of this river through the dún, the beds are horizontal just as in the Dabka; but, when the dún is ended, its passage through the low hills to the south is a deep-cut gorge among more disturbed strata than we have yet seen. (See section III.) It begins abruptly near Sitabani temple (8), the level of the dún giving way to a line of steep scarps and bare cliffs, into which the river dashes. The country here is very wild and luxuriant, and full of large game. Standing on the top of one bare cliff, with spear grass, creepers, and sál forest all round one, we may look across the Khichri gorge and with a field-glass make out on the opposite cliff bed after bed of warm brick, or ochre coloured conglomerate and clay. There are hundreds of feet of it, and among its ledges we may see a solitary sámbar, or numbers of actively climbing serow. The skeleton of the hillside thus laid bare is a silent and grand witness to the slow but irresistible action of running water, combined with earth movements, in cutting out that knife-like gorge. The sight is the more impressive, I think, from its being brought to one's notice among these flat plateaux and low hills, which in many of their larger features retain almost unmodified their shapes as impressed on them by the forces of upheaval. It is to one of these forces that the abrupt termination of the dún at Sitabani, and the sudden line of cliffs to the south, is

due; for a fault runs E.S.E. and W.N.W. at that point, with upheaval to the south; an earth-movement which has hoisted up these conglomerate masses to their present position, and which has not yet been masked by the levelling of denudatory activity. Only the solitary thread of the waters of the Khichri has gone on for ages eating through the rocky gorge as the hilly mass rose; its cutting power thereby quickened and strengthened, just as the cutting power of a circular saw is proportional to the pressure of the wood or metal against it.

The fault appears to die out in the direction of the Dabka, being represented in the latter river by a sharp bend only (see section II). It also dies out in the opposite direction. About ¾ mile up the Jáman Páni sót (9), north-west of Sitabani, a good illustration of the fault can be seen. The beds to the north are horizontal, those to the south being at first vertical, and then decreasing gradually in their angle of dip up to the top of the ridge, where they are about 30° S. W. Beyond this in a W. N. W. direction the fault gradually comes to an end; for in the Tehra (Taila) sót, and along the road from there to Bhalaon (Baloon) forest bungalow (10), the dip is conscientiously towards the north-east, at very low angles of about 5°. Thus the structure seen in the Dabka N. is returned to very nearly in that direction owing to the extinction of the fault.

Down the Khichri N. from Sitabani the dips are also to the south, but rather to the east of south than to the west. The first visible dip is 60°, which lowers to 15°, and then to 10° near Sál Khét chaor, about a mile from Sitabani. The beds then flatten out into a synclinal, on the south side of which the dip is N.N.E. at 10° for another mile or so, where a flat anticlinal runs along the Jirar sót (11). South of this the dips continue S.S.W. as far as the outlet from the hills, where the culminating amount is 27°. The lowest beds seen in the Jirar anticlinal are rather more sandy and clayey than any of the other conglomerates.

Here there are seen dips of between 30° and 20° S.S.W. from the south edge of the hills up to 1,432 feet,

Bahárdagarhi sót. (12)

bar.

In this stream, on the contrary, the dips are on the other side of the anticlinal, namely, in a direction E.N.E., and this direction continues completely across the north-west end of the Kotah dún. At the point where the Garja-ka-sót (14) is crossed the conglomerates dip at 30° N. E., and they keep this dip up to the 1,893 feet hill to the north. Their junction with the Nahan sandstones is not seen in a definite exposure; but there seems no doubt that it is a reversed fault. The material of the conglomerate here is somewhat more angular as the higher hills are approached, a fact indicating the limit of deposition of the Upper Siwalik stage in this locality.

Tehra sót (Taila sót) (13).

The structure of the Kotah dún and the fringing hills, therefore, is remarkable for the very perfect way in which the features of positive and negative contortion impressed on the Siwalik strata have been directly influential in determining their present surface features. The flat dún is composed of level conglomerates and clays, whilst the low hills to the south, in height and importance, are determined by anticlinals the steepness of which corresponds to the steepness of the hills. Wherever these low hills slope gradually down to the flat country, the dip of their strata falls gradually in unison with it. On the other hand, at Sita-bani this is not the case, the strata do not dip gradually under the dún, but are turned up sharply in the opposite direction, owing to elevation along the south side of the fault. That is to say, the sudden way in which the hills rise to the south is nothing more than the obvious result of upheaval in that direction with production of a fault-scarp. Again, at Chúna Khán and Madan Bhél, the southerly dip of the strata has increased rapidly to the vertical at the edge of the plains; and this corresponds to the very prominent steep low scarp, which one cannot fail to notice as we travel along the sub-montane road from Káladhúngi to Bael parao. The extinction of the Kotah dún to the north-west is a signal that the gentle undulations of the Upper Siwalik strata are giving way to the more compressed state of things which we shall find obtains in the country now to be described between the Kotah and Pátli dúns.

Kotah dún as a whole.

A word or two may be said here about the horizontal sections which accompany this work. They are drawn with the horizontal and vertical scales equal, from the heights and distances given on the 4-inch maps reduced one-half. Taking the datum line at the level of the sea, this gives sufficient room in the section to represent the folds of the strata without the exaggeration which follows on an increase of the vertical scale. By looking at the sections fore-shortened lengthwise, any desired exaggeration for the sake of distinctness can be obtained. The three sections across the Kotah dún show the several steps by which an almost completely horizontal disposition of the Siwalik conglomerate becomes raised into folds and faulted.

COUNTRY BETWEEN THE KOTAH AND PÁTLI DÚNS.

The Sub-Himalayan zone here, also, is divided from the older rocks by a reversed fault, presenting no peculiarities that need be noted in this place. Its position can be seen on the map. The lowest member of the Siwalik series, namely, the Nahan sandstones and shales, though keeping generally to a position next this boundary and north of the Upper and Middle Siwalik stages, has become somewhat more entangled with the latter. This is owing to the greater lateral compression of the area, and the appearance of fresh outliers of the conglomerates north of their proper zone. The scale of formations is supplemented here by the in-coming of the Middle Siwalik sand-rock beneath the Upper Siwalik conglomerates, and next to the plains. The map, therefore, shows three bands of Sub-Himalayan rocks, which are respectively, beginning from the south, the Middle Siwalik sand-rock, the Upper Siwalik conglomerate and the Lower Siwalik or Nahan sandstone. In addition, there is another broken line of outliers of the conglomerate to the north of the main mass.

I will now detail a series of individual sections.

Kosi R.

This river is larger and more important than any of the smaller streams we have yet met with west of Kálá-dhúngi. Its channel lies along a wide, open

picturesque valley through much of its course, and especially in the Upper Siwalik tract. This valley forms a natural highway for Bhootias and other hill-men from the higher parts of the Himalaya, a race of thick-set, swarthy men, with long locks of black hair and Mongolian features; who, accompanied by their flocks of sheep and goats laden with little bags of borax, red pepper and other products of their simple trade, form a characteristic element in the landscape as they slowly make their way down to the plains. It was also until recently a highway for the troops marching to the military stations of Ránikhet and Chaubattia: and in addition much of the timber wealth from the surrounding forests is discharged through it down to Rámnagar. These facts help out the idea which struck me forcibly, *viz.*, that the valley was once filled by a mightier river than now occupies it; whilst the connecting Upper Siwalik beds between it and the Rámganga R. seem to point to the hypothesis that a connection between the two rivers once obtained in Upper Siwalik times; that in fact the Rámganga was once a tributary of the Kosi, and that it has since been gradually diverted from it by earth movements.

The lower north and south reach of the river, between Rámnagar and Dikoli, is characterised by broad terraces of Recent gravels rising about 200 feet above the level of the river. They form chaors a mile wide on each bank, with only a low cliff at their base, where the underlying Siwalik conglomerates are displayed. At Rámnagar the dip in the Siwalik conglomerate is 20° N. W. It trends more west on the opposite side of the Kosi, and gradually merges into the S.S.W. dip prevailing still further east along the foot of the hills. A mile west of Rámnagar, in the Chorpáni sót (15) the dip in the conglomerate is E. and E.S.E. at high angles of 60° and 40°; so that between Rámnagar and this sót there must be a synclinal, with axis running about N.N.E. At Ringora parao (16) a continuation of this synclinal is again seen in the low cliffs by the river side. It is very sharp, and is doubtless accompanied by some slight faulting along the axis. To the east of the Kosi in the Súk sót (17) (joining the Kosi near

Lakwa) the dips are 15° and 10° N.E., that is to say, conforming to the dips in the Tehra (Taila) sót. How the dip in these sóts merges into the N.W. dip in the Kosi along this reach cannot be seen, on account of the Recent gravels and the absence of cliff exposures; but it seems probable that there is first a flattening out towards the river, and then a new inclination N.W. consequent on a crushing at right angles to the axis of the sharp synclinal already mentioned.

The Kosi river, therefore, in this place is not so much a gorge cut out among the strata as a flat valley, depending for its main aspect upon the features originally impressed on it when the Siwaliks were disturbed. Higher up stream we shall find it becoming a gorge, and displaying great walls and slopes of rock through which it has eaten its course; but just here its task has been the simple one of finding a meandering basin among transverse gentle folds. The material forming the Siwalik conglomerate resembles that in the Kotah dún, with perhaps a slightly more marked quantity of the sandy and loamy matrix. Sandy clays are especially abundant near Ringora parao.

North of Ringora parao the south-easterly dip prevails for some way, and then veers towards the east, and then to N.E. and N.N.E. near Dikoli. The strata have, therefore, finally resumed their normal N.W. or W.N.W. strike, which is also approximately the normal strike of most Himalayan and Sub-Himalayan formations.

West of the Kosi gravel plateaux, on the right bank of the river, from a point half a mile south of Dikoli down to the latitude of Rámnagar, the country is low and undulating and much cut up into irregular small hills and water-courses. It is a labyrinth of hillocks, which very much resemble sand-dunes. They are deeply covered with jungle of a miscellaneous kind, and have much marshy ground and small lakelets between them. Exposures are rare, but the nature of the soil shows that the Middle Siwalik sand-rock has now come to the surface. A couple of miles west of the Kosi the dips in this set of rocks are, generally speaking, N.N.E., the regular normal Himalayan dip. It is, therefore, very probable that near

Dikoli, the division between it and the conglomerates which stretch away to Rámnagar is a fault, running nearly parallel to the Kosi, and also to the sharp synclinal flexure which we have already noticed.

The nature of the fault is not very well indicated; but it seems to be rather more of a horizontal displacement, or lateral shift (*décrochement horisontal*) than of a vertical fault. It may be that both movements are combined. In the Chorpáni sót the fault appears to have died out, and given place to a sharp bending of the strata instead; for there is a regular conformable junction of the Siwalik conglomerate and the sand-rock, both of which are dipping E.S.E. at high angles. The conglomerate is there seen, along a very good exposure, to establish itself by degrees, the pebbles gradually increasing in number and size, whilst the interbedded sandy clay material becomes less prominent. As a fault of the above kind is merely the ultimate result of a sharp bending of the strata, whereby a tearing along the line of bending is produced, it is necessary to be somewhat arbitrary in assigning exact limits to it. The general meaning and result of the fault is clear however: whereas the conglomerate is next the plains at Rámnagar, beds of the same horizon west of the fault (or horizontal displacement) have been carried forward in the crushing of the mountain mass to a great distance further north, where they are now found forming the Gauriagani and Karaungia ridge (S.E. of Chinal trig. station). Thus the beds west of the fault are in a more inclined condition, constituting but one-half of a great anticlinal, and having a uniform dip in one direction (see section IV); whilst those to the east of the fault are thrown into one or two undulations transverse to the great normal undulation of the former. Elevation on the west side of the fault, and depression on the east, would also help to bring about the same result; materially assisting the horizontal displacement, which I suppose to have been the more prominent factor of the earth movement.

North of Dikoli the valley of the Kosi closes in to a certain extent, and its waters pour through steep high cliffs of warm

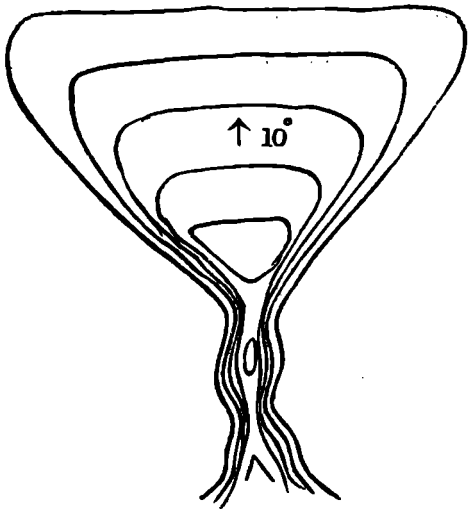
tinted conglomerate. A little north of the suspension-bridge at Garjia (two miles N. of Dikoli) a solitary pillar of the conglomerate stands up in the middle of the river-bed, and is crowned by a small native temple. That rock marks the northern boundary of the Siwalik conglomerate, which is there dipping at 20° N. by E. The narrowing of the valley in this direction coincides with the assumption of the normal northerly dip. A greater vertical thickness of rock has been cut through, and the gorge is, therefore, narrow and shut in as at Sitabani. This northerly dip conspires with the similar dip in the Gauriagani and Karaungia ridge to the west, whilst to the east it is only retained as far as the commencement of the Kotah dún, when it gradually slackens off to the horizontal.

North of the temple rock the first exposure is seen in the Súki Rau (18); and here we have the Nahan sandstone dipping N.N.E. It is, therefore, clear, from the steady dip of these two formations in one direction (approximately), that the relation between them is of the same nature as between the Nahans and the still older Himalayan rocks (see sections I and IV); in other words, it is a case of younger rocks dipping towards older, with a reversed fault as the present result.

The next reach of the Kosi flows south-east along the boundary between the Upper Siwaliks and the Nahans. On the right bank broad gently sloping chaors of the conglomerate rise from the river-bed and contract upwards into the advanced northerly spurs of the Gauriagani ridge. Their slopes follow the dip of the conglomerate, just as the line of the ridge follows the strike of the same. This reach is broad and open, the visible expression of the folded flexure (now become a fault) along which the river ran readily, as compared with the difficulty it experienced in cutting through the ridge to the south. Near where the Dhangari (Thunghully) sót (19) joins the Kosi, the boundary leaves the river bed and turns away west. It will be well, therefore, just here to examine the section up that sót, following the fortunes of the boundary (which we may call the Nahan-Siwalik boundary as named by Mr. Medlicott), and afterwards return to the Kosi R.

Dhangari (Thunghully) sót. (19)

The boundary runs some way to the south of the sót itself, as the map shows; but a complete separation of the Nahan rocks from the conglomerate has not, by its means, been effected. Uplifted portions of the conglomerate to the north of the main mass are left running out along the hill-spurs, whilst the Nahans occupy the intervening stream-beds. There are thus numerous examples of the conglomerate lying unconformably upon the Nahans. The main mass of the conglomerate composing the western continuation of the Karaungia (Chinal) ridge approaches the faulted boundary with a dip of 15°, or 20° N. by E. except near the Kosi, where the dip is more N.E. The conglomerate on the uplift side has a lower dip in the same direction, scarcely ever exceeding 10°, which is also its average dip. The spurs which form the uplift expand out northwards, as they gently descend into the Dhangari and Sanguri (Shanguni) (20) sóts; and give rise to a number of sloping chaors, of triangular form, and of the annexed shape :—



This is a very common form of hill-slope in this country, both among the Siwalik conglomerate and the sand-rock stages, and occasionally in the Nahans, wherever the dip is down hill at moderately low angles. The larger four-inch maps show the structure perfectly, but the same cannot be said of the smaller scale map accompanying this memoir. This hill-structure is especially favourable to the growth of the sál tree. In the stream-beds between the chaors, and

extending some way up the sides of the gorges, the Nahan sandstones and shales present a very high dip of 70° or 80° immediately north of the fault, and lowering to 30° or 40° further away, the direction of dip being the same as in the conglomerates. There is thus a most manifest unconformability between the Siwalik conglomerates of the triangular chaors, and the Nahans of the stream-beds between them (see section V). The chaors and their composing conglomerates tail off in the bottom of the Dhangari and Sanguri sóts where they come to an end, partly by what is apparently a limit of deposition, and partly by another small fault. There is, at first sight, a suggestion of doubt as to whether the conglomerates here so manifestly overlying the Nahans can be of Siwalik age; but on mature deliberation I see no reason why they should not be. They are inclined at a low angle, and extend to such heights as to preclude their being of Recent age; not to mention the difficulty of finding any Recent river to account for them. The fact of their immediately overlying the Nahans unconformably indicates that there must have been considerable overlap of them above the sand-rock formation, inasmuch as the latter, on the other side of the ridge to the south, passes conformably beneath them. The high angle of dip in the Nahans denotes considerable disturbance of them prior to the depositing of the conglomerate above them.

At the same time, though I believe them to be of Upper Siwalik age, that is to say, continuously laid down with the regular main mass of the undoubted Siwalik conglomerate, it is certainly the case that they must represent the very uppermost beds of that age, and as such probably approach in point of time as near to the present day as they do to the age when the sand-rock was formed, on which they lie conformably. It does not seem to me to be in accordance with the natural laws of deposition to assume always a long interval of time between two sets of strata which are unconformable to one another, and to grudge a sufficiency of time for the deposition of two thick but conformable rock stages. I am inclined to think, on the contrary, that we have a better gauge in the thickness of the deposits themselves than in the fact of unconformability between

such; for who can say how long an age it takes to crush strata into a highly inclined position? It depends on causes which are quantitively less known than are those of deposition. I, therefore, urge that conformability, where the rocks attain great thickness, is a better proof of great age than unconformability, which merely indicates a break in deposition which need not always have been of immense duration.

The great extension of the fault between the conglomerates and the Nahans, and especially its passage in an easterly direction into a monoclinal fold (Dabka N.), as also its perfect parallelism to the strike of the beds, seem to point out that it belongs rather to the class of fold-faults than to those of normal dislocation. Still, there is no need to invoke a mighty sigmaflexure to do the work here: although horizontal pressure of the earth's crust must have had large lateral effect on the strata as a whole, it is probable that the immediate results were rather of an elevatory and depressive, than of a tangential, order in this locality. The fault, therefore, partakes of the nature of a vertical fault, slightly inversed; but it cannot have been due to a mere shrinkage, or to local accidents in the earth's crust, as is the case with an ordinary fault: rather, it must have been due to a larger movement of the mountain mass. Further on, when speaking of the Pátli dún, I shall have additional reasons to put forward in support of this.

Kosi R.

Returning to the Kosi R. section, the Nahan sandstones continue (generally obscured in the actual river-bed by Recent gravels) up to Mohán. One and a half miles north of that place the main boundary fault is reached and the Himalayan rocks set in. Between Mohán and the main boundary, however, there are several small chaors of nearly horizontal conglomerates which I am inclined to place with the uppermost Siwalik conglomerates. It is, however, possible that they belong to a slightly younger stage. This line of flat chaors continues, as will be seen from the map, westwards to join similar beds in the Rámganga R. at the junction of the Pandali Rau (21). From Mohán the Kosi bends away up stream E. S. E., along the strike of the rocks, keeping very near the main boundary. The latter finally cuts the river obliquely near

Okaldhúnga (22), whence it runs across the ridge in continuation of that north of the Kotah dún.

Rátapáni, Bijráni, Garjia and Sawaldeh sóts. (23)

The watershed of these four streams, and of other smaller ones in the vicinity, is the ridge of Siwalik conglomerate which I have mentioned as lying south of the Dhangari and Sanguri sóts. Over much of its length it has a steady N. by E. dip of about 20°. The southern aspect of this ridge is naturally a steep scarp as a rule, the conglomerate standing out very prominently in various tinted brick and ochre colours. The base of this scarp coincides with the base of the conglomerate, the sand-rock occupying all the country to the south of this down to the plains. These strata are well developed here, and show their many peculiarities and characteristics in a striking way. Having already embodied all the petrological detail concerning them in Chapter III, I shall not re-describe them here from that point of view. Just as takes place in the Chorpáni sót, the Siwalik conglomerate gradually merges into the underlying sand-rock by interbedding; the pebbly layers become thinner and scarcer, whilst the sand-rock increases in an inverse ratio. We have thus a complete unanimity of strike and dip, with complete proof of conformity in sequence between the Upper and Middle stages of the Siwalik series.

The low country into which we have now entered at the base of the conglomerate scarps is one of glistening sand hillocks: nowhere does it rise to any great height, and the banks of the streams, when they have water in them, are generally steep little cliffs, in which the various beds of sand and clay stand out well defined in their brilliant yellow colours. The knolls and small ravines and flat chaors are covered with more or less dense timber, but generally small in size. It is a habitat loved by the chital or spotted deer, and it is also a favourite retreat of tigers and wild elephants. Towards the plains there is a gentle rise in the height of the country, owing to a greater degree of hardness in the lower beds of the sand-rock stage. The various dips, as seen in the stream-beds which wander through this part, give an average of from 10° to 20° N.N.E. Down the lower reach of the Sawaldeh Rau it becomes

N.E. in places, though varying a good deal. There are a few banks of Recent gravels along the margin of this reach. There is no turning over of the dip towards the plains as we near them, but a continuous ascending series from them to the Nahan-Siwalik fault, which must represent the northern half of an anticlinal fold; the southern half having no hilly representative at all, probably on account of its early disappearance by reflexing and fold-faulting (see section V).

Denudation therefore has made much more impression on the country here than on that of the Kotah dún. The strata also show more lateral compression, and orography is not so entirely dependent on disturbance for its distinguishing features. The development of a slightly reversed fault between the Siwalik conglomerate and the Nahans, in place of the mere bend in the Kotah dún, is another point evincing greater compression. As compared with the lower reach of the Kosi, there is a return to the normal direction of disturbance, namely, along lines running W.N.W. and E.S.E. Nevertheless, in most of the small streams in this part near their debouchure on to the plains, there may be noticed a slight tendency of the direction of dip to vibrate on one side or the other of the normal direction, thus hinting at a disturbance, at right angles to the normal one, of the same nature as, but less intense than, that which produced the lateral shift and north and south folds in the Kosi.

Travelling in a westerly direction along the foot of the hills from the Sawaldeh Rau, we find numerous other streams flowing in much the same manner and generally in a southerly direction, named as in the margin. They take their rise also from the same ridge of Siwalik conglomerate and cut entirely across the sand-rock strata. The country they traverse is merely a continuation of that further to the east. It is lowest near the base of the conglomerate scarp, where the streams have widened their beds, and left some Recent gravel deposits in their vicinity. As they near the plains the dip increases in height, and with it the general

Khasaria (Ringola-ka) sót (24).
Dela N. (Jhada-ka-sót) (25).
Láldháng N. with its tributaries the Heri (Haili) Rau, the Súk Rau and the Choti Koti Rau (Jumnu gádh) (26).
Koti Rau with its tributaries the two Maunpani sóts.

level of the ground. Near their origin the streams cut through conglomerates dipping 20° N.N.E. This lowers a little to 15° or 10° in the sand-rock, which, as before, sets in gradually by interstratification with the conglomerate. Towards the plains the several minor streams unite into one gorge, where the dip is about 25° or 30° in the same general direction. There is also an accompanying hardening of the beds southwards, though the rock has still no title to be called a sandstone.

All the features of the sand-rock stage are now laid bare in very beautiful and perfect sections, illustrating the sequence and variations described under the heading of Petrology (Chapter III). Where the streams empty themselves into the plains, there is usually a well-marked vibration of the direction of dip on each side of the normal direction, as alluded to in the last paragraph. There is also no southerly dip of the strata at the margin of the hills: no preservation of the south portion of the anticlinal or middle limb of a sigmaflexure.

The great uniformity in the lie of the rocks in this part is reflected in the surface features. Standing on the conglomerate ridge between Barsóti and Láldháng, one looks down southwards into the country drained by the afore-mentioned streams, and the eye can grasp nothing except a broken and disturbed sea of jungle. The streams are too much shut in and too winding to be made out from this position. There are no lofty peaks or marked ridges to catch the eye: the whole is so alike, that it is as impossible to individualise any hill as it is to distinguish each wave in a wide ocean. Only, when looking along the strike of the more lofty portion near the plains, can one see the regular dip of the strata N.N.E., a structure which relieves the monotonous maze of hillocks to a certain extent. Northwards from the conglomerate water-shed one looks down a long series of side-spurs of the conglomerate, expanding into triangular chaors as they near the Rámganga R. Turning our gaze more in the direction of the Pátli dún, we may see these chaors approaching one another and levelling out more and more to form its southern slopes.

Before going on to describe this dún, I must give a few details

about the Nahan band, as it is exposed in the Rámganga R. north of Garral (Gurrul) (27). It represents the same set of beds as extend east into the bed of the Kosi; but whereas in the latter river they are obscured by gravels, in the more gorge-like Rámganga and in the Mandál R. (Mundal) (28) they are well seen. Generally speaking, it is much more difficult to get a reliable section through the Nahan beds than through the Upper and Middle Siwaliks; for their composition does not lend itself so much to observation as that of the two higher Siwalik stages: it very seldom weathers into the same cliff-like sections along the streams. In this case, however, there is a fairly good section along much of the river-bed.

Rámganga R. (Ramgunga).

Commencing near Barsóti on the Rámganga, the first beds of the Nahans met with north of the Nahan-Siwalik boundary are dipping nearly due north at 70°. Travelling up the river this is seen to lower to 30°. Near Garral, where the Sanguri sót joins the river, the dip is 60° in the same direction, although a little to the south of this it is 40° and 45° W.N.W. and N.W. For half a mile north of Garral there is an absence of good exposures, and then there is a solitary dip of 45° S.E. immediately followed by 60° N. E. The N.W. and S.E. dips just mentioned indicate a little irresolution in the normal dip, owing probably to cross-flexuring along the river-bed. It is a cross-flexuring which has tended in addition to widen the river-bed near Garral, and which, in its position at the south margin of these Nahan rocks, holds a similar place in the Nahan zone to the cross flexures in the Kosi and other streams at the south margin of the Upper and Middle Siwalik zones. Thus early we begin to see an homology between the behaviour of the latter zone with regard to the Recent deposits of the plains, and the behaviour of the Nahan zone with regard to it—a point to be borne in mind in view of future discussion. A little further on up stream we appear to pass over a synclinal; for the dip changes to S.S.W. at 80° and 70° which continues for some way. We next appear to pass over an anticlinal, the dip becoming 70° N.N.E. This gradually increases to the vertical. At the junction with the

Mandál R. the dips become 70° S.S.W. once more, indicating that a synclinal has again been crossed. The last mentioned dip continues up the Mandál R. as far as the Khakasgadi sót; when the beds become vertical once more, and then fall by degrees to 50° N.N.E. at the main boundary fault, which coincides with the great turn of the Mandál E S.E. If we plot the dips, as in section V, and add the flexures as shown by the dotted lines, we get a general idea of the crushing to which the strata have been subjected. We see that, whilst to the south near the Siwalik conglomerate there is a wide synclinal with a rather flat southern limb, the ensuing anticlinal and synclinal to the north become much more closely packed together, and finally inverted. This presumes more intense crushing as the main boundary is reached. The strata north of the main boundary fault are Himalayan rocks, quartzites, &c., which curiously mimic in outward appearance the sandstone of the Nahan stage. An inspection by eye alone would scarcely enable any one to pick out the Nahan from the Himalayan rocks; but when the hammer is brought into play the great difference in the hardness and metamorphism makes the dissimilarity sufficiently conspicuous.

If we follow along the Rámganga itself from the point where the Mandál R. joins it, we have much the same sort of thing, namely, steep reversed dips in the Nahans and a reversed fault separating them from the Himalayan rocks. The latter, however, a little way from the fault, shew much more evident signs of crushing than the Nahans; so that we have a still closer set of folds than before.

In concluding the description of this part of the Sub-Himalayan zone between the Kotah and Pátli dúns, it is necessary once more to draw particular attention to the distinctive characteristics of the three sets of rocks composing it. The Siwalik conglomerate does not form the same flat plateaux that we found it to do in the Kotah dún, but it has a marked though gentle inclination to the north. Nevertheless, it is still free from complications, such as folding inversions, &c. The same remarks apply to the rocks of the Middle Siwalik stage: only near the plainward edge of the hills do they even acquire an angle of

dip amounting to 40°. At the same time, the single great flexure, into which the Upper and Middle Siwaliks are thrown, indicates earth movements and subsequent denudation on a scale much above that of the Kotah dún.

The Nahan sandstones, on the other hand, lie in an elevated zone by themselves, and are marked unmistakeably by their greater hardness and jointed appearance, by their being folded into several flexures with resulting dips of 70°, 80°, and 90°, and by inversion at the main boundary fault. They have thus a more ancient appearance than the rocks of either of the other stages, and show signs of lateral compression of greater intensity than has influenced the latter in the same area. In this respect they bear the same relation to the Upper and Middle Siwaliks that the Himalayan rocks bear to them. We see also that this contrast is most probably due to the difference in the lengths of time in which each formation has been subjected to mountain-forming and indurating causes.

It is essential to bear this in mind when considering the date of the upheaval of the Himalaya as a whole; for, so long as local sections show these different amounts of compression in neighbouring zones of different age, we shall not fall into the error of dating the whole of the Himalayan disturbance from late Tertiary times, on the insufficient ground that in one locality the Siwalik conglomerate is vertically inclined.

A similar contrast to the above is of course very noticeable in the Kotah dún; but I forbore from pressing the point there, as the Middle Siwaliks were invisible, and the only real conclusion to be drawn would have been that the Nahan sandstone zone had been much more disturbed than the uppermost Siwalik conglomerate.

There seems no room for any doubt whatever, therefore, that the disturbances which have affected the rock stages which have so far come under our cognisance cannot be imputed to one or more paroxysms acting in post-Siwalik times. It can with no truth be baldly stated that the "Siwaliks have been involved in the last colossal movements whereby the Himalayas have been upheaved." The

Siwalik series may not be spoken of in such a sweeping manner. They are like an old pile of buildings, that have been added to and restored during several historical periods, and that show several styles of architecture; so that, neither in the material, nor in the workmanship, can it be said that they are of one rock, or erected in one age.

THE PÁTLI DÚN.

Under this heading I propose to describe the country which lies in the Sub-Himalayan zone between the parts already disposed of, on the one hand, and the Peláni R. and lower reaches of the Rámganga on the other. This will include the Pátli dún itself. The latter is the largest of the dúns on this side of the Dehra dún. It is of a somewhat crescent shape, with the concave side facing south. It consists partly of the Recent, and sub-Recent river-bed of the Rámganga, which has deposited immense terraces of gravels at different heights, and partly of the low slopes of the Siwalik conglomerate which run up into the hills between the Pátli dún and the Pathair (Puthur) páni (29). It has no definite orographical commencement on the eastern side, but is simply an expansion of the ordinary bed of the Rámganga. Its western side is also somewhat indefinite as it merges into the Sona N. On the north it is pretty distinctly marked off by the river itself, which flows at the foot of a low fault-scarp. On the south it imperceptibly ascends into the slopes of the hills in that direction.

It is one of the most beautiful spots that the north-west provinces of India can boast. It is undisfigured by villages and bazars. A solitary forest bungalow, or chowki, is all that breaks the magnificent monotony of its billowy forests and grass-grown alluvial flats. But to imagine that here we are in the presence of a real bit of virgin country would be a mistake; many of the river terraces were once cultivated, and the sites of old fields can still be met with. These forests are in every sense a Government preserve; so that their richness in tree and jungle is due to the exclusion of agricultur-

ists and villagers; the establishment of numerous safeguards against loss by fire and axe; and the destruction of useless kinds of timber; not to mention other minutiæ of forestry which have helped to bring the forests to their present flourishing condition.

How the geology of to-day links itself with that of former ages, and how the present time is but a moment of the immeasurable past, and may in future ages come to be regarded rather as a portion of a continuous geological cycle in this region, is very well illustrated in the Recent and sub-Recent gravel deposits of the Rámganga. During the dry rainless season of the year the waters of this river are seen to form a narrow stream in a wide bed of glistening white pebbles, which marks its expansion in the monsoon, or its periodical changes of the last few years. Next, there are slightly elevated islands or banks of still older gravel which are now in the process of being cut through by the river, and which to some extent have become clothed with vegetation of young sissoo (shisham) and khair, with débris of broken drift-wood, dead trunks and tangled sprawling tree roots. Above these, rising well out of the river-bed, we see still older terraces, spreading in long flat steps one above another over most of the level portions of the dún. They are somewhat covered with soil, and support a dense grass jungle in which a tiger is as easily hidden as a grasshopper among the shoots of a well-kept lawn. Still higher slope the uppermost Siwalik conglomerates, or slightly coherent gravels, gently inclined to the north and flattening out under the gravels; but marking as plainly as the present river deposits the former existence in this locality of a river, which we can only regard as the direct parent of the Rámganga. Looking back in imagination through the ages involved in the accumulation of this sediment, we see an evolution from past conditions into present, as plainly stamped on the features of the earth as we do when we trace back the existing forms of life, the elephants, carnivores, and ungulata, which to-day swarm in these jungles, into their ancestral forms lying embedded in these very deposits.

Mr. A. R. Wallace, in his fascinating book on the Malay Archi-

pelago, described the great influence exerted by the sharp though marked geographical line of division (Wallace's line) between those islands of the Archipelago which belong to the ancient Asiatic continent and those which belong to the Australian continent, in keeping distinct the fauna (especially birds and mammals) of these two great zoological divisions of the earth in later geological and Recent times.

We have here among the upper members of the Sub-Himalayan formations a converse order of phenomena ; the unbroken sequence of deposits, that is, the merging of past geological into Recent deposits has carried with it a coherent chain of like forms, so that the same type of animals exist now in this part of the earth (though greatly reduced in the numbers of their genera and species) as existed in the remoter ages of the Siwalik period.

The present section of the Sub-Himalayan region is wider than any we shall have to consider in this work. To the north of the dún proper, there is a Nahan sandstone zone, a continuation without break of the Nahan beds to the north of the last described section. The slopes of the conglomerate south of the dún are similarly merely a continuation of those which form the range to the south of the Sanguri sót ; and so is the sand-rock zone south of it a continuation of the sand-rock zone described above. But the plainward edge of the hills shows a change in this locality. The sand-rock hardens by insensible degrees, and takes upon itself features which ultimately blend with those of the Nahan sandstone : in other words, we have the sand-rock passing down into the Nahans ; so that the latter now abut against the plains. In the petrology of the sand-rock and Nahan stages I have already indicated this passage, but without proof. The present and other sections show unmistakeably that such a passage does really exist. The likelihood of this was foreshadowed by Cautley (Fauna Sivalensis) on fossil evidence, collected further north-west in the beds near the town of Nahan, and has been discussed by Mr. Medlicott (Mem. III, G.S.I., pp. 105, 106). Later on Ishall go a little more fully into the subject of the consequences which follow on a

recognition of its truth. With this passage a greater disturbance of the beds ensues; they are inclined at higher angles, and their harder nature makes them stand out into more prominent hills than heretofore. But, besides this introduction of Nahans at the south edge of the section, we have a corresponding introduction of more of the sand-rock stage, in a synclinal with faulting, among what has hitherto remained a Nahan zone, to the north of the Pátli dún. In the Peláni R. this fresh appearance of them is well displayed, and will be described presently. We have thus an ever-increasing complexity in the strata as we travel westward along the Sub-Himalayan region. In place of the two zones at the east end of the Kotah dún, and the three in the Kosi R., we have now six zones arranged in the following order:—

N.
Nahan.
.....
Sand-rock.
Nahan.
.....
Siwalik conglomerate,
Sand-rock.
Nahan.
S.

These six stratigraphical zones may be grouped into three disturbance zones, as indicated by the dotted lines, which represent fold faults.

But not even here does the complexity end; for, if we cross the main boundary fault, we find the flexures into which the Himalayan rocks have been thrown involving with them representatives of the lowest Tertiary, namely, the nummulitics, and also of mesozoic strata in long narrow outcrops. At the conclusion, therefore, of the description of the Pátli dún I shall give a particular account of the section along the Peláni R. and the lower part of the Rámganga; in order to illustrate, by means of the very clear natural section there exposed (see section VI), the relations of the Sub-Himalayan zones among themselves, also their relation to the nummulitic and mesozoic zones, and finally the relations of all the foregoing to the older Hima-

layan zone. This cannot be considered to be beyond the scope of this memoir; for, as all knowledge is relative, we may not be said to possess a thorough mental grasp of the Sub-Himalayan zone, unless we study it not only in its own relations but also in connection with the older rocks in contact with it.

Kiláni sót. (30)

This sót is a little east of Jinti Rau trigonometrical station, and cuts across the Nahan zone north-east of the Pátli dún. There are no very good rock exposures, but such as there are give a W.N.W.—E.S.E. strike—the normal Himalayan strike. The dips are sometimes high and sometimes low, in a general N.N.E. direction. It is impossible to say whether these represent a uniformly ascending series or not: most probably not, however, and what we really have is a few closely packed and probably inversed folds, something similar to those in the Rámganga above Garral. The south edge of the Nahan zone in this locality coincides with the river bed, and also with the strike of the rocks, that is to say, it lies W.N.W. and E.S.E., but when the Delidúnga and Gaujera Raus are reached there is a noticeable change.

Gaujera (Goajada) Rau. (31)

This stream cuts across the greater part of the Nahan zone in a diagonal direction. In its lower part it is named the Delidúnga Rau on the maps of the Forest Survey. It rises in the higher ridge overlooking Jhirt, in the Mandál valley. This ridge, in its main features, is a synclinal; but, as the exposures on the north face are few and rare, it is possible that there may be a N.N.E. inversion abutting against the main boundary fault, as is the case lower down in the Mandál near where it joins the Rámganga, and as will be found in the Peláni R. Still, generally, it is a steep synclinal with dips of 30° and 40° S.S.W. on the north face, and with opposite dips on the south face. The latter dips continue down from the ridge until the bed of the Gaujera stream is reached, and increase in height up to 60°, 70°, and 80°, verticality being reached finally. About half a mile from the ridge a sharp anticlinal fold comes in, and the dip turns over towards the S.S.W.

again, the amount of dip being high as before. The direction of dip now becomes gradually due south, and, ultimately, when half a mile E.N.E. of Simal parao, east of south; and the road then follows the stream bed along the axis of another synclinal. The brown sandstones of the Nahans are here varied by a large amount of purple and chocolate coloured shales, which indicate the proximity of the base of the stage. The dips on each side of the synclinal axis are high, at angles of 60°, 70°, and 80°. At the point where the Delidúnga (32) is joined, the change in the strike has become even more pronounced, the dips now being N.W. and S.E. on each side of the axis. The lower parts of the Delidúnga, where it opens into the Pátli dún, are not very well exposed; but there seems to be some uncertainty of dip owing to a flattening out with faulting which brings in younger Nahans to the south. It is to be noticed that, coinciding with the change in the strike of the Nahan beds, from W.N.W.—E.S.E. to W.S.W.—E.N.E., the southern edge of the Nahans changes in the same way. We thus have the north-west portion of the Pátli dún bounded by low Nahan sandstone cliffs, which take a direction W.S.W.—E.N.E. The Pátli dún, therefore, owes its northern convexity to the oblique meeting of these two directions of strike, and to the strike faults which accompany them. At the same time, as a result of the change of strike, there ensues a greater widening of the Nahan zone towards the west: a spreading out of it, and flattening out of the dips, which allows the sand-rock stage, as already stated, to make a second appearance among what has hitherto been exclusively a Nahan zone.

Pátli (Patlee) dún.

If we now turn our attention to the southern slopes of the Pátli dún, we observe that the Siwalik conglomerate which forms them has no corresponding change of dip and strike. Its southern boundary keeps an unflinching direction W.N.W.—E.S.E.; and the dips both at the west end of the low range, and further east, can be seen by the maps to be N.N.E. at angles varying between 10° and 20°. The sand-rock stage, which comes conformably beneath the conglomerate, also has the same

direction of dip in the Pathair páni and its numerous tributaries. In the Rámganga, however, the sand-rock evinces a certain amount of yielding to the new direction of strike, its strike becoming east and west, and the dip directly towards the north. The consequence of the Siwalik conglomerate not having shared in the change of strike which is so manifest in the Nahans, is that the former become nipped out by degrees (with accompanying faulting) in a westerly direction against the latter. Along with the nipping out of the conglomerate ensues the extinction of the dún in the same direction.

The features of the Pátli dún, therefore, as were those of the Kotah dún, are directly dependent on the mode of disturbance of the strata. Its wide level expanse is a result of the low dip of the Siwalik conglomerate, of its regularity, and of its freedom from folds and flexures. Its abrupt termination on the north, and its westward extinction, are in like manner but the expression on the surface of the earth of disturbances in the crust. Thus, although we are entering on a more complicated arrangement of the strata as we travel west, it is still as true as ever that the youngest rocks show their internal character in a marked way by the tenor of their outward features.

The lower reaches of the Rámganga and the Peláni (Palaine) R.

I now turn to the Rámganga in its lower reaches, and the Peláni R. These two form one continuous section across the Sub-Himalayan region (see section VI). The Rámganga, where it issues on to the plains, partakes of the nature of a deep gorge with very steep sandstone cliffs on the east bank. For about 1½ miles this gorge is nearly north and south, and is the outward sign of the greater hardness of the Nahan sandstone through which the river is cutting its way (for, as already mentioned, the Nahans have now appeared conformably underneath the sand-rock stage at the plainward edge of the hills). No one gazing up-stream between the portals of dark sandstone would ever guess that in the course of a few miles the banks would flatten out and the river-bed widen into the picturesque upland valley of the dún. The river here, in cutting through this plainward hardened band, has had to cut straight and with set purpose. The

elevation of the rock into an inclined position of 40° has given no time to the river to meander and widen out its bed. With its action sharpened by resistance, the river has had to cut as it were against time, else the barrier of rock would have risen against it and driven it to find an exit by some other track, just as it had already been turned far out of its direct course to the plains by the rising barrier of strata further east, alluded to in Chapter II. But in the dún, the flatter arrangement of the beds marks a less energetic elevation of them: there was less necessity for the river to cut a vertical track, and so it had leisure to wander capriciously, changing its bed again and again, and spending horizontally the energy that lower down was acting vertically. It is necessary to bear in mind this law of river action, when contemplating the formation of dúns; for, though their main features and boundaries are exclusively due to the original moulding of the earth's crust by a lateral compression, the whole is subsequently softened, and brought to a more general level by the secondary action of the river in changing its bed and by reason of its sinuous course.

The plainward zone of Nahans begins as fairly hard, yellow sandstones and shales of the ordinary type and with concretions in their upper layers. The dip is 30° to 45° N.E., increasing in steepness as we reach the first important bend in the river. As we still ascend, following the forest road to Boksár, the sandstone gradually becomes less hard and merges imperceptibly into the sand-rock stage. About $1\frac{3}{4}$ miles above Kálagarh the sand-rock sets in with certainty. There is no change of dip, which continues N.E. and N.N.E. at from 38° to 40°. At the junction with the Sona N. the rock has become thoroughly of the sand-rock type, so soft and friable as to be unmistakeable. The orography in this neighbourhood, especially near the boundary between the sand-rock and the Nahans, is remarkable for the great prevalence of the triangular wedges of strata which form the hill spurs. They rise one behind the other, displaying in plan a set of contours as shown in fig. 1, and in profile as shewn in fig. 2.

Fi . 1.

Fig. 2.

They resemble a gigantic staircase that has suffered some convulsion of nature. Beyond the Sona N. in a N.N.E. direction the river shows no exposures for some way, and widens out into the alluvial flats which form the western termination of the dún. Near Boksár, however, low cliffs washed by the river still give exposures of the sand-rock, but the dip is more nearly due north than before at a uniform angle of 20°. Suddenly, nearly a mile N.N.W. of Boksár, they cease altogether, a fault intervenes between them and the Siwalik conglomerate, and we then enter upon one of the most striking features in the structural geology of the Sub-Himalaya. The fault, however, between the conglomerate and the sand-rock is probably of no great throw in relation to others that we are about to examine, and has taken place along a synclinal bend. It has been sufficient, however, to cause the thin band of conglomerate to vanish on the south side of it It is doubtless a mere local fracture and does not extend far in either direction. On the north side of this fault the Siwalik conglomerate forms the north limb of a compressed synclinal fold, dipping generally 50° S.S.E. Its outcrop in the river section is about half a mile across, showing the attenuated condition to which it has been reduced by the nipping-out process already referred to, though, as will be shewn later on, the conglomerate was probably never very thick west of the Pátli dún. The northern boundary of the conglomerate is a reversed fault, near which the previously mentioned

dip of 50° S.S.E. gradually increases up to 90°, and then becomes inverted 40° in the opposite direction at the position of the fault (see section VI). North of the reversed fault, lowermost Nahan sandstones, with a great display of purple shales, and much crushed, dip north at high angles. It is of the utmost importance to get a right conception of the relation of the three rock stages to one another in this locality. If we examine the horizontal section (No. VI) we shall see that, for the sake of simplicity, the southernmost fault may be neglected. What we have to consider is the reversed fault separating the Siwalik conglomerate from the Nahans. It is apparent at a glance that this Nahan-Siwalik boundary is not the simple thing we saw it to be south of the Sanguri sót, represented in section V. In the latter section there are to the north of the fault uppermost Siwalik conglomerates lying in marked unconformability upon lowermost Nahans; from which the inference was drawn that the lower part of the conglomerate, and the whole of the sand-rock stage, had been overlapped as if deposited against a shelving slope of Nahans. That is to say, the position of the fault had to be regarded as a limit of deposition for the Middle and most of the Upper Siwalik stages. The case in the present section, however, is different. From the fact that to the north of the reversed fault, the Nahans are again covered conformably by the sand-rock at Gutua gádh, we cannot regard the fault as a limit of deposition for that rock stage. It must have once spread over the high Nahan ridge, continuously, from what is now the west end of the Pátli dún into connection with the corresponding rock higher up in the Peláni R. Of course we might assume that the Nahan ridge was a ridge in part when the sand-rock was deposited, and that the latter was laid down synchronously on each side of it; but this would be a gratuitous assumption, and not borne out by sections across the same ridge further north-west. If we look at section VII across the Sona N. near Dhánsi chaor, we find no signs of the sand-rock thinning out or overlapping itself against a cliff of Nahan sandstone; on the contrary, the northern half of the inverted synclinal (which at the same time is

part of the middle limb of a sigma-flexure into which the sand-rock is thrown) is preserved almost in its entirety: the thickness north of the axis of the fold is almost equal to that on the south; and the nature of the rock changes by becoming harder and more Nahan-like as we diverge both north and south from that axis. The structure is as far removed as possible from that in section V; and warrants us in believing that, immediately south of the reversed fault in the Rámganga, the sand-rock is of proportionate thickness beneath the thin band of conglomerate, and *ergo* that, immediately north of the fault, a similar thickness has been denuded away from the top of the Nahan ridge.

The only question that seems to me to need considering is whether we are to regard the position in the Rámganga as *entirely* a modification by further faulting of that in the Sona N., or whether we may accept a compromise between that and the position as shown in section V. The two extremes will be seen to be exactly equivalent to those drawn by Mr. Medlicott across the Una dún and the west end of the Pinjor dún respectively.[1] I think on the whole the position in question must be regarded as more nearly agreeing with that in the Sona N. We must picture a sigma-flexure, as in the Sona N. section, suffering further compression and tearing along the middle limb; resulting ultimately in the formation of a thrust-plane, and almost complete obliteration of the middle limb. The magnitude of the result is, however, somewhat startling. The uppermost beds of the sand-rock, or the lowermost beds of the Siwalik conglomerate, on one side of the reversed fault lie at the same height as the visible base of the Nahans on the other side. If we go back along the section to the point where the Nahan sandstone band, north of Kálagarh, dips conformably below the sand-rock, and carry an imaginary junction line forward *beneath* the section up to the reversed fault continued downwards, and if we then go forward along the section to where the Nahans are again covered by the sand-rock, at Gutua gádh, (33) and carry the junction line backward *above* the section up to the reversed fault, we shall find the two

[1] Manual of the Geology of India, p. 550.

points where they cut the fault separated by an enormous gap, representing a distance along the fault of about 11,880 feet, or 2¼ miles, which is a vertical distance of about 6,380 feet, or 1⅛ miles. The enormous compression which the strata must have suffered, to enable the northern portion to work up over the southern, in this remarkable way, has left considerable traces behind it, in the crushed and shattered condition of the lowest Nahans, well seen at the junction of the Peláni R. with the Rámganga.

In an E.N.E. direction the reversed fault follows the line of cliffs which lie to the north-west of the Pátli dún; all of which cliff-sections exhibit conspicuous crushing. At the most northerly point of the dún where the strike changes, we find the continuation of the fault (obscured by Recent gravels) changing also and taking an E.S.E. direction to the south of the Sanguri sót. It is manifest that this line of fold-faulting along its course, from near Dhánsi chaor up to the Kosi R., culminated in a maximum break in the Rámganga; and that it dies away to a certain extent in each of the opposite directions. To the E.S.E., beyond the Kosi, in the Dabka R., we have already seen that it becomes a mere monoclinal fold, and later we shall see what becomes of it in the opposite direction.

Our section now leaves the Rámganga, and we enter the gorge which the Peláni R. has cut out through the flexured and elevated Nahan sandstone. Dips of 50° N. are first seen in the crumpled and shattered sandstones and shales. These dips increase to 90°, and we pass over a sharp synclinal. Then follows an anticlinal with axis along the westward bend of the river, and north of this steady dips N.N.E. continue for a long distance up the Peláni R. or Túmriah (Toomreeah) R (34). The amount of dip lowers from 70° to 50° in an ascending series of sandstones, which become less hard and less jointed as they merge into the sand-rock. At the junction of the Gutua (Gutu) gádh the sand-rock stage is fairly represented. The change is coincident with a lowering of the surface of the country, with a slight lowering of the angle of dip which now continues between 50° and 40° N.N.E., and with a change in the character of the river-

bed. The latter now widens out, horizontal chaors and alluvial flats become more common, and the river winds to a greater extent than before. So abundant are the natural sections in the river cliffs that all the petrological characteristics of the two rock stages, in this section along the Peláni, are passed in review like an open book of which not a page has been effaced.

As will be seen by the map and the horizontal section VI, the centre of the synclinal in the sand-rock stage is broken by a slight vertical fault, of no constructive importance, it being a mere fracture of the same kind as that dividing the sand-rock from the Siwalik conglomerate further south. North of it higher dips in the opposite direction set in amongst beds of slightly higher horizon than those to the south of it. They soon become vertical and then inverted against the next reversed fault at Halduwala. The appearance of these sands, clays and loams, softly tinted of an ochre, brown, and purple colour, and in an absolutely vertical position, is a strange sight to one accustomed to the gentle undulations of the Tertiary strata in England. Slates and schists we are accustomed to see in highly inclined positions, but to witness these sediments of yesterday (geologically speaking) in so incongruous a position fills one with wonder. We follow their vertical lines into the air above the level cliff-top, but we can never conceive in their entirety the great piles of material that have vanished by denudation since the Middle Siwalik age.

The fault at Ḥalduwala (35) is of the same nature, structurally, as the previous reversed fault, though it does not appear to be of so great magnitude. Beds moderately low down in the sand-rock stage on the south of it are in contact with lowermost Nahans on the north, and the change from one to the other is sufficiently striking to the eye and hammer; though of course not so vivid as that between the Siwalik conglomerate and the Nahans in the Rámganga. The fault, therefore, indicates a similar compression of the strata resulting first in a monoclinal fold, then a sigma-flexure, and then a tearing along the middle limb of the sigma-flexure and production of a reversed fault. To-

wards the south-east in the direction of the Gaujera Rau this fault appears to die out.

The sand-rock stage in the Peláni is now left behind. Nothing but Nahan sandstone intervenes between this point and the main boundary. The folds into which the Nahans are thrown, however, can be better seen in the section than described in words. Generally the result is a great synclinal, with lesser secondary folds borne on it. At the centre of the section the rock is evidently very near the top of the Nahan stage, from the greater softness of the rock and its appearance of being about to pass into the sand-rock stage. At the main boundary fault the strata are neither uppermost nor lowermost Nahans, but their horizon seems to be intermediate. A marked feature of this Nahan zone is the greater folding to which the strata have been subjected, together with the inverted state of many of the folds, which gives an appearance at first as if the whole were an ascending series in one direction. In many respects it can be seen to be analogous, in its folds, to the structure already noticed in the Gaujera and Delidúnga Raus.

We have now reached the main boundary fault once more. The Peláni R. cuts through a steeper and higher set of hills than heretofore, which marks the in-coming of the mesozoic, nummulitic and Himalayan zones. As being a very illustrative section, therefore, I shall continue the description up the Peláni R.; for, although I shall thereby be trenching somewhat on a subject foreign to the matter of this memoir, I hope the better to exhibit the true status of the Sub-Himalayan zone by comparing it with those older zones.

A few remarks may be made upon the surface features of the country to the north of the main boundary. The change from the low-lying ground of the Sub-Himalaya to the much higher ranges to the north is very apparent. We lose for ever those flat and undulating dúns and chaors which so characterise the zone of younger formations. With the change in the nature of the rock there follows a change in that of the soil, and in the vegetable products of the soil. The jungles lose their depth and vastness, and their tropical characteristics seem to give way with magical abruptness.

No longer can it be said with truth that the surface features have much dependency on the lie of the rocks. Denudation alone, as embodied in the vermicular tracks of the streams, has laid out hills and valleys according to its own caprice; and especially is this the case when the schistose group of strata is definitely entered upon. A homogeneity of composition, and an unknown amount of reflexing and contortion, doubtless dating far back in the history of the schists, has caused all inequalities due to simple disturbance to be effectively masked by sub-aerial influences. Along with the change in the vegetation, and in the surface of the ground, the denizens of the jungles become scarcer and of a different stamp. The spotted deer (*Axis*) utterly ceases with the dúns and chaors, on whose flat surfaces they can alone live naturally. The elephant, as if baffled by a charm, never passes beyond the ridge which marks the line of the main boundary. In the same way many other examples of large game equally seem to cease to thrive among the higher hills, or if they do pass into them it is from some artificial reason and not in accordance with their normal instincts. Tigers, for instance, are known to travel up to great heights, following herds of buffaloes seeking pasture in the more elevated region during the hot months; but in this light they may be regarded as semi-domesticated animals.

Indeed, on passing into the higher Himalaya, the change is an all-round one. The reserved forests as a rule cease, or, if they extend a short distance, they never pass beyond the zones of nummulitic and mesozoic age. The country is much barer to the north. The associations, climate, and inhabitants are very different. With the absence of reserved forests a quiet domesticity steals over the landscape; the hillsides become covered with small villages, each with its little plot of terraced fields and straggling uncared-for jungle round about. To the traveller the change means a great deal; he must reorganise his camp equipment, exchanging camels or elephants for coolies or mules; because, not only is he ascending slowly but surely into a more temperate climate, but deeper ravines and steeper hill-

slopes, void of good roads, will meet him every day in place of the gentler slopes and more softened country which he is leaving behind.

At the outset of this subject some difficulties appear. There are no such good natural sections among the rocks of the zones we are now entering upon as there were in the Sub-Himalayan zone. Although the Peláni R. is better off in this respect than many others which flow through corresponding country, still, owing to the nature of the rocks, such continuous sections cannot often be found. The geologist must gird up his loins and go to work with all his observing faculties awake if he would obtain a rational result.

I have, in another place,[1] partly described the geology of the Himalayan zone in this neighbourhood as divisible, for the purposes of classification, into an inner and outer set of formations; the inner being composed of schists and other crystalline rocks; and the outer in ascending order, of a slate and volcanic breccia series, a massive limestone, a lower and upper Tál (mesozoic) series, and a thin band of nummulitic rocks. To a stranger or novice in Himalayan geology (as I can testify by my own experience), the section we are now called upon to examine would be full of pit-falls and obstacles. As he advanced, step by step, tracing the geology as it would be provisionally laid down on a working map, he would be puzzled by a great similarity in the dips among different formations; so that less indurated appear to underlie more hardened, and less metamorphosed under more metamorphosed strata. No trace of strike faults or thrust planes would be manifest, as they are in the younger Tertiaries; no conspicuous crushing along junctions, nor apparent unconformability. True he would eventually be certain that some of the outer formations must be younger than the very metamorphosed schists in the Jhar (Thél) gádh (36), but he would be at a loss to fix the position of the stratigraphical hiatus. He would be further hampered by an appearance of passage from the uppermost nummulitics into the southern beds of the purple slate and volcanic breccia series; for the former have become much more hardened here than I have elsewhere seen them,

[1] Records, Geological Survey of India, Vol. XX, p. 26.

and no sharp break can be detected between them and the slates with which they have become welded as it were by a sustained pressure. That such a break must exist I have shewn in my previously quoted paper, by reference to a portion of the country further north-west, where the differences of metamorphism are more conspicuous. In detailing the section to follow, I shall again put forward a weight of argument, which must disprove what would otherwise be a somewhat fascinating, and on the surface of things plausible, theory, that the schistose series were, as their position seems to indicate, of really younger age than the nummulitics, above which they might be considered to lie in a great synclinal.

At the main boundary fault the bed of the Peláni divides into two channels, and it is in the western of these that a junction section is exposed. The Nahan sandstone, fairly hardened, is seen to dip apparently N.N.E. at about 60°; and above it, with merely a few inches of grey calcareous mudstone intervening, comes the massive limestone dipping also in the same direction, and with the same amount as the inverted Nahans. There is no crushing or disturbance of the rocks visible, though the hidden ground on both sides may contain examples of such crushing. No one, from the composed appearance of the rocks, would dream that there was a fault, much less a reversed fault or thrust-plane, along that plane of junction. And yet, looking forward along the section, we see, by reason of the appearance of mesozoic and nummulitic strata normally above the limestone, that the main boundary cannot be an inverted plane of natural deposition, even approximately. We see absolutely that immense faulting must have supervened.

For about a quarter of a mile north of the main boundary, the exposures of the massive limestone in the river section are not good. The banks are hidden by stalactites of calcareous tufa in dripping, mossy cliffs. There is next a short distance of massive limestone, and a few grey slates, dipping from 80° to 60° N.E.; and then a purer band of the limestone. This rock is of the same nature as those repeatedly mentioned in my previous papers on the Himalaya, that is to say, it

is a dark grey-blue dolomitic limestone, with a few slaty bands; and altogether barren of fossils. The dip steepens a little towards its northern boundary, becoming between 80° and 90°. In the horizontal section, No. VI, which is drawn due north and south, the apparent dips are necessarily much less. The mesozoic Tál beds do not actually occur in the river section, owing to a cross-fault running nearly E.N.E.—W.S.W., the line of displacement in the river-bed being just such that the nummulitics on the north of the fault are in contact with the massive limestone on the south of it. The mapping here differs a little from that accompanying my paper in the Records.[1] Sufficient prominence there was not given to the fault in its westward extension; and the nummulitics are represented as being folded amongst the purple slates. I have since found out that what I took to be purple slates on the south of the nummulitics are really hardened beds of the latter stage, and that therefore their normal position is directly above the Tál beds, as is shown over the rest of my former map.

Although the Tál beds do not appear in the river section, they are prominently displayed on the two ridges on either side of the Peláni river. It was on the western of these that I first found the fossils which afterwards identified these beds with the original Tál beds of Mr. Medlicott, and gave their probable age as mesozoic. They are composed in this locality, as elsewhere, of a hard grit and sandstone with a few pebbly bands in their lower part, and of a calcareous grit or oolitic limestone, weathering an indigo-black colour in their upper part. In the latter the fossils were obtained. I can do no more here than refer to them thus briefly, as this memoir does not concern them directly. Besides which consideration, a better collection of the fossils must be obtained before any more definite geological horizon can be assigned to them. The dips in the Tál beds coincide very nearly with those in the massive limestone below, and the nummulitics above; that is to say, they are very steep, averaging between 70° and 80°, though in the horizontal section this

[1] Records, G. S. I., Vol. XX, p. 26.

is much reduced on account of the direction of the section being diagonal, and not at right angles, to the strike.

The nummulitics in the river-bed show a certain amount of purple shale associated with them, which in some instances is very difficult to distinguish from the purple slate series to the north. Generally, however, it may be laid down that the beds near the nummulitic calcareous layers are less hardened and slaty, more of a shale in fact, and they contain a sufficient amount of lime to effervesce slightly with acid. Among them two or more bands of grey nodular impure earthy limestone appear containing nummulites. In certain places on the ridges the nummulitics have also a sandy element, which occasionally weathers into a soft brownish sandy rock, very friable, in which casts of foraminifera and bivalves can be seen. It may be remarked here that generally on the ridges, away from the influence of the river, the strata have become softer, and can be more readily and sharply divided off from the purple slate series. This is not altogether due to the weathering of the rock in this more exposed position, but also to the selective action of the river, which has cut away all the softer portions of the beds, leaving only standing up in small cliffs on the visible section those portions which were sufficiently hard to offer a certain amount of resistance to the river action. River sections in very many cases give a better index of the structure (dip, sequence, &c.) of the rocks than of the finer differences of composition: the laving water cuts and moulds every rock to a much more uniform appearance than the slower action of sub-aërial agencies.

On the north edge of the nummulite-bearing calcareous layers, there is a doubtful zone of purple shales and purple grits, which sometimes seem to merge into slates; after which there come grey slates with wavy bedding, almost vertical and passing upwards into undoubted thorough-going slates of purple and greenish colour, and these in turn finally pass into the volcanic breccia. The grey and purple slates and breccia are almost vertical, and somewhat folded among themselves, no doubt, but it is difficult to say how exactly. The latter half of the purple slates and the southern half of the breccia

are perfectly vertical. Up the Jhar (Thél) gádh, however, we notice, after nearly a quarter of a mile of vertical breccia, a gradual lowering of the dip to 25°, and the in-coming apparently superposed on them of slightly schistose slates, which merge into definite schists, dipping at various angles N.N.E.

It will be seen from this description that there is a complete absence of reliable superposition between many of these strata. Their dips are nearly vertical, and their planes of junction often so obscured as to be unrecognisable as faults or unconformabilities, from a purely local examination. The slight tendency of all the members of the series to underlie towards the north at first pre-disposes the stranger to regard them as a real ascending series from the main boundary to the schists. The first step therefore in getting a right understanding of their real position is to dismiss this false impression.

That the nummulitics cannot be a calcareous portion of the purple slate series is sufficiently shown, I think, by analogy in the first place. In numerous other sections, as the map with my aforementioned paper will show, the nummulitics are dipping down against the schistose series direct, and are separated from the purple slates by a very great thickness of Tál and massive limestone. They are thus out of all relation with the purple slates and breccia, in a part of the country where the rocks are less disturbed than in the Peláni. But the most convincing argument is one deduced from the general lie of these rocks over the large area through which they have been traced. Everywhere along the southern face of the outer Himalaya, both as mapped by myself in Garhwál, by Mr. Medlicott in the Simla area, and by other workers, the nummulitics present but the aspect of a thin band or two of fossiliferous calcareous rocks enfolded with, or faulted against, slates or schists. Now the metamorphism which has affected those slates and schists, on the above supposition that the nummulitics are one with the slates and schists, obliterating their primitive structure, and developing in them schistosity, hardening them and sometimes cleaving them, has certainly destroyed all traces

of fossils, if fossils ever existed in them. On that supposition, therefore, how does it happen that the agents of metamorphism have worked over such great areas, and left such extraordinary linear oases of nummulite-bearing rocks near the outer margin of the hills? If we assume the metamorphism to be of the nature of all known metamorphism, that is to say, either regional or due to intrusions of igneous rocks, we cannot believe, considering the wide extent of country which has been metamorphosed, that any action of such nature would be able to cease along such abrupt lines as the necessities of the case would demand if the fossiliferous strata were only slightly altered portions of the same series. If, on the other hand, the schists be regarded not as metamorphic but as primitive (in a sense), the distinctness of the nummulitics needs no comment.

Perhaps I may be deemed to be exerting myself unnecessarily to demolish what may be thought by the reader to be an unwarranted belief; but from my own past experience I know how apt the mind is to neglect these larger and indirect results of reasoning over wide areas in favour of a local section showing an apparent passage. For instance, in the Peláni R. the lie of the two sets of strata is exceedingly similar. Through the zone of purple slates there stand out from the shingle of the river-bed, long, low quays of the thinly bedded rock with an almost vertical dip. Through the nummulitic zone identical quays of a thinly bedded rock with a high dip seem so palpably a continuation of those slates that the keenest geologist, if by chance he missed the fossil-bearing bands, would map them all as one.

But I have shown that, if our knowledge of the laws and conditions of metamorphism be not entirely a myth, this cannot be the case. The nummulitics, therefore, must be newer than the slates and schists, and therefore there must be a fault separating them from these rocks. Thus, in the Peláni R. section we have to place a fold-fault on the north side of the nummulitic band of strata, of at least 4,500 feet vertical throw; for the fault once being granted, there is then no reason for referring the purple slate and breccia series to any other horizon than one below the massive limestone, in conformity with

the results of observations made further west in Garhwál, where, as already stated, clearer sections show them to be in that position.

Having disposed of the principal difficulty by the interposition of a fault, we observe that between it and the main boundary there is merely a regular descending series, perfectly intelligible by itself, and needing no faults to explain it, except a slight cross-fault along the Peláni, which is of small structural importance. Thus, the massive limestone, the Tál, and the nummulitics form one block of formations, homogeneous from a structural point of view, and in their normal order; though there is most probably slight unconformability between certain of them. Throughout a very large area, indeed, the same three formations ever present the appearance of a regular sequence, their order always being the same. No fold-faults have ever been detected which would bring a younger one of these three formations in a position of dipping down against an older.

The remaining point to be considered is whether the schists in the Jhar gádh, and which occupy much of the higher ground to the north of that position, are really younger than the volcanic breccia and purple slate, above which they appear to lie; or whether here also is indicated a reversed fault. There is very little doubt that the latter is the correct supposition, and that the schists are really the oldest formation exposed in the section. In other parts of Garhwál, the purple slates and breccia, about whose striking identity there can be no doubt, are seen to normally underlie the massive limestone and the Tál beds in a series of symmetrical flexures without the interposition of the schists, which on the other hand lie in a higher central zone by themselves. By a similar reasoning to that advanced for the reversed fault between the nummulitics and the purple slate, we may therefore point with practical certainty to a reversed fault between the schists and the volcanic breccia.

We have now gone over the section in the Peláni step by step, perhaps more in illustration than in proof of the relations of the Sub-Himalayan system to the Himalayan groups. In this brief glimpse of the older rocks one cannot help assuming a good deal that it will

be my duty, I hope, later, to prove in a separate work; still I have endeavoured to make this section as complete in itself as possible, so that we may now note those few general laws that seem to hold with so steadfast a pertinacity in *all* the relations of the Sub-Himalayan zones among themselves and with respect to the Himalayan zones, and of which laws the Peláni R. offers so brilliant and striking a resumé.

In the first place, we cannot fail to be impressed by the aspect along this section of intense lateral crushing, no matter at present how or when originated. If the strata in the section, which is 19 miles long, were flattened out, so that the folds were annihilated and the faults allowed for, the section would be about 8 miles longer than before. In other words, since the beginning of these rocks, this portion of the earth's crust has been so compressed laterally as to take up at greatest only $\frac{11}{19}$ths of its former space. Perhaps the amount would be less than this could we but follow out the folds of the older rocks southwards beneath the Tertiary zone.

Secondly, the plications are sharper and more numerous in the older zones, and longer, more undulating, and less closely packed together in the younger.

Thirdly, reversed faults are common and normal faults scarce, and the former always hade N.N.E., or thereabouts, and are parallel to the strike of the rocks. These reversed faults are full of deep significance; they represent inversed middle limbs of sigma-flexures, often of great size, which have become reduced by traction and tearing to an apparently clean-cut fracture; and by their means we can mark out the section into disturbance blocks, or bands. Numbering the stratigraphical zones in order from the oldest upwards, and grouping them into disturbance bands as marked off by the dotted lines, we have as below:—

N.N.E.

Schistose group (1).

.....

Slate and breccia series (2) and (3).

.....

Nummulitics (6).
Tál (5).

Massive limestone (4).

.....

Nahans (7).

.....

Middle Siwalik sand-rock (8).
Nahans (7).

.....

Siwalik conglomerate (9).
Middle Siwalik sand-rock (8).
Nahans (7).

S.S.W.

In all there are twelve stratigraphical zones, grouped into six disturbance zones.

Fourthly, each disturbance zone, except the purple slate and volcanic breccia, has its ascending order of rock stages at the surface from south to north; nowhere is there an ascending series of different stages dipping south; for such a position in this greatly crushed region is unstable. As soon as formed, it would tend to become vertical and then inversed by the ceaseless horizontal crush of the rocks; and then following on inversion would come the tearing along it (now become the middle limb of a sigma-flexure), and the final condition of a reversed fault. As a corollary to this, every formation, when its southern neighbour is younger than itself, is divided from it by a reversed fault; and, when its southern neighbour is older than itself, it is in normal superposition upon it. Only among the younger Siwaliks do we see, in an individual stratum, a normal dip to the south still left as evincing portions of a middle limb not entirely inverted or disseminated.

Fifthly, each disturbance zone is, considering the average age of its rock stages, older than the succeeding zone to the south; because each succeeding zone introduces a newer member than was previously present; this is shown in the table above by the numbered formations, a higher number and a higher average number coming in with each disturbance zone to the south. Should the present plainward edge of the hills be a reversed fault, it will in due order come to pass (when a further crushing of the margin of the hills has taken place)

that a still younger member will be then introduced with the new disturbance zone, namely, what are now the Bhábar gravels and alluvium of the Ganges valley.

Sixthly, I think we are entitled to consider it in the highest degree probable, amounting almost to certainty, that the five reversed faults cannot have been contemporaneously produced. I have laid especial stress on the part these faults play throughout the section, first, because of their magnitude, and, secondly, because of their undoubted connection with the flexures into which the earth's crust has been thrown. They are *de facto* the ultimate expression of a flexure, and, therefore, cannot be separated from the flexures of the strata between which they lie.

If then, as I have repeatedly insisted, the older zones show more folding than the younger zones, and if that is to be imputed to the longer intervals of time in which they have suffered compression (than which I see no other explanation), then we must also believe that the fold-fault between two older zones must be of remoter antiquity than a fold-fault between two younger zones. Thus, not only does each disturbance zone as we travel south exhibit a set of strata younger, as regards the mean time of its deposition in the form of sediment, but, also, each disturbance zone, from the point of view of its disturbance, must be regarded as a younger product than the zone immediately to the north of it. Therefore, *pari passu* with deposition of these sets of strata at the margin of the Himalaya, there has gone on a crushing and upheaval of their neighbour zones to the north, which has resulted in stranding them, periodically, one after the other, in the form of these disturbance bands; thereby adding, by an unconscious accretive evolution, fresh strata to the mountain mass as the ages rolled along.

CHOKAMB AND KOTRI DÚNS.

Surface features.

Under this heading I shall include the whole of the country between the Rámganga and Peláni rivers, on the one hand, and the Kho R. at Kotdwar (Kotdwara)

on the other. The Kho will be seen to mark a very great change in the geology of the Sub-Himalayan zone, inasmuch as everything younger than the Nahans will be found to cease there. The sand-rock and conglomerate bands we shall find gradually dying out, as the Sub-Himalaya narrow in that direction, by a somewhat abrupt northern bending of the plainward edge of the hills. The Chokamb and Kotri dúns, as they are called, do not by any means make up the whole of the country included within these boundaries: nor are they, in the strictest sense of the word, dúns at all; for there are no flat valley plateaux of any extent, moulded by Recent or sub-Recent rivers. They more nearly resemble much of the country to the west of Rámnagar, that is to say, their condition is that of an undulating diversity of small hillocks of rapidly weathering sand-rock material, whose summits all lie much about one level. They have thus a general resemblance to dúns, especially when they are considered in conjunction with the higher Nahan ridges, which shut them in on their north and south sides. They need, however, the Siwalik conglomerate as a superficial layer, dipping at low angles, or horizontal, to give them that plain-like unity of surface which is so characteristic of the Dehra, Pátli, and Kotah dúns. The low country through which the Peláni runs near its junction with the Mandálti R., and the similar tract through which the Sona N. winds, might, with equal propriety, be called dúns, for they present very much the same appearance, and only require a more complete encircling of the higher ridges to give them as doubtful a title.

With regard to the general features of the country and its flora, nothing need be said that has not already been remarked about the similar country to the west of Rámnagar. Everywhere dense jungle prevails, rising and falling in billowy irregular forms, which mount into steeper crested ridges in those places where the harder Nahan sandstone bands are present. A few temporary village communities of gold-washers thrive on the banks of the Sona N. during the rainy season, when the streams are in flood, and the glittering micaceous alluvial mud and sand spread in thick deposits with a modicum of the precious metal.

The Sona N. and Mandálti R. are longitudinal streams which follow the strike of the softer beds, whilst the corresponding ridges on either side of them are made up of the harder Nahan sandstone. The Kotri or Sanneh river (37) is a transverse stream flowing through the Chokamb and Kotri dúns.

Sona N.

The Sona N. (or "gold river" as the word signifies) joins the Rámganga a little below Boksár, and is separated from the plains by a well-marked ridge of Nahans, the direct continuation of the same band which is seen in the lowest reach of the Rámganga, and which has been already described. From henceforth this Nahan zone holds its own fronting the plains all the way up to Láldháng. There is nothing remarkable about it in this locality: its general lie being very much the same as in the Rámganga. The road from Kálu-Sháhid (Káloosyud) to Mota-Sál (38) exhibits a good section through the upper portion of it, which is dipping at angles of 40° and 35° N.N.E. or N.E. Its passage up into the sand-rock series also presents no new features; the line of junction as drawn on the map being seen to be nothing but a prolongation of the line which cuts the Rámganga. The sand-rock stage, in like manner, has no complications until the Sona N. is reached; but dips steadily N.N.E. and N.E. at angles of 30° and 45°. There is then a certain amount of complication, by the introduction of the Siwalik conglomerate in a very thin broken bed; and by the flexuring which lets in the Nahans once more on the north side of the Sona N. This line of disturbance is a continuation of the line of thrusting or reversed faulting observed at the junction of the Peláni and Rámganga rivers.

As stated above, the general course of the Sona N. is through the sand-rock stage. For some distance up stream from the Rámganga the dip is 15° N.N.E. No other formation is seen in the actual river-bed until near Háthi-Khúnd; but on the slopes north of the river-bed the Siwalik conglomerate band, which has thinned near Boksár, is continued for a short distance and then becomes lost, to reappear again at Háthi-Khúnd. Thus, the horizontal section No. VII shews

no conglomerate, but the sand-rock is continued across the valley in a reversed fold, the axis of which follows beneath the line where the Siwalik conglomerate must once have been. In explaining the first reversed fault in the Rámganga-Peláni section, this state of the rocks has been alluded to. The thickness of the sand-rock north of the axis is very nearly equal to that to the south. The beds likewise harden away from the axis, and there is only a small amount of faulting or thrusting along what is very nearly an uninjured sigma-flexure. The lower bend of this sigma-flexure embraces the strata between the Sona N. and the plains; the middle limb is made up of the inverted sand-rock and Nahan sandstone between the Sona N. and the Káli-harpál (Kalee Hurpal) ridge (39) to the north, only slightly torn along the junction of those two formations; whilst the upper limb is formed of the strata on the north-east slopes of that ridge. This state of things not only proves the former extension of the sand-rock over that ridge to the north, but it also indicates that the first thrust plane or reversed fault in the Rámganga originated in a sigma-flexure, and did not *ab initio* begin as a thrust plane.

Continuing up the Sona N. above Dhánsi Chaor, we find at Háthi-Khúnd itself the Siwalik conglomerate once more retained in a thin bed along the axis of the flexure, which has now become almost a normal (unsymmetrical) synclinal, with the fault reduced to a minimum, or perhaps even absent altogether for a short distance; for the dips in the Kánia sót (40) on the north side of the axis are all S.S.W. at high angles of 70° &c., none of them being inverted, and there is very little discrepancy in hardness between the uppermost Nahans and the lowermost beds of the sand-rock stage. This dipping S.S.W. of the sand-rock stage, followed by a younger series in normal order, is an exception to the rule as previously formulated (from the section up the Peláni R.), that there is never a regular ascending series from north to south in anything but the youngest beds. Its exceptional character is further shewn if we ascend to the head of the Timal sót (41), an affluent of the Sona N.; for we there find the strike of the Siwalik conglomerate carrying it directly up to the high scarp of Nahan sand-

stone, the Thakal gádh dánda (42), which appears as a sudden bulging towards the south-west of the normal ridge of Nahans. There is therefore a manifest dip-fault, or horizontal displacement here, running E.N.E., which is doubtless connected with the slight cross-fault in the Peláni R. at the point where the nummulitics appear. It is owing to this exceptional fault that we have the seldom-seen normal synclinal fold, involving an ascending series from north to south. The following seems to have been the chain of cause and effect:—A sigma-flexure with reversed faulting was in the process of forming all along the south edge of the middle band of Nahan rocks. In some places, as in the Rámganga, the thrusting southwards of the Nahans over younger beds has been more prominent than elsewhere. Differential thrusting of this kind might either cause a transverse rupture of the above nature; or the order of events might be reversed, and a transverse rupture bring about differential thrusting. In this case the rupture seems also to be partly due to the sharp wrench in the general strike of the rocks which becomes north and south as it nears the Kotri N. But, whichever event came first, the joint resulting position is that, whilst the Nahans on the west side of the rupture have been carried southwards a great distance, the same beds on the east side, being relieved, have simply collapsed into the form of a normal flexure. The strike of the beds, on each side of this horizontal displacement, bends round towards it in the proximity of the line of rupture. Thus, its aspect, viewed on the surface of the ground, is the same as that of a fold-fault viewed in section. The south-westward bulging of the Nahan band west of the horizontal displacement is obviously a return to the position seen in the Rámganga; the amount of the thrusting is about the same; lowermost Nahans appear to be superposed on the top of a thin band of Siwalik conglomerate; whilst all trace of the northern half of the normal synclinal or the middle limb of the sigma-flexure in the sandrock has vanished.

On getting to the head of the Sona N., the sand-rock to the south of the line of disturbance is still in force, rising into undulating hillocks with their triangular wedges very distinctly seen. Away to-

wards the plains they gradually rise into higher ground as lower and harder beds set in; and, finally, the Nahan sandstone shews beneath them in a normal and conformable succession. Travelling along the road to Kolu chaor, in the Kotri dún, from the head of the Sona N., we keep entirely to the sand-rock, and the only trace of the horizontal displacement is to be found in the curving of the strike. At the head of the Sona N. the latter has become east and west instead of S.E. and N.W.; then, after crossing the low divide into the Kotri dún, we find a return of the strike to S.E. and N.W., which is retained for some way, until near the Kotri stream when the strike becomes due north and south, and then a little east of north. The S-shaped trace which the strike thus makes is obviously of an analogous nature to the S- or sigma-shaped bend of a sigma-flexure.

Kotri or Sanneh R. (37)

In a section up stream from the plains along this river, there are first Nahan sandstones, somewhat disturbed, near the timber depôt at Sanneh (Sanai). As we traverse the first north and south reach of the river, we cross a synclinal with axis east and west and dips of about 20° on either side, increasing on the north side to 40°. The next reach, N.W. and S.E., shews dips of 40° towards the east, that is, at right-angles to the previous dips. Again, at Mandawala parao, half a mile further up stream, we have an anticlinal with axis east and west. A quarter of a mile further, at Gosam parao, an E.S.E. dip of 60° sets in and steadily continues decreasing in steepness to 30° as the Nahan sandstone merges into the sand-rock at Sain parao.

Kotri dún.

The river-bed has been a gorge hitherto, except near the mouth, but it now begins gradually to open out among the softer sand-rock. Several alluvial flats appear, helping to give the low undulating country the fictitious appearance of a dún. Remarkably good sections are exposed the whole way up this portion of the river. After the sand-rock has set in, the dips increase by degrees until at the junction with the Lakrawála sót the angle is 60° and the direction E.S.E. as before. Between here and Kotri village it oscillates between 60° and 55° and then once more

increases to 70° and 80° where the Siwalik conglomerate, the continuation of the thin band of the Sona N., is met with. It is very thin here, a mere relic, and after turning over to 80° W.S.W., there is a small interval of unseen ground where it may be inverted, and then we have the reversed fault separating it from the Nahans, which rise in a steep scarp and display very markedly their characteristic basal brownish and purple shales. The river-bed is now a gorge again, cutting through the Nahan ridge. The dips are at first due east at 60°, but this gradually changes to E.N.E. and then to N.E. at angles of 60° and 50°. This ascending series across the middle band of Nahans insensibly merges into the sand-rock at the junction with the Dimkeh sót (43), at which place the dip is 55° N.N.E. So far then there is a great resemblance between this section and the Rámganga-Peláni section; and the rest of the way to the main boundary across the Chokamb dún is also very similar.

Chokamb dún.

The Chokamb dún, which we now enter, is essentially low country, but, like the Kotri dún, lacking the real characteristic of a true dún, namely, the Siwalik conglomerate. It is entirely carved out of the sand-rock series, a continuation and expansion of the second sand-rock band through which the Mandálti R. runs. The expansion is due to the twisting of the strike, whereby the southern boundary of the sand-rock is thrown more towards the plains, following in an indirect and imperfect way the southward bulging of the middle Nahan zone in the direction of the Thakal gádh dánda. The dip in the sand-rock of this zone is N.N.E. along the Dimki and Debineh sots, first at angles of 50° and 40°, which increases to 90° at Debineh parao (44). It is not clear whether there is an inversion, or not, towards the next Nahan zone. If there be one, it must be slight; for the great disparity between the two rocks at their junction shews that the junction is far from being normal and conformable. Up the Bhir gadi (45), where it joins the Dimki, the dips are 40° and 30° E.N.E.

Mandálti (Mundaltee) R.

The Mandálti R., which is parallel with the Sona N., and analogous to it in every respect, takes its rise near Chokamb in a low flat divide between its bed

and the Chokamb dún. There are no good exposures of the rock in this very shut-in and winding stream. Such as there are merely shew sand-rock the whole way, dipping at high angles (80° and 90°) N.E. or N.N.E. A forest fire-line leading from Chokamb up to the Deolbári dánda (46) shews a fairly contrasting junction between the sand-rock and the third Nahan zone, indicating the presence of a reversed fault; but reliable dips cannot be obtained. The Nahans on the ridge are dipping N.E. 40°. The southern boundary of the Mándalti sand-rock band is simply one of passage from the Nahans into the former. The structure here, therefore, is merely a continuation of what we have seen in the Peláni R. above Gutua gádh. The third Nahan zone to the north of this is also simply a continuation of the same zone in the Peláni R. above Halduwála; whilst there is no reason to doubt that the main boundary to the north of it is in any way different to the same divisional line in the Peláni R.

Westward extinction of these dúns and longitudinal valleys.

As we stand on the flat little chaor of Chokamb, where there is a forest bungalow, we look west towards the Kho R. and observe that the low country which forms the Sona N. and the Kotri dún on the one hand, and the Mandálti R. and the Chokamb dún on the other hand, gives way gradually, so that the east boundary of the Kho R. is a continuous transverse ridge running N.E. and S.W. This expresses the fact that the two sand-rock zones, which give rise to those longitudinal valleys and dúns, have come to an end. After describing the section up the Kho R., we will consider this extinction of the sand-rock zones in its physical bearings.

Country between Kotdwar and the Mitawála (Mithi) Sót.

Orographical features.

The Sub-Himalayan zone between these two places is of narrower width than we have yet seen it to be. Having left behind us the Siwalik conglomerate and the sand-rock, the former of which practically dies out at the Rámganga,

and the latter at the Kho, we find that the Nahan sandstone and shales, which alone are left constituting the Sub-Himalayan band, present no orographical features which are distinctive of themselves. There are no longer a set of longitudinal ridges rising one behind the other, with dúns, or even low country between them. The Nahan sandstone of this tract is merely cut into a set of transverse hill-spurs, which descend towards the plains from the higher mesozoic and Himalayan ranges of hills, lying further to the north. The main boundary, in fact, is merely marked at the surface by a set of low gaps in these transverse ridges. The Sub-Himalayan zone, therefore, may be said to be welded without break into the older zones above it, so that denudation has cut through the whole as if they were one uniform block of conformable strata. A simplicity of structure is thereby presented by these Nahans which will not delay us long.

As a rule, the strata dip uniformly to the north-east, or thereabout; and, though very reliable sections are wanting, we shall see that the probability is in favour of the view that the whole is an ascending series from the plains to the main boundary, or very nearly so.

Kho R. (Kotedwar Glen). (47)

Up this river, in the Sub-Himalayan zone, there are dips of from 35° to 60° N.E. and E.N.E. The lowest beds seen near Kotdwar, at the mouth of the glen, have a large proportion of purple shales among them of the usual nature of the visible base of the Nahan stage. There are also some few of the conglomerate bands peculiar to this stage. Throughout the rest of the way up to the main boundary there are sandstones with occasional shales of the ordinary Nahan type. The following peculiarity, however, is to be noted. About two miles from Kotdwar the sandstone loses most of its ordinary characteristics, and becomes as if about to pass into the softer sand-rock. Thus it is certain that, though the two sand-rock bands are not actually present in the Kho, having died out as mentioned in the last section, the reversed faults to the north of them are still continued with less intensity across the Kho section; for further to the north-east, up the Kho, the

sandstone suddenly hardens again and then ascends gradually to the main boundary.

Nature of the dying out of the M. Siwalik stage in this direction.

There are three possible explanations of the dying out of the sand-rock bands in this direction. We may suppose (1) that they were deposited continuously over the area we are now entering upon, which was then upheaved, and they were denuded away before the two thrust planes came into existence; (2) that they were deposited continuously and then thrust over and buried by the Nahans, each in the form of a detached trough core (*noyau synclinal détaché par étranglement*)[1]; (3) that they were not deposited over this part of the country at all, or, in other words, that the Nahans here were elevated before the M. Siwalik age. I think a combination of the first and third of these suppositions the correct interpretation. It would be difficult to account for their sudden cessation west of the Kotri and Chokamb dúns entirely by thinning out, because there is such a very great thickness of them seen along the section up the Kotri stream. On the other hand, it would be also difficult to account for them entirely by the first or second hypothesis, because the reversed faults manifestly cease a short distance west of the Kho, there being no trace whatever of them in the Rausan N. in that direction. We may conclude then, that partly by thinning out, due to elevation, and partly by reversed faulting, the two bands of M. Siwalik sand-rock have thus come to a rather sudden termination.

Rausan N.

The section up this stream shews that, though the Nahan zone is as wide here as in the Kho, there has been no piling up of the strata, no reduplication of them by reversed faulting. The angle of dip is consequently low in a gradually ascending series, from harder Nahan beds with purple shales at the south end of the stream, to softer Nahans at the main boundary. The latter are not sufficiently high in the stage to be called sand-rock.

[1] See "Les Dislocations de l'écorce terrestre" par Emm. de Margerie and Dr. Albert Heim, p. 60.

CHÁNDI HILLS AND COUNTRY WEST OF THE MITAWÁLA (MITHI) SÓT.

This is the most westerly area which I shall have to describe in this memoir. It is bounded on the west by the Ganges; and so brings us into conjunction with the work already done by Mr. Medlicott, and with that which Mr. R. D. Oldham is now engaged in mapping on the 4-inch scale. Mr. Oldham has previously given a sketch map of this part,[1] the result of a few rapid traverses; whilst some of Mr. Medlicott's investigations extended a short distance in this direction east of the Ganges.

Surface features.

The aspect of the country shews a return to that in the neighbourhood of the Chokamb and Kotri dúns. There is a widening of the Sub-Himalayan area, embracing a further extension towards the south, and an inbaying up the Ganges valley towards the north. This widening is dependent on the appearance once more of the two upper members of the Siwalik series. Unlike the way they gradually disappear near the Kho R., they set in suddenly in this locality by a north and south fault; and having done so they continue for great distances along the Dehra and Kyarda dúns, &c. The widening of this portion of the country is accompanied by a slackening of the angles of dip, by undulating normal folds of gentler aspect than we have seen anywhere west of Rámnagar, and by a sudden dropping of the level of the country. The orographical features also at once mark the country as different from that I have just described. The low ridges follow longitudinally the strike of the beds, and the water-courses between them, in the main, also follow in this direction. In other words, the country once more takes its surface aspect very much after the pattern of the folds into which it has been thrown by the disturbing forces of upheaval, anticlinals forming ridges and synclinals valleys, all of which are more or less openly disconnected with the ridges and ravines of the Nahan and Himalayan zones above (see section IX).

[1] See Rec., G. S. I., XVII, p. 161.

Ganges R.

The Ganges, which flows along the western boundary of this portion of the country, marks the beginning of the Dehra Dún (48). The country here described is indeed structurally the termination of that dún. The same formations are found on both sides of the river, but in the Chándi hills, and the part west of the Mitawála sót, they shew a little more disturbance as they near the north and south fault which divides them from the Nahans. The Ganges at this place possesses a very wide river-bed of glistening white pebbles, cut into many channels, the water of which is artificially turned along certain courses for the purpose of feeding the great Ganges canal, the head works of which are at Hardwar. Hardwar is a well-known sacred bathing-place of the Hindus, full of small brick and stucco temples with their bathing ghâts facing the sacred waters. At certain times of the year the place is thronged with multitudes from all the surrounding parts of India, who attend the great fairs and for the purpose of dipping in the stream. But besides this, the Ganges valley at this point is the focus to which all going to the still more sacred fanes of Badrináth and Kedarnáth must trend. During the warmer months of the year, the dusty roads are trodden by a continuous stream of pilgrims, chiefly old men and women; who with their scanty savings, and a stout staff in their hands, make their way laboriously up stream with wonderful patience, that they may reach those snowy slopes and glaciers 12,000 ft. above the sea, the birth-place of the Ganges, before they die.

The following sections will illustrate the geology of this area.

Sidwála sót. (49)

This stream emerges from the low Chándi Hills near Kángri. Ascending it from that village, we first strike sand-rock dipping 70° S.W. This high dip gradually drops to 40° in that direction, a mile further up stream. There is then a normal anticlinal with beds on the north side dipping 20° N. E. This continues for two miles, sometimes increasing in amount to 30° or 35°. The Siwalik conglomerate then comes in, so far as I could judge, by interbedding with the sand-rock. The pebbles are at first small and sparingly dotted about in a sandy or loamy matrix,

and with numerous pure sand and clay beds interstratified. By degrees the pebbly beds increase in thickness and number, and in the size of the contained pebbles, until the well-known Siwalik conglomerate of ordinary type prevails with a dip of 30° N.E. It rises into steep scarps of bare rock. These cliffs form the watershed for the various feeders of the Sidwála sót, the Diowála sót (50), and other minor streams which flow S.W., and S. On the north-east side of the irregular line of cliffs the Siwalik conglomerate continues with the same dip as before, the country lowering in the direction of the Ghá-zirám-ká-sót, (51) towards which the water is now shed.

Returning to the sand-rock, we find the same general structure obtaining in it in a northerly direction along the edge of the hills from Kángri towards Chándi Pahar and the Ganges; save that the strike becomes N.N.W.—S.S.E. The southern half of the normal anticlinal is almost entirely swept away by denudation, and we have merely an ascending series dipping E.N.E. at 30°. The southern edge of the Siwalik conglomerate similarly bends round with the strike, but not quite to such an extent.

In the other direction from Kángri, towards Ganan trig. station (52), we have the same features marked in the sand-rock stage; the axis of the normal fold running a little south of that peak. Towards Godahwáli trig. station (53), however, the flexure gradually dies out, and the dips radiate downwards under the alluvial deposits of the plains in that direction. Thus, following the cliffs along the Paili Rau, up stream, we have first a dip of 60° S.S.W., then 40° S. and S. by E., then 35° S. E., then 30° and 20° E., and then E.N.E. and N. E. as the Diowáli sót is entered. The southern edge of the main mass of the Siwalik conglomerate does not however keep to the same line of strike, but bends round from the position we saw it had in the Sidwála sót to an E.S.E.—W.N.W. direction, then to an E. and W. direction with the inclination to the north, until it strikes the Mitawála sót and the north and south fault as shewn on the map. An outlier of the Siwalik conglomerate has, however, been left north and north-east of the Diowáli sót, bounded by a fault on the north-east side. This out-

lying portion, therefore, continues the structure and strike of the country as exhibited in the Sidwála sót. The fault on the north-east of the outlier brings in the sand-rock again, which shows signs of considerable wrenching near Khaira Chowki (54); but which eventually settles down to a dip of 20° N. underneath the main mass of Siwalik conglomerate. An inspection of the map will make this clear.

It would seem that the line of fault along the Mitawála sót has caused this singular wrenching, whereby the outcrop of the main mass of the Siwalik conglomerate takes a crescent shape. The strike of the sand-rock near Ganan trig. station not having followed this bending, a break became inevitable to ease the strain, and by it the outlier of the Siwalik conglomerate was dropped into its present position.

The Chándi hills, or "silver hills" as their name implies, are doubtless so named from the glistening appearance of the mica in the sand-rock, which is in a very rapid state of decay. The material of the hills is weathering in places at an enormous rate, so that the surface of the slopes is constantly suffering small slips which carry the soil and forest with them. It is probably on this account that the forest here is so poor as to be not worth working. The cliffs opposite Paili Chowki have their faces scored with deep vertical rain-furrows, and streaked by innumerable depending tear drops (imitating stalactites) of sand, which have dried in the act of running down. The country shews a great area of naked cliff, so that the rocks are ready dissected for geological examination.

Mr. Medlicott has generally described the geology of the Chándi hills in his memoir; and he draws attention to the return evinced here to the normal condition of the Sub-Himalayan zone, with a normal or unsymmetrical fold on the south edge, the steep limb of which is south of the axis.

I have dwelt upon the aspect of conformability between the sand-rock stage and the Siwalik conglomerate, because such an impression has invariably followed on every examination I have made with regard to the relations of these two rock stages. It is but fair to add,

however, that Mr. R. D. Oldham considers that there is an unconformability in some pebbly sandstones not far from the Diowáli encamping ground (55).[1] I was unable to find the precise position of this unconformability, which may have become covered up since Mr. Oldham visited the place. Mr. Oldham also states that he has found similar unconformabilities in the Siwaliks south of the Dehra Dún. From some correspondence which passed between us, my colleague seems inclined to regard them as mere local unconformabilities. From the numerous excellent sections which I have seen through the whole of these series, I gladly acquiesce in this, inasmuch as any thorough unconformability would surely have been manifest among these naked well-exposed strata.

Gházirám-ka-sót. (51)

This sót is cut out entirely among the Siwalik conglomerate, which has a good many clay bands interbedded with it. The sót runs generally along the axis of a synclinal fold, which is the complement of the normal anticlinal at the south edge of the Chándi hills. The hill spurs of the conglomerates on the south side of this sót display the triangular wedge structure noticed previously in many places, *e.g.*, in the country south of the Sona N. This, as before, is owing to the moderate dip of between 20° and 30° down the hillside.

Mundhal N. (56)

In the stream next to the north, named the Mundhal on the four-inch maps, but unnamed on the one-inch maps, the dips are entirely S.W. or W.S.W. at very low angles of 5°, until near Mundhal village where they are underlaid by the nearly horizontal sand-rock, which appears as a shallow dome, and occupies the low ground to the east of that village. The boundary between the two rock-stages forms a semicircle, and the dip of the upper beds is outwards from this line of junction. Northwards from this dome a narrow outcrop of the sand-rock follows parallel with the north and south fault, which can be traced the whole way from the Mitawála sót to the Bheng R. (situated on the north edge of sheet II of the one-inch maps.) The disturbance along this line of

[1] Rec., G. S. I., XVII, p. 164.

fault appears to have turned the dip in its vicinity at right angles to itself.

Country north of the Mundhal R.

The country to the north of the Mundhal R. is composed of the Siwalik conglomerate up to, and beyond, the Dogadi sót; and the beds seem to be very nearly horizontal, or with a slight flexure along the line of the Súnt sót (57). In the upper part of the Dogadi sót the dip is 30° S. W. and W.S.W.: but it lowers to 3° and becomes nearly horizontal on the north bank of the stream. The lower reaches become much covered by Recent gravels in the direction of Gouri-ghát; so that it is difficult to say how the rocks lie exactly, though they are very probably in a more or less horizontal condition. The continuation of the sand-rock outcrop, which appears east of Mundhal village, is last exposed in a very small cliff in the Bheng N.; save for one other isolated exposure opposite Rhikikes (Rikheekhes) which has a high dip of 70° S. E. (not included in the map).

Kauria chaor (58), and the plateaux between the Bheng and Rhikikes, are very much covered by Recent gravels; so that we can say no more about the Siwalik series here, than that they take a great curve up the Ganges valley.

It will be seen from the map that the main boundary in the Bheng meets the north and south fault a little further north in covered ground, and, therefore, that the Nahan rocks also come to an end with the Bheng. Their position up to that point from the Láldháng N. is simply a continuation of the same normal ascending series that we saw present in the latter stream.

Fault in the Mitawála (Mithi) sót. (59)

As described by Mr. Oldham, the sharp line separating the Nahans from the younger Siwaliks is undoubtedly a fault. A remarkable feature of it, so far as the younger Siwaliks go, is that the latter, although their general strike is nearly at right-angles to that of the Nahans, often have, in the immediate vicinity of the fault, a sharp bending either down towards or away from the fault. If the map be examined it will be seen that the south-east edge of the Chándi Hills, which follows the

course of the Paili Rau and the Mitawála sót, shows an abrupt twisting of strike; so that, by one means or other, the dip comes to be chiefly towards the line of fault. In the Mitawála sót, about 1½ miles up stream from the present Láldháng-Chila road and near the old one as marked on the map, the Siwalik conglomerate is striking north and south, and the bedding is vertical.

It needs but a glance to see that this Nahan-Siwalik boundary is of a different nature to that which we have seen in any of the areas described further east. In many points it resembles the fault running parallel to and west of the Kosi R. It is certainly, as in the latter case, a fault separating gently undulating anticlinals and synclinals from a set of strata which forms but one-half of a much larger and grander flexure in an older rock stage. Again, by the way the different strata of the U. and M. Siwaliks impinge against it on the west, we see that it is not essentially a fold fault, like the Nahan-Siwalik boundaries we have hitherto examined. Primarily, then, it seems to have been a lateral wrench of the strata, or horizontal displacement; but in later times it would seem to have been influenced by an east and west crushing, which has brought about the sharp inclinations of the younger beds along the line of fault.

The Ganges fault.

In joining up my observations on the banks of the Ganges with those made by Mr. Medlicott and Mr. Oldham, I must first say a word or two about the Ganges fault. The curving of the axis of the normal anticlinal, as exhibited in the Sidwála sót, to a more northerly direction as seen near Chándi Pahar, favours the belief that it represents the Bhimgoda anticlinal of Mr. Medlicott,[1] the axis-fault having died out as stated by him. The flat synclinal in the conglomerate of the Gházirám-ka-sót I would also correlate with the synclinal in the Motichúr Rau (60). The normal anticlinal at Raiwála, which as taken by me had an axis N.N.W.—S.S.E. (not N.W.—S.E. as taken by Mr. Medlicott) would fit in with the similar flexure on the east side of the river up the Súnt sot. The flexures, however, are not quite continuous on both sides

[1] Mem. G. S. I., III., p. 123.

of the river; those on the west side are all a little further to the north-east. This expresses the break along the Ganges fault. But it also shews that simple upheaval and depression on one or other side is incompetent to produce the shifting. Apparent lateral shifting of beds may be produced by a vertical upheaval or depression if the strata are inclined in one direction only; but a series of undulations of anticlinals and synclinals can only be laterally shifted by a horizontal displacement. I am led, therefore, to the conclusion that the Ganges fault, like most of the cross-faults that I have seen in the Sub-Himalaya, arises from a horizontal displacement (*décrochement horizontal*). The bending round of the strike towards the line of rupture is manifestly part of the same movement: the bending was the precursor of the breaking.

The opposite dips on each side of the Ganges at Hardwar are (owing to this bending) not entirely due to the fault, but also in part to deceptive appearances; denudation having carried away most of the south-west half of the normal anticlinal near Chándi Pahar, and left it intact at Hardwar. The Bhimgoda[1] fault must have been a relief in part to the more energetic horizontal moving of the strata west of the Ganges. It, therefore, lessened the ultimate horizontal shifting, by retarding the movement of the Bhimgoda anticlinal in a north-easterly direction.

Mr. Oldham mentions[2] that at Raiwála the conglomerates on the west side of the river are opposed by the sand-rock on the east side. I think this must be a mistake, as I found nothing but conglomerate on both sides, as the map will show, until Rhikikes is reached. I connect the exposure there with the exposure in the Bheng, and with the long outcrop of the same running to the head of the Mundhal R. parallel with the north and south fault.

The horizontal section No. IX will be found to illustrate the general structure of this portion of the country.

[1] See Mem. G. S. I., III, p. 123.
[2] Rec. G. S. I., XVII, p. 166.

COUNTRY BETWEEN THE KOTAH DÚN AND THE WESTERN FRONTIER OF NEPÁL.

General remarks.

We may now return to the point whence we started at the beginning of this chapter, namely, the Kotah dún; and travel in imagination over the remainder of the Sub-Himalayan country intervening between that point and the Sarda R. The latter marks the boundary between Kumaun and Nepál; and where it issues from the hills is as great and important a river as the Ganges at Hardwar. The river-basin forms a main artery for such commerce as the hills afford; it being thronged during the greater part of the colder months by Bhootia traders and other travellers to and from the higher hills. This part of E. Kumaun possesses no regular dúns, although the valley of the Nandhaur, a few miles above Aonla Khéra, approximates very closely to one. This is accounted for by the prevailing rock being Nahan sandstone; whilst the M. and U. Siwaliks only appear as a few closely approximating thin bands in the central and wider portion of this Sub-Himalayan tract.

Having described with some minuteness the several portions of the country taken up in the earlier part of this chapter, in order to gradually familiarise the reader with the type of Sub-Himalayan rock structure, it will be unnecessary now to so closely detail each river section. Much of the country being a monotonous repetition of Nahan sandstones, with no striking peculiarities and no prominent geological horizons, there will be nothing lost by this brief treatment. Those parts, however, near the head of the Nandhaur and the Sara N., where a very complicated arrangement of the strata ensues, will be given due attention in the sequel.

Geological structure south of Naini Tál.

We have already seen (p. 33) that the eastern edge of the Kotah dún rises abruptly into a high ridge of Nahan sandstone, with numerous transverse side ridges and spurs; and that the Siwalik conglomerate of the dún is disposed horizontally against the up-turned edges of those sandstones,

as against a cliff. The Nahan sandstone here is of great width, holding entire possession of the Sub-Himalayan zone, and it continues so as far as the Balia ravine (61) which descends from Naini Tál. The main boundary up to this point continues in a fairly straight line cutting the Naini Tál-Káladhúngi road at Bijaun village (62), the Nehál R. near Nehálpúr, and thence crossing a little S. of Balne Khán and following parallel to and a little north of the Naléna R. (63) to Jóle kót. It is lost to view eventually in the Balia N. by a covering of superficial gravels.

The disposition of the Nahans appears to be that of an inverted synclinal, the axis of which runs along the ridge south of the Nalena valley. Whether this synclinal is broken along the axis, or not, by a fault, there are no data to say. North and south of it the beds harden considerably, and apparently by degrees; whilst along the axis they are soft and typically the uppermost beds of the Nahan stage. There is thus an inversion of the Nahans immediately south of the main-boundary fault.

At the Balia ravine this arrangement is broken by a cross-fault, a lateral wrench of the strata, plainly indicated by the swerving round of the dip towards it in the neighbourhood of the Nalena bridge on the bridle road to Naini Tál from Ránibágh. The cross-fault follows a line very nearly coincident with the Balia ravine, as far as the suspension bridge at Ránibágh (64). The main boundary by this fault is thrown southwards on the east side of it, so that the continuation of the main boundary, instead of passing a little south of Bhim Tál (as it would if undisturbed by the cross-fault), takes a new departure near the suspension bridge and follows the course of the Góla R. for some miles up stream. This general statement with regard to the Nahans in this neighbourhood will be sufficiently intelligible if the map with the dips marked on it be studied in conjunction with it. It must be inferred, however, that the lateral wrench of the strata along the cross-fault has been supplemented along its southern extension near Ránibágh by an up and down movement, the upthrow being on the east side; for the main boundary along the east and west

reach of the Góla R. divides uppermost Nahans from an old volcanic and granitic set of rocks to the north of it: in other words, the inverted half of the synclinal in the Nahans is not preserved here. It will be remembered that near the head of the Kánia (40) and Timal (41) sóts a similar cross-fault was accompanied by a like disparity in the sequence of the beds on each side of it. We had the uninjured synclinal in the sand-rock and Siwalik conglomerate on the east side of the cross-fault (corresponding to the uninjured inverted synclinal west of the Balia fault), and the ordinary ascending series with reversed fault on the west side of the fault (corresponding to the similar arrangement on the east side of the Balia fault). The difficulty of assigning the right order of cause and effect in the production of this arrangement is as great in the present case as in the previous one.

Golá R.

This river rises among Himalayan rocks, and after a while traverses very nearly along the line of the main boundary fault, and finally at Ránibágh turns south, cutting a gorge for itself through the Nahans to the plains. Tracing its course up stream from Káthgodám we find the section through the Nahans to be a very striking one as far as Ránibágh, on account of the great masses of strata that it reveals; bed after bed of sandstone and purple shale or hardened nodular clays coming into view with very nearly vertical dips over this 1½ miles of its course. I have already (Chapter III) drawn attention to the very great thickness to which the Sub-Himalayan formations attain; the Nahan band in the Kotri stream being over 6,000 feet and the bottom not seen there as elsewhere in this region. To the mere traveller by the tonga road to Naini Tál, or to the fisherman working his way along by its pools, the Golá R. section is a perplexing and striking one from the vast amount of strata laid bare. Even the geologist may be excused for momentarily losing his head when he passes across strata of one rock stage attaining such profound thicknesses. He may mentally compare this section with the sections exposed on the south face of the Salt Range, where the whole Palæozoic and Mesozoic record, including silurian, carboniferous, triassic, jurassic and cretaceous rocks, at its greatest is but

5,000 feet; and question within himself whether there is not something wrong about these great thicknesses. The stern logic of facts, however, must compel him sooner or later to see in the strata exposed from Káthgodám to Ránibágh nothing but a gradually ascending series of Miocene or Pliocene ages, from nearly vertical beds much jointed and hardened, to softer beds near the top of the Nahan stage, dipping 65° N.N.W. near Amratpúr. Not only is there a strong individuality in the rock, a general likeness throughout the section to warrant this belief, but it may be mentioned that specimens of fossil leaves have been obtained from the Nahan sandstone of this river and from that of the Nandhaur R.[1] which from their form and venation are seen to be angiospermous exogens, differing in no important points from those constituting the foliage of many trees living at the present day.

Main boundary near Amratpúr.

Ascending from Ránibágh along the bed of the Góla R., a very interesting assemblage of rocks is observed in the neighbourhood of Amratpúr, and one which has been wrongly interpreted by General Strachey.[2] I have stated that, if the lateral wrench of the strata along the Balia N. had not taken place, the main boundary would have passed much further to the north of its present position near Amratpúr. It was this break of continuity in the line of the main boundary, together with the presence of trap and granite apparently detruded south where the break occurs, that must have led General Strachey to regard the igneous rocks as intruded among the Tertiary strata, and therefore as being of Post-or younger Tertiary age themselves. With the good maps available to-day, and the systematic geological surveying of the area continuously from one point to another, a different light was at once thrown on the subject, which is really of vital importance in connection with the geological history of the Himalaya. In the first place, it must be understood that these traps exposed along the road from Bhím Tál to Ránibágh are not intrusive dykes, but consolidated

[1] Many good specimens have been obtained by Mr. Dhoarty whilst excavating for the canal at Chorgalia.

[2] Quart. Journ. Geol. Soc., 1851, Vol. VII, p 296.

beds of old basic lava-flows; for they are not only regularly interstratified with slates and quartzites of sedimentary origin, but they are also frequently charged thickly with amygdules of chalcedony and other secondary minerals, which fill up what were vesicles in the rock at the time of its birth. These filled up vesicles proclaim at once that the rock was exposed at the surface in a molten condition, that it was a flow or lava sheet and not a dyke rock. Furthermore, these supposed intrusive traps have not baked, hardened, or metamorphosed the Nahans in any degree whatever. On the contrary, these sandstones at Amratpúr in the vicinity of the trap are rather soft and friable, and exhibit no sign of having been subjected to such volcanic heat as must have been developed at the time those vast beds of lava welled up from beneath the crust. Still further, the rock next to the Nahans at Amratpúr and Amia village is not trap mainly, but a good strong granite of normal character and white colour: that is to say, a deep-seated rock, which could not have been formed except at great depths under conditions of pressure and very elevated temperature, and in the presence of water or water vapour—conditions which must have left traces of still more intense metamorphism in the rocks among which it was intruded than that due to lava. Again, the quartzites and purple slates interbedded with the traps represent contemporary sediments that were forming at the time the lava was formed; and the signs of age stamped on them, that is to say, the pyro-metamorphism and dynamo-metamorphism which have affected them, illustrate the *least* degree of metamorphism we should expect also in the Nahans, were the latter older than the traps.

It is clear, then, that the Nahans are a younger set of rocks, separated from an older set of bedded volcanic and plutonic rocks which happened to be exposed in this locality during the time when the main-boundary fault was in progress of formation. As such, they are as distinct from them as from any other Himalayan rocks elsewhere in contact with them at the main boundary.

There are many other points of interest in these Pre-Tertiary igneous rocks, as we trace them along the course of the Góla R. up

stream, sharply marked off from the Nahan sandstone by the fault; but such detail belongs to the history of the strictly Himalayan formations, and cannot be introduced here in a memoir devoted to the Sub-Himalaya only.

From a little east of Amratpúr the main boundary follows the actual river-bed to a little beyond Amia. All along this line the rocks on both sides are much crushed. It then crosses and re-crosses the river, and afterwards follows a line north-east of the village of Jamiráni; the distinction between the two sets of rocks being well marked at the surface. The line of the main boundary has now gradually become south-east and north-west, instead of east and west,—a direction which takes it once more along the south side of the Góla R. close by the village of Múrkúndia. At the last-mentioned place a complication is introduced by these uppermost Nahans becoming still softer until they merge into a thin band of the sand-rock stage striking in the direction of Patráni. The map will shew how this band runs, the composing beds dipping 60° N. E. Its northern edge does not abut against the main boundary itself, but against more Nahans of a very low horizon from which it is separated by a reversed fault. E. S. E. of Múrkúndia these Nahans may be seen to be of a very hard and dark type of sandstone, dipping 60° and 80° N. by E. The main boundary to the north of the latter has now diverged entirely from the Golá R. and crosses the Karai-ki-gádh obliquely, and then re-crosses it some 2½ miles higher up, from which point it slopes gradually up the hill-side to Sháli lake (65) and Lohakhám temple, taking a direction about E.S. E. There are now two bands of Nahans and an intermediate one of sand-rock, occupying the Sub-Himalayan area. The narrow band of M. Siwalik sand-rock at Patráni trends south-east into the Nandhaur R., a little east of Khonáni (66), and concomitantly the Nahan band to the north widens and shews several closely packed folds.

Nandhaur R.

The portion of the Nandhaur R. below Khonáni resembles in its general curve that of the Gola R. and of many of the rivers further west, *e. g.*, the Kosi,

Rámganga, Ganges, and Beas, inasmuch as it first follows the strike of the beds and then by a bend (in the opposite direction to the hands of a watch) gradually works across the strike of the beds as it escapes to the plains at Chorgalia. Beyond the very interesting discovery of fossil leaves in the Nahan sandstone of this locality, there is but little to remark with reference to the lower parts of this river. The normal Sub-Himalayan dip prevails of 60° N. E. or E. N. E., until beyond Khonáni, when we gradually strike the sand-rock band, a continuation of that at Patráni. As far as the Ásni gádh (67) this band is not very broad, and it passes down into the sandstone to the south of it with which it conforms in direction and amount of dip. To the north its relation to the northern Nahan band is first normal, dipping steeply 80°, &c., to the south, as exhibited in a few stream beds such as the Ásni and Aonla Khéra gádhs. The valley of the Nandhaur, therefore, near Aonla Khéra (68), in its very apparent widening, expresses this synclinal in the sand-rock; which is shortly to be supplemented further east by Siwalik conglomerate being enfolded in that synclinal, the latter at the same time gradually becoming inversed as to its northern limb. The river at this position keeps to the south of the conglomerate by a series of sharp twists in steep-walled gorges. Further up stream, E. of Gauniá Rau (69), it widens again, and the landscape is very beautiful and undulating; the inversed northern limb in the Siwalik conglomerate becomes lost, as also that of the sand-rock. We then have the Siwalik conglomerate dipping in normal order against, and separated by a reversed fault from, the Nahans; or, if there be a thin band of the sand-rock between the two, it is completely hidden in all the exposures in the side-streams. The regular descending series from the reversed fault at the Nahans, through Siwalik conglomerate and sand-rock down to Nahans again, is evidently the normal Sub-Himalayan structure, such as was observed characteristically in the Pátli dún. The Nandhaur valley, along this reach, very much resembles a dún; it becomes broad and flat, and the river winds about in serpentine curves among recent gravel banks covered with sissoo and khair. The high dip of 60° and 70° in the conglomerate is the

one bar to the formation of a regular dún. With regard to the northern Nahan band, it can be seen from the map to gradually lessen in width in the direction of Dúrgapipal; the main boundary running towards that point from Lohakhám by the upper stretch of the Gaunia Rau.

In an easterly direction from this dún-like part of the Nandhaur, as far as Pátli village, there comes a very interesting and complicated arrangement of the strata, which is illustrated in the sections X, XI, XII, XIII and XIV. For the present, therefore, we will leave the Nandhaur, in order to describe those sections.

Kalaunia N., and country north of the Sára N.

The first section is taken parallel with the Kalaunia N. It illustrates the general structure prevailing across the whole of the Sub-Himalayan zone. Travelling up the Kalaunia gorge every variety of the Nahan sandstone is perfectly familiar; we recognise the well-bedded and jointed sandstones of dark greenish, greyish, and brown colours, with their subsidiary hardened clay and purple shale bands, the latter being very prominently seen about 1½ miles north of Kalaunia gót; we recognise the hardened concretionary layers, and the conglomerates of sub-angular pebbles of shale and clay and sandstone; and, finally, the passage up into the sand-rock stage in the Sára N. is also the same as of old, save that it is perhaps a little more sudden. The dips are due north near Kalaunia gót and apparently inverted, there being an inferred lying anticlinal (*pli couché*) near this place. The northern limb of the fold dips normally north at first, afterwards becoming N. by W. and N. N. W., and the angles increasing from 35° to 60°.

A little south of Silna jála the river bends east and west, and is named the Sára N. At this point the sand-rock comes in, and we keep on due north up the Réla or Raiála gádh (70). Entering that stream from the south we have the sand-rock stage for some way as characteristically displayed in all its composing elements as were the Nahans in the Kalaunia N., except that the thickness of the sand-rock is somewhat less than we have elsewhere seen it. The soft sands

and loams, slightly coherent, the inter-bedded concretionary layers standing out in the cliff sections, as also the clay beds and fine conglomerates, are as typically shewn here as anywhere in the western area near the Ganges; so that there is no mistaking them for anything else. They dip steeply at from 55° to 50° N. N. W., and at Bhút Bhéra they change into the Siwalik conglomerate by a gradual interbedding. The Siwalik conglomerate, however, has but a short career. Its exposure is less than ¼ mile across in this stream, and its lie is that of an easy synclinal, with low flat dips at the position of the axis. To the north its beds steepen, and the sand-rock then follows in normal order dipping 50° S. S. E. The E. S. E. strike involved in this dip, and the E. N. E. strike of the beds on the south side of the synclinal axis, if produced, meet about ⅛ mile to the east; so that the Siwalik conglomerate in that direction comes to an end. A curious case of pebble distortion in the conglomerate exposed here has been recently described by me[1]. It is not a mere flattening out of the pebbles against one another, but a crushing of one set over another set; so that they have been first powdered *in situ* (but in such a way as not to destroy the general structure of the pebbles, be they granite, trap or quartzite) and then drawn out along one line, either into fine thread-like processes, or into puckered or undulating layers like the mineral layers of a foliated rock. The sand-rock to the north of the conglomerate, through a short space of less than ¼ mile, increases in dip to the vertical, and then becomes inverted. Typical Nahans of very low horizon then come in suddenly, the thinness of the sand-rock on this side of the synclinal and the absence of passage beds into the Nahans shewing only too plainly the presence of a reversed fault between the two. In the sand-rock near the reversed fault, there are not wanting signs that more than one line of thrusting is present, and it seems extremely probable that a great many of the reversed faults in this Sub-Himalayan region are but seldom a single clean-cut fracture, and are rather a number of closely packed tears, all parallel to one another.

[1] Rec. G. S. I. Vol. XXII, pp. 68.

Bág Khóla (71).

The Bág Khóla section only differs from the preceding one by having a slightly wider exposure of the Siwalik conglomerate, which is also inverted at its northern edge. Nothing could be prettier, however, than the clear view of the folded synclinal obtained in the clean-cut little cliffs; every step in the process of inversion of the northern limb of the synclinal being well portrayed.

Raula Kándlo and Dhárapáni gád (72).

The view of the rocks of this glen is very nearly coincident with that depicted in section XI. The valley opens into the Sára N. near Kichail, among beds of Siwalik conglomerate. There is a black carbonaceous layer, about one foot thick, among the latter, near the entrance to the stream. There is no sand-rock to the north, but the Siwalik conglomerate abuts directly against the Nahan band; the Nahan-Siwalik boundary having obliquely truncated the latter so that it is not visible in the section. The Nahan band to the north, save that it is more contorted than usual, preserves a general resemblance in its main folds to the same zone further east.

Sections south of Katauti.

In the sections to follow complexity and added interest set in. The reversed fault between the younger Siwaliks and the Nahans can be seen to be a nearly uniform straight east and west line from the Raiála stream to the Pátkhóli Rauli. The main-boundary fault, in like manner, keeps a uniform line nearly parallel with it as far as the Gangolia gád south of Katauti. Furthermore, if these lines be produced in a westerly direction into the Nandhaur, we shall find their representatives as described in the paragraph devoted to that river. The intervening country, however, shews no Nahan sandstone at the surface; everything is Siwalik conglomerate as far as, and even beyond, the main boundary. In brief, we have overlap of the Siwalik conglomerate upon the older beds.

In section XII this is first illustrated. The Siwalik conglomerate in the Sára N. forms the lower bend of a sigmaflexure, broken by a reversed fault to the north of it. The Siwalik conglomerate in the

Gangolia gád (73) is a portion of the upper limb of the same sigma-flexure, though in a certain sense only, inasmuch as the conglomerates there are of much higher horizon in the Siwalik stage than those in the Sára N., and inasmuch as there is no sand-rock below them. Thus the conglomerate of Gangolia gád unconformably overlies the Nahans with no intermediate sand-rock, which must have been denuded away along what was a rising line of disturbance during an early phase of the same sigmaflexural movements; which movements continuing later, when the conglomerates of Gangolia gád were deposited, finally influenced them also.

Herein it may be remarked that the section is very similar to that south of the Dhangari (19) and Sanguri (20) sóts; and I would apply to both the same explanation regarding the absence of the lowermost Siwalik conglomerate, and of the sand-rock below the conglomerate, on the uplift side of the fault. That explanation demands that the line of the reversed fault be mentally represented, not as a sudden break, but as a continuous line of weakness from early in the M. Siwalik age up to late U. Siwalik times. Thus the sand-rock, and the lower beds of the conglomerate, if thinly deposited north of the fault at intermittent times, must, owing to the constant rising of that part, have ever been suffering almost contemporaneous denudation; whilst the beds to the south were preserved by being forced below the reach of denudation. The Gangolia gád conglomerate, therefore, and that of Jirinjála (section V), are remnants which are on their way to obliteration. Their temporary preservation, however, is a valuable index as to the style of earth-movements along the lines of these reversed faults.

But we have also another very important deduction to make from this same conglomerate. We see that it overlaps, not only the Nahans, but also the Himalayan traps to the north, and that it truncates the main boundary fault in a most absolute and uncompromising manner; thus shewing that the latter was altogether anterior to the formation of those uppermost Siwalik conglomerates. Lastly, the reversed fault bounding the Gangolia gád conglomerates on the north must be the most recent of all these lines of weakness.

Just as in the Peláni R., therefore, we have by an independent mode of reasoning arrived at the same conclusion, namely, that the reversed faults bounding different zones of the Sub-Himalaya are successional and not contemporaneous, and that therefore we cannot ascribe the whole of the folds and faults therein exhibited to one great earth-paroxysm of Post-Siwalik age.

Section at the head of the Sára N.

Section XIII, further west, shews at the surface an apparently consecutive ascending series in the Siwalik conglomerate from the Sára N. to the Mawala panigád (74). That such is deceptive, however, and that the reversed fault (Nahan-Siwalik boundary) is really present, but hidden, is indicated very plainly by the change in the conglomerate near the top of the ridge. It becomes almost entirely made up of large boulders of Nahan sandstone, instead of the elsewhere prevalent quartzite pebbles. The main boundary is overlapped by the conglomerate in the same way as in the last section.

Section south of Durgapipal.

Finally, section XIV begins to shew a return to the ordinary position seen in the Nandhaur R. The Siwalik conglomerate on the uplift side of the Nahan-Siwalik fault still over-rides a portion of the Nahans, but it does not pass across the main boundary. In addition, there is preserved a thin band of the sand-rock to the north of the uplifted Siwalik conglomerate. The latter is very remarkable for the large amount of the torrent boulders of Nahan sandstone contained in it. A somewhat parallel change in the sand-rock is also to be noticed. It becomes slightly conglomeratic, with pebbles of quartzite in it, though it never can be mistaken for the Siwalik conglomerate even for a moment.

Country east of Raiála gád and Kalaunia N.

The main boundary from near the head of the Raiála gád crosses through a gap in the ridge north of Maitiabanj, and from that point gradually descends the hill-slopes to the north; after which it strikes the Ladhia R. 1½ miles W.S.W. of Uparkót. Thence it keeps ¼ mile south of Uparkót, joining the Ladhia R. again 1½ miles further east; after which it follows a line generally coincident with the Ladhia as far as the Nepál frontier.

Except for a narrow band of the sand-rock east of Patli village, and extending as far as the small ridge east of Baiála, there is nothing but Nahan sandstones to the south of the main boundary, the whole of the rest of the way to the Sárda R. The Nahan zone presents the same characteristics as the Nahan zone south of Naini Tal; that is to say, it is a great inverted synclinal, with probably lesser folds borne on it. Beds considerably low down in the stage are present at the main boundary, and also along the plain-ward edge of the hills; whilst softer upper beds of the stage prevail along the central line of the zone. It needs no special description, therefore, and the mapping will be sufficiently clear by itself.

CHAPTER V.

GENERAL CONSIDERATIONS.

Resumé of earlier chapters.

In the preceding chapters we have briefly considered the superficial aspects of the country; we have also made, as it were, a dissection of the rocks from a mineralogical and petrographical point of view; subsequently, separate portions of the country have been taken and described as minutely as seemed necessary, with regard to the present disposition of those rocks, the nature of the disturbances which have affected them since deposition, the folds into which they have been thrown, the faults which have supervened, the relations of each of the formations to one another and to the older zones of the Himalayan area, and, lastly, proximate causes have been assigned to account for these folds and dislocations.

It now remains to consider the rock stages of this region in a wider sense, both in time and space: it is necessary to connect my work with that of other geologists among rocks of the same age and position, and to take a general view of those larger questions in which these rocks are involved in the whole scheme of the Himalaya.

I must, however, here state that it is not my intention, even if it were in my power, to discuss the whole question of the formation,

upheaval and present features of the Himalaya in their entirety. This memoir is simply concerned with a limited portion of the Sub-Himalaya; therefore, only so far as those fringing ranges offer evidence in behalf of the great chain shall I trouble the reader at present.

I presume that every reader of this work has previously made himself acquainted with at least the second part of the Manual of the Geology of India. That being so, he will appreciate the difficulties which surround any generalizations about the earlier history of these remarkable mountains. He will see that without crowding these pages to an enormous extent, and thereby obliterating any clear perception that might be gained, it would be impossible to do justice to all that has been written by former observers. Mr. Medlicott alone has put forward so many possible and probable hypotheses, so many alternative solutions, all of which are of the greatest use to the subsequent investigator, but the greatest torment to the scientific reader who merely seeks for a clear and coherent *view*, that it would be difficult to discuss the subject thoroughly without reviewing in all their different lights and bearings the issues that he has so well indicated.

In the remarks that follow, therefore, I shall only point out those deductions concerning the Himalayan range which must certainly follow from the study of the Sub-Himalayan tract. If they coincide with Mr. Medlicott's and other observers' prognostications, well and good: if not, it must be left for a future work to reconcile, uphold, or dismiss them.

Unity of work with that of Mr. Medlicott.

From the description given in Chapter III, of the petrography, there can be no shadow of a doubt as to the general identity of the formations with those embraced in Mr. Medlicott's classification. The fact that I examined the Dehra dún previous to setting about the study of my own area, and the fact that our two working grounds adjoin at the banks of the Ganges, make it as certain that the formations of both agree respectively as that the individual parts of my own area agree with them-

selves. The different bands of rocks, besides having strongly marked characteristics whereby they may be recognised, actually pass from one to the other of our working grounds (a proof of their sameness the most complete possible). That being the case, it would be waste of words to say more in enlargement of this truth. Beyond this, there is really very little else to do in this connection. As already stated, this work aims at being an extension of Mr. Medlicott's, and, therefore, so long as our two classifications correspond, the chief business of correlation is at an end.

The advantages of larger maps have enabled me to mark, with a separate colour, the M. Siwalik sand-rock, following Mr. R. D. Oldham[1] in this; whereas Mr. Medlicott represented the U. and M. Siwaliks by one tint on the map accompanying his memoir.

Possible slight discrepancy.

There is only one minor point on which I think it at all likely that I may prove at variance with Mr. Medlicott, At page 132 of his memoir he canvasses the possibility of a fourth group or rock stage, of lower horizon than the Nahans, and of higher horizon than the Sabáthu. (*N.B.*—Sabáthu here includes the whole of the Sirmúrs, *i.e.*, Kasauli, Dagshai, and Sabáthu proper). I have never seen any reason in Garhwál and Kumaun for the creation of a fourth stage. On the other hand, I have taken as the basis of my classification that the lowest rocks exposed south of the main boundary be called Nahans. Of course, had a section shewed nummulitic-bearing rocks in normal succession beneath Nahans, this decision would have had to be modified and an arbitrary line drawn between the two; but, until fossils had proved such a succession, I thought it better to call the older rocks south of the main boundary Nahans, although the presence of purple shales in greater preponderance in the lowest beds seemed to indicate a petrological change into deposits something resembling the uppermost Sirmúrs. I cannot but think that somewhere along the plainward edge of the hills there will eventually be found a section embracing nummulitics and Nahans in one normal succession, just as

[1] See Rec., G. S. I., XXVII, p. 161.

I have here shewn Nahans and M. Siwaliks in a like succession. But until they are so found it is safer to call the lower beds Nahans. I think also that this classification best agrees with that which Mr. Medlicott has adopted over the larger part of his area.

Still, should there be a slight discrepancy between our two classifications, I think it will be in this respect. My Nahan beds may possibly be, as a whole, of slightly lower horizon than Mr. Medlicott's; that is to say, I may have included with the Nahans older beds than he has, and drawn the line between them and the sand-rock stage a little below his.

Source of material of Sub-Himalayan rocks.

If we refer to what has been written in the foregoing pages about the petrology of the Sub-Himalayan system, we shall see that the mineralogical composition of the strata suggests something about the area from which the material forming them was derived. The presence of so much mica, in well preserved plates; of magnetite; and of occasional fragments of felspar; not to mention the very granitic appearance of much of the rock; shews unmistakably that the area from which this detrital material was drawn was one of crystalline schists or granitic rocks. The freshness of the material also proves that it cannot have travelled far. Every presumption is in favour of the belief that it came from the higher Himalayan range. That being the case, we cannot suppose that range plunged beneath the sea, or below the general level of denudation at the time of the deposition of the greater part of the Sub-Himalayan series. Apart from their geographical distribution and their fossil contents, there is this indication afforded by their minerals that the schists and granites of the Himalayan range were exposed at that time, though there is no proof here that they were in their present greatly elevated position. That the same minerals might have been derived from some other land is of course a possible, though not a probable, hypothesis. But, besides the commoner minerals herein mentioned, General McMahon (Rec., G. S. I., Vol. XVI, p. 186) has described several accessory minerals whose presence still more convincingly points to the crystalline rocks of

the higher Himalaya as their ultimate source. In rocks of the Sirmúr series and the Siwalik series he has found schorl, garnet, triclinic felspar and microcline, besides quartz shewing polysynthetic structure and containing liquid cavities and microliths. He writes, "All the above are eminently characteristic of granitic rocks and could be matched over and over again in the granites and gneissose granites of the Himalayas." At the very outset then we are reminded of the high probability that a barrier of crystalline rocks existed in Tertiary times between the Sub-Himalayan deposits of this side and those in the Hundes.

Conditions under which they were deposited.

The structure and fossil contents of the beds indicate the geographical conditions which prevailed during the deposition of the Tertiaries, as plainly as their mineralogical composition indicates the nature of the rocks forming the land from which they were derived. The marine origin of the Sabáthu beds, and the fresh-water origin of the upper Tertiaries, have long been recognised as facts. Moreover, the gradual passage of the Sabáthu clays into the sandstones of the Dagshai and Kasauli stages has also been accepted as proving a gradual change from marine conditions to those of fresh-water. Elevation was clearly going on in the localities where these rock were laid down, so that seas became estuaries, and estuaries dry land, and finally the younger Tertiaries, namely, the Nahans and M. and U. Siwaliks were deposited under conditions much like those under which the present deposits at the foot of the hills are being accumulated. I need not, therefore, make any further remarks upon this head, seeing that the rocks of this epoch, in the district I am describing, agree in all their facies with those as described by Mr. Medlicott. It is only when the Himalayan area is left, and we pass on to the Salt Range, the Suleman Range and the hills of Sind, that we find marine strata of greater thickness, and encroaching somewhat higher into the Tertiary series—a fact which indicates that the wave of elevation took place from the east to the west, whereby the sea was driven in that direction, and estuarine and fluviatile conditions supervened.

Another general consideration that strikes us in looking over the petrological characteristics of the Tertiaries is that they present, as Mr. Medlicott has shewn, "a well defined petrographical whole of some order." There is no alternation of deposits, such as would indicate a fluctuating condition of the earth's crust, except on a small scale. The whole set of deposits is steadily evolving in one direction. As to how this evolution, depending as we have seen on a wave of elevation proceeding from east to west, took place, we shall enquire later; I am at present merely drawing attention to those conclusions which follow from a simple inspection of the material and fossil contents of the rocks.

"A well defined petrographical whole of some order."

A marked feature, on which I would lay stress, is that throughout the whole of the Tertiary zone there is no metamorphism of the strata, beyond a mere hardening of the lowermost beds by age. There is not even the presence of trap in the lowest Tertiaries, such as has been shown to exist in the Sind area and probably in that of Ladák. In the Góla R. I have described granite and trap in close conjunction with the Nahans, but from their not influencing the latter and from other reasons we have seen that they must be regarded as pre-Tertiary. At Kotedwar, also, in the area treated of in this memoir, we have an example of the near approach of the main boundary to the intrusive gneissose granite of Kálogarhi (Kálandánda), which is only about five miles away; but as there is no more metamorphism of the Tertiaries, including the nummulitics, in this position than elsewhere, we must without doubt relegate that gneissose granite at least to a pre-Tertiary time. Thus the absence of metamorphism in the Tertiary rocks pre-disposes us to regard the whole of the intrusive granite of the Himalaya as at least as old as pre-Tertiary—a point which has been disputed by some authors.[1]

Absence of metamorphism.

Beyond the few inferences above, I do not think we can draw more from a purely petrological examination of the Tertiary strata. I see no evidence

No evidence of glacial conditions.

[1] See McMahon, Rec., G.S.I., XVI., p. 192.

for glacial action in any of the strata east of the Dehra dún. The presence of well-rounded pebbles in a clay matrix does not seem to me, of itself, to be proof either of glacial or extraordinary diluvial conditions. It seems to me merely to point to that particular form of deposition which must always obtain in a country subject to periodical rainy and dry seasons, namely, that during the rains each belt of deposited material stretches a long distance out from the mouths of the streams, but, when the amount of water in the stream bed diminishes, the carrying power diminishes with it, and mud is therefore deposited among the interstices of the torrent boulders discharged during the rains. Sub-angular and scratched stones, in anything approaching to a till or boulder-clay, are unknown; as also is that peculiar form of ice-refuse of the nature of the contorted drift of Norfolk.

General considerations depending on distribution, and method of disturbance of the strata.

In turning from the broader questions involved in a study of the petrology of the country to those connected with the horizontal extension of the rocks, and the nature and meaning of the folds and disturbance zones into which they are thrown, there is a great temptation to wander aside into the fields of speculation: the mind is eager to leave the Tertiary records behind and to run riot among those scarcely decipherable monuments of the higher Himalaya. It would be a very pleasant excursion for the writer, and one might plead innumerable excuses for doing so: is not the Himalayan chain one, and can we divorce the Tertiary zones from the rest of the Himalaya? Has not every throe, as new formations were cast up from their deposition ground, vibrated through the great central mass of those glistening schists, and rugged granites, which rear their pine-clad summits far and still further beyond until they seem to melt among the clouds? But though such a prospect is seductive enough, the still small voice of scientific caution whispers to one that, if such license be prematurely given to the mind, to play with the bubbles of speculation, there may be a day of reckoning in the future when the minuter history

of the older rocks is more thoroughly worked out. How many heart-rendings will there then be should our theories too hastily formed dissolve like a dream before the clear daylight of advancing knowledge. Yes, we had better keep to the task imposed, as closely as human nature will allow.

Structure imbriquée (écaileuse).

Attention has already been drawn, in the section up the Peláni R., to the disposition of the disturbance zones, to their great extension lengthwise in the form of bands, to the northerly dip of their composing formations, and to the reversed faults bounding them on their northern edges. They are disposed in what has been elsewhere called *structure imbriquée* (*écaileuse*);[1] but with this peculiarity, that the uppermost member of each step or zone is younger as we near the outer margin of the hills. Let us look at this structure a little more closely. We have seen that it is extremely probable that the reversed faults belonging to this *structure imbriquée* were not contemporaneous, but successional; and I think there are certain considerations which will enable us to date their succession with some approach to accuracy. If we cast our eye over the map accompanying this memoir, and the smaller scale map of part of Garhwál,[2] we cannot help being struck by the peculiar manner in which a long narrow zone carries, as its uppermost member, a still narrower outcrop of some one formation. For very great distances we may see on the map, running parallel with the reversed fault, a thin line of colour representing a single rock stage. I may first instance the nummulitic band, which with a total thickness of a few hundred feet extends for 30 or 40 miles thus without any very marked increase in the width of the zone. I may also mention the thin band of Siwalik conglomerate which continues from the Kotri dún to the Rámganga R. and many of the members of the Sub-Himalayan series and the still older mesozoic formations. Lastly, the Sub-Himalayan group taken in its entirety is also an example of the great extension of a narrow belt of strata following a reversed fault for immense distances.

[1] See "Les Dislocations de l'écorce terrestre" par Emm. de Margerie and Dr. Albert Heim.

[2] Rec., G. S. I., Vol. XX., p. 26.

This peculiarity surely has a meaning, and the question is, what is it? I think it means that the uppermost member of each zone has been preserved intact for such long distances, because the fold involving that zone, and the reversed fault to the north of it, were the companions of the upheaval of that zone from a condition of deposition; that is to say, the uppermost stratum had only just been deposited when it was folded, and faulted, and so wrapped up with the older zone to the north that it was preserved from sub-aërial denudation.

Interpretation of the above structure.

For let us imagine a contrary case: let us suppose that the nummulitic strata, at the points where they are now seen to lie in thin bands, were horizontal, or approximately so, and covered by an immense thickness of Nahans and U. and M. Siwaliks before the reversed folding and faulting took place. What would have happened in that case? There is no such thing as a state of quiescence in nature: either a rock is being added to by deposition or it is being denuded away by erosion. Consequently, from the moment the nummulitics with their horizontal burden of Nahan sandstone and U. and M. Siwaliks rose from the level of deposition, they would begin to be acted upon by rain and rivers. As they continued rising, they would become cut into and sculptured in every direction by valleys and gorges; so that a geological map, if then drawn, would present all those winding, circular, and ellipsoidal outcrops peculiar to a country of horizontal strata. The result of a lengthy interval between upheaval and folding would be an irregular patch-work of strata, with innumerable outliers of younger formations upon older. In some places the nummulitics would remain covered by a great thickness of newer strata, in others they would be worn away perhaps to nothing. Let us now suppose that a crushing sets in, a lateral pressure of the mountain mass acting since the deposition of the U. Siwaliks, and accompanied by reversed folds and fold-faults. Could we then have that irregular patch-work of strata falling into zones of formations of the regular kind I have described as actually existing? Could we then expect to see the long narrow outcrops of

the nummulitics and other strata continuing without alteration in thickness for a distance of thirty or forty miles? I think not; the outcrops of different beds would constantly impinge against the fault, so that the fault would now lie to the north of one formation, and now of another, whilst it would never continue for any distance inseparably connected with a single formation.

Thus, coming back to the state of things as they are in the region before us, I see no escape from the conclusion that the unvarying thickness of the *outcrop* of the uppermost member of a disturbance zone is the direct projection on the surface of the earth of a *deposit* of unvarying thickness from one end to the other of the exposure; that is to say, of a deposit that has never suffered denudation to any extent before the folding process began. But it is clear that, if the strata were not elevated above the line of deposition, they must have been depressed beneath it, and therefore in the act of forming, up to the moment of their upheaval and crushing.

The concrete result of this somewhat cumbrous argument is that we can supplement the inference that the five reversed faults in the Peláni R. were not contemporaneous, but successional, by the additional inference that the date of the production of each must have been a little later than that of the formation which lies to the south of each. Therefore, the southermost reversed fault in the Rámganga-Peláni section was produced, or at least completed, about the conclusion of the U. Siwalik stage; the next reversed fault about the conclusion of the M. Siwalik stage; the third reversed fault about the conclusion of the Nahan stage; the fourth about the conclusion of the nummulitic stage; and the fifth doubtfully at some period between the massive limestone and nummulitic stage.

Another important point in connection with this subject is that in nearly every case I believe the fold-fault to have taken place approximately near to the original shore-line or mountain-foot, as the case may be; so that these reversed faults are at the

Each reversed fault represents an ancient shore line, or mountain-foot; *i.e.*, a limit of deposition.

same time in a certain measure limits of deposition for the formation immediately south of each.

Northern limit of the Siwalik conglomerate.

Mr. Medlicott very early came to the conclusion that the nummulitic boundary, the main boundary, and the Nahan-Siwalik boundary were practically limits of deposition; and his reasons are so clear and decisive as to be convincing. Taking the youngest member of the Tertiary zone first, namely, the Siwalik conglomerate, no man having once looked at its geographical position would for a moment entertain the idea that it had ever extended in an unbroken sheet far away into the region of the Outer Himalaya. As early as the first quarter of this century Dr. Hugh Falconer, whilst collecting the vertebrate remains from the Sub-Himalayan hills, remarked on the similarity between the Siwalik conglomerate and the present deposits of the large rivers. He says[1], "If the beds of the Jumna and Ganges were to be upheaved in the "same way as those of former rivers, the appearance of the strata "would be exactly similar." Mr. Medlicott, carrying out the same idea, found in the course of mapping the area north-west of the Ganges that the Siwalik deposits varied according to their position with regard to the great rivers. He remarks[2] "in the range between "the Ganges and Jumna clays are very subordinate, and the conglo- "merates are composed of the harder quartzite pebbles, just like the "shingle now found in the great mountain torrents. This portion of "the range is in fact an ancient diluvial fan of the rivers Tons, Jumna, "and Ganges." A similar generalization holds in the country taken up by the present memoir. Between the Ganges and Rámganga, a short distance from the plains, there rises an elevated schistose area, crowned by a mass of gneissose granite forming the summit of Kálogárhi (Kálandánda), and without any important rivers draining south. Now, it is here that there is a corresponding absence of the U. Siwalik zone. The eastern termination of the Chándi hills represents the eastern limit of the deposits of the direct parent of the Ganges and

[1] Palæontological Memoirs, Vol. 1, p. 33.
[2] Manual of Geol. of India, p. 541.

for a long distance both U. and M. Siwaliks are absent. Beyond the Kho M. Siwaliks set in. As we near the Rámganga the narrow band of Siwalik conglomerate running from the Kotri stream to the former river indicates the very opposite of energetic torrent and river action in accumulating thick beds of coarse detrital material. On the other hand, at the debouchure of the Rámganga and the Kosi, we have once more a great thickening of the conglomerate; the wandering of the Rámganga to the west along the Pátli dún leaves in its train all that thick low range of conglomerate to the south as an indelible mark of its former activity. Again, the Kotah dún conglomerates are so palpably an ancient river fan spreading out from the present Kosi river-bed that they need no remark. Their eastern boundary at Káladhángi in a similar manner marks the limit of the Kosi's former activity in that direction; for there are no more conglomerates at the foot of the high Naini Tál hills where large rivers are absent.

Nothing is more clearly demonstrated in the whole range of Sub-Himalayan geology than the connection between the position of the debouchure of the present large rivers and the deposits of Siwalik conglomerate. That being so, we are bound to believe that these deposits were formed by the direct parents of those rivers, in the places where they are now found; and it would be as impossible to credit the belief that the conglomerates could once have extended far into the hills as it would be to find the Bhábar deposits in a similar locality.

Apart from these considerations, I have shown that the northern boundary of the conglomerate becomes undoubtedly an approximate limit of deposition in the section south of the Sanguri sót, and actually a real limit on the north side of the Kotah dún. Thus, the configuration of the southern margin of the Himalaya must have been very much what it is now in Upper Siwalik times. The absence of outliers to the north of the boundary is negative evidence favouring the same conclusion; but too obvious to be more than mentioned.

If we now take the fault separating the sand-rock from the

Nahans, we find that what is true as regards the original limitation of the Siwalik conglomerate is true also of that of the sand-rock, though in a less degree. The rivers then were not so exactly placed as they are now, but still their general disposition must have been very much the same.

The main boundary also a limit of deposition.

The main boundary between the Nahans and the older rocks to the north must also be looked upon, though still less absolutely, as a limit of deposition. The winding nature of this fault, as it follows the main curves of the Himalayan range, is the chief argument that we have to rely on here. In the case of many of the larger rivers we see an inbaying of the boundary towards the hills, corresponding to what would be a present contour line. Take a look at the geological map accompanying Mr. Medlicott's memoir, and see how at the north-west end of the region there is a sharp inbaying up the Ravi; then a steady line following the trend of the Dhaoladhar ridge; then a great inbaying, on a large scale, towards the debouchure of the Beas R. from the higher hills; and then a more or less steady line until the Jumna is neared, when another inbaying of the boundary takes place, followed by smaller bends between that point and the Ganges. That the same is true in the region covered by my own memoir is similarly apparent to the eye. Can a boundary such as this be anything but an approximate boundary of deposition? Can we for a moment suppose the Nahan zone a fragmentary relic of a great fold of the rocks which carried them once far above the Outer Himalayan mountain mass? Decidedly not; this moulding of the Nahans in and out among the irregularities of the older mountain mass is the natural result of deposition round a winding mountain-foot. The Himalaya must have stood roughly blocked out as they now stand when the Nahan sandstones were being deposited. We have already seen that the minerals of the sandstones tell the same tale; whilst the embedded mammalian remains point also to a limited deposit, with high land not very distant, from which the material was derived in which their remains were speedily and

regularly engulphed. Then, as now, there was a sub-tropical Bhábar zone at the foot of the Himalaya, where a mightier race of giant proboscidians, and other extinct vertebrates, trod the earth by the banks of rivers not so very unlike the Rámganga, the Ganges, the Beas and the Ravi of to-day, and which had their source in a range of central peaks of an outline much resembling those which now prevail.

Limits of the nummulitic zone.

With the nummulitic zone our proofs of a northern limit are rather weaker, and cannot be too much insisted upon here; but, considering the estuarine conditions under which they must have been formed, their rapid horizontal change in a northerly direction, as mentioned by Mr. Medlicott, near Sabáthu, and their tenacious restriction to heights of about 3,000 feet on the plainward face of the Himalaya, I think we are justified in denying that they ever existed over those higher tracts of the outer and central Himalaya, where never an outlier of them has been detected. That this general conclusion is not affected by their presence at 12,000 and 15,000 feet near the source of the Indus, and by the probability that there was a depression in nummulitic times running through Kashmir, connecting those deposits with the nummulitics of Hazára on this side of the main range, I shall shew later on. For the present I think there is sufficient evidence to prove that many, if not all, of the reversed fold-faults, which cut off each of the Sub-Himalayan zones to the north, are approximately coincident with limits of deposition; and that, therefore, they took place either along a shore-line or mountain-foot.

Physical aspect of the present mountain-foot.

And this argument is strengthened greatly by the behaviour of the present mountain-foot towards the deposits of the plains. There are not wanting signs that the southern margin of the hills has become, or is tending to become, a reversed fault. These are some of the signs. Nowhere along the whole length of the Sub-Himalayan zone can we point out a low, steady dip of the Siwalik conglomerate towards the plains; although it is absolutely certain that such a dip must have obtained on the first elevation of those strata. What has become of that southerly dip?

I think the question is best answered by reference to the south edge of the Kotah dún, where we have the Siwalik conglomerate very little disturbed as a whole, and therefore more likely to shew the preliminary stages in the development of any marginal fault that may occur. We see there at the south edge of the hills a rapid bending over of the beds towards the vertical, with even inversion as in the Ladwa gádh. That accelerated dip in the more disturbed areas of the Siwalik rocks further west has vanished, and the problem is, how? Taking a definite portion of the country south of the Pátli dún (see section V), what has become of the southern half of the normal (unsymmetrical) anticlinal in the sand-rock and Siwalik conglomerate, which we may assume by analogy was once present? There is no reason to suppose it denuded away entirely any more than the northern half; but there is strong reason for believing that, if we accentuate the earth movements which in the gently undulating area of the Kotah dún were nevertheless able to produce so sharp a bending to the south with slight inversion, we shall arrive, in the more crushed area of the Pátli dún, to a state of complete inversion and production of a fold-fault. The normal fold with its sharp "*dejettement*" to the south must result in an inversed fold, or sigma-flexure, when further crushing has supervened; and the latter will inevitably carry with it a fold-fault of the nature of those about which I have already written sufficiently.

I see no escape therefore from the general conclusion that, wherever the southern margin of the Siwaliks shews no relic of a "*dejettement*" to the south, it is because a fold-fault has supervened along what is now a limit of deposition for the Bhábar zone of gravels, sands and clays.

Contrast of the south face of the Himalaya with the eastern aspect of England.

How different is the structure of this fringing zone of Sub-Himalayan rocks from that of the eastern counties of England! As we travel inland from the shores of the North Sea, we ascend over strata successively older; our feet tread first the Tertiary or the post-Pliocene boulder clays, then the cretaceous chalk formation, then the Neocomian, then the oolites, and so on; whilst every one of these strata dips,

as a rule, beneath those of younger age, that is to say, towards the present region of deposition. Here on the margin of the Himalaya we have the *structure imbriquée;* we ascend from the plains over blocks of strata all dipping away from the present region of deposition, and, though each step or disturbance zone is older as a whole, the individual members are arranged in the opposite manner to what they are in England. There is no parallelism, there is no compromise, between the two countries; and the deduction that sober reasoners will draw from this is that either the nature, or the amount, of their disturbance must be very different.

Some other points of general importance may now be noticed.

Nature of the unconformability between the Siwalik conglomerate and the Nahans, south of Sanguri sot.

In describing the country to the south of the Sanguri sot I mentioned the occurrence of uppermost Siwalik conglomerates in most palpable unconformability on the up-turned edges of lowermost Nahans. A similar relation is also seen on the north and east sides of the Kotah dún and north of the Sára N. In other parts of the country, for instance, in the Rámganga-Peláni section, I pointed out a normal ascending series of strata without break from the base of the Nahans up to the top of the Siwalik conglomerate.

From the very many excellent river sections that I have observed I cannot persuade myself that this ascending series is anything but regular and conformable, and I think it unnecessary to assume, as Mr. Medlicott has done on similar grounds,[1] that the state must be one of apparent conformability only, with an undetected line of division between the two. As already stated by me, the immense thickness of the Sub-Himalayan deposits from the Nahans upwards, which average 16,500 feet in the area covered by this memoir, as well as other considerations, imply a long epoch of time; so that there is no anomaly in imagining their continuous deposition along one line, and a gradual and simultaneous crushing up of them along another adjacent line. Indeed, the evidence of the progressive and successional folding and faulting that have taken place throughout the Sub-Himalayan zone leads

[1] Mem. III, G. S. I., p. 104.

me very strongly to accept the view that the southern edge of the hills at the present day is a limit of disturbance in that direction, and that it was so during the ages when all the different stages of the Sub-Himalayan series were deposited. Thus I conclude that quiet and uninterrupted deposition was ever going on south of the southern border of the elevated land or mountain area, and that progressive slow and regular crushing was taking place north of that border. It can readily be seen that, by these processes, the apparent anomaly of great unconformability between the uppermost and lowermost beds of the series at one point, and of regular conformable sequence through that series at another, is accounted for—the great interval of time required for the deposition of the conformable series being represented by the gap in time implied by the unconformability.

The same reasoning would lead one to suppose that though the Recent gravels and alluvium of the river terraces are seen in many places to lie unconformably upon the edges of Siwalik strata, they may, nevertheless, be conformable to, and pass down into, the latter a little distance away to the south of the edge of the hills. The conditions for bringing about this state of things, when brought to their lowest terms, are simply a sinking or under-thrusting of the plains at the foot of the hills and a rising or over-thrusting of the hills themselves.

The disturbance of the Sub-Himalayan rocks not representative of that of the older rocks.

Another and a very burning question is, how far the disturbances evinced by the Sub-Himalayan zone are represented in the older Himalayan rocks. It is constantly assumed by many geologists in England that the immense contortions and inversions of the Sub-Himalayan formations express, in themselves, all the machinery of upheaval and contortion of the great Himalayan chain itself. This is a point I cannot concede. Even if, as is often assumed, the Himalayan and Sub-Himalayan sets of rocks shewed a perfect parallelism in their lines of disturbance, I should still be unable to subscribe to it. But, in the first place, such a parallelism does not exist *everywhere*. Over a great part of Kumaun there is a direction of strike running north and south. It begins in a set of basic volcanic and

micro-granulitic rocks which are folded, crushed, and cleaved by a pressure which has acted in an east and west direction. These rocks run from Bhuwáli near Naini Tál to Khairna, and the same line of strike is continued east of Ganai along another set of volcanic rocks up to and beyond Lobah, near which place, as I have described in the "Records," they are separated from the schistose area of Dúdatoli by a great fault running also north and south for a great distance, until near Chándpur Garhi where it turns away to the west. These two sets of rocks disturbed by east and west crushings are interfered with across the middle of their course by the schistose series at Ránikhet and Dwaraháth; but I think they are, nevertheless, connected. That line of north and south strike extends for about 60 miles, and makes an angle of 60° with the neighbouring strike of the Dúdatóli schists, &c.

Neither can it be considered to be due to a mere accidental variation of dip. The intensely crushed condition of the traps and micro-granulitic rocks about Khairna is of exactly the same order as that which I have described in the traps north of the Dúdatóli area. The crushing is one which has taken place in the cold and solid state of the rock. It has affected not only the finer crystalline portions of it, but also the amygdules present in the vesicles of the rock, which have become drawn out into shreds. It has cleaved the rock; and where larger crystals occur in the micro-granulite they have become eye-shaped by the same means. In some cases the rock is absolutely powdered up into dust.

More than this, this set of rocks at Bhuwáli is continued south nearly to the Góla R., interbedded with a few quartzites and slates. The strike of cleavage and bedding is, as before, north and south very nearly. Close by the Góla R. they come to an end suddenly by the Nahan sandstone, which is striking in an exactly opposite direction, and dipping towards the north at 65°.

The lines of disturbance, therefore, in *some* Himalayan rocks do not coincide with those of the Sub-Himalaya, nor with other Himalayan rocks, and must have been due to other and older directions of thrust.

But, besides the *direction* of disturbance not always being the same, the *amount* of it is very dissimilar in the two rock groups. The older rocks exhibit a very much more intense and prolonged crushing than the younger Tertiary rocks. This is represented by the dynamic metamorphism to which the former have been subjected. Examples of plutonic, volcanic, and sedimentary rocks which have all undergone intense crushing, with production of either cleavage, augen or lenticular-tabular structure in them, have been given by me in the Records.[1] Ordinary granite is very seldom to be met with: it has nearly always been converted into gneissose-granite, the individual felspars having been crushed into one another until the rock assumed a lenticular banded appearance. Some basic plutonic rocks have suffered in the same way. It is also difficult in many places to find a normal unaltered trap; and the rock is sometimes so much altered as to be scarcely recognisable. Quartzites, containing pebbles, have also been described as converted into quartz-schists; the different grains of quartz having been broken and run together into lenticular bands, like the crystals of felspar in the gneissose granite, and films of mica developed between them. All these peculiarities bespeak age and intense dynamic metamorphism. And there are no like evidences among the Sub-Himalayan rocks. The latter have been crushed and contorted as to their strata; they have been wrapped into immense sigma-flexures, and cut up by reversed faults; but of cleavage and dynamic metamorphism they show no sign.

In his memoir, Mr. Medlicott declared his belief in the distinctness of the disturbance which upheaved the main Himalayan chain, and the disturbance which in later times affected the Sub-Himalaya. He wrote[2] "These remarks lead me to the conclusion that the fea-"tures of disturbance in these youngest rocks have no direct connec-"tion with *the formation of the mountains*. But connection there "most decidedly is. I believe the disturbance of these rocks to be "entirely a *reflex* effect. As the composition of the Siwalik strata "and their enormous accumulation give evidence of the vast denuda-

[1] Rec., G. S. I., XXI., p. 11. [2] P. 169.

"tion to which the older Himalayan rocks have been subjected, so the "disturbance of these strata gives more positive evidence of a period "of *decadence* of the Himalaya. I can see no explanation of these "contortions but in the thrust from the mountain mass consequent on "the sinking of that mass." This was Mr. Medlicott's belief when he wrote the memoir. His later remarks in the manual are more uncertain, and he appears to leave it an open question whether the Himalaya were first contorted and upheaved in pre-Tertiary times, and then upheaved again; or upheaved first in the form of a "*bosselement*" or warp, and contorted only during the later Tertiary ages.

It will be seen from what I have written above that I so far agree with his former statement in the memoir as to believe in the distinctness of the disturbances affecting the Himalaya and Sub-Himalaya, respectively, in the part of the country examined by me; but I look upon it as one of degree and not of kind. Instead of the Himalaya sinking, I think they are still growing; and that the upheaval of the several bands of tertiary rocks is simply the result of a continuance in later times of the same earth movements that have for many ages before been upheaving the older formations of the Himalaya.

Other Hymalayan problems.

That there are many difficult problems concerning these mountains not yet satisfactorily disposed of, no one will deny. The word "Himalaya" is extensive in its application, and covers such vast regions that a uniform scheme of upheaval and contortion can only very doubtfully be applied to every part of it. There are one or two points that always have, and always will have, the greatest prominence in the consideration of any such scheme. These points are (1) the undisturbed position of Siwalik strata at 12,000 feet in the Húndes; (2) the presence of nummulitics in a rather more elevated position near the head-waters of the Indus, highly disturbed, and resting unconformably upon disturbed gneiss;[1] (3) the great sequence of unaltered sedimentary

[1] Mr. T. D. La Touche, Deputy Superintendent, Geological Survey of India, has recently described (Rec., G. S. I., Vol. XXI, p. 160) nummulitic bearing strata in Zánskar at an elevation of 18,500 feet, the greatest altitude at which these strata have hitherto been obtained *in situ*.

formations, ranging from Silurian to cretaceous, described by Stoliczka, and occupying heights up to 20,000 feet, in a very little disturbed basin to the north of the main gneissic axis of the Himalaya. These points have been discussed by Mr. Medlicott in the manual. Until Captain Griesbach's memoir on those and neighbouring regions is published, or until some other investigator brings forward more positive physical details concerning their arrangement than are at present forthcoming, it would be inopportune to discuss the subject again.

There is only one consideration that I would like to lay stress upon, namely, that if in any one or other locality, though all are embraced in the general name "Himalaya," there are found to be physical interpretations of the structure of the mountains differing essentially from those which have been attempted in this memoir, or from those of any other part, I would ask that not therefore on that account should one interpretation be held as disqualifying another; but that all be taken as applicable, each in the individual area with which it is concerned, until all the different localities have been so dovetailed together by further research that a fair and reasonable generalization can be undertaken, it may be on wider, more liberal, and more intricate principles than have yet been conceived.

CHAPTER VI.

GENERAL CONSIDERATIONS—*continued*.

Abstract theories of mountain-making.

Every worker in mountainous regions, besides keeping his eye on the ground beneath his feet, and keeping in mind the problems connected therewith, is naturally impelled to see in the inferences that he draws a justification of some, and a refutation of other, cosmical theories with regard to mountain ranges in the abstract; and especially is this the case when the geological structure he is engaged upon has been adduced by any writer in support of any one abstract theory of mountain formation. I therefore feel it a duty to say a word or two in this

connection, for every writer who puts forward a world-wide hypothesis of this kind should, and no doubt does, expect it to be confirmed or refuted by different labourers in their own fields.

The subject is of course a little discursive, and must lead one to consider principles as well as facts, and to touch on evidence derived from other countries. Let us then turn to a recent book, "The Origin of Mountain Ranges," by Mr. T. Mellard Reade, and see whether the structure of the Sub-Himalaya as interpreted in the foregoing pages of this memoir is in agreement or otherwise with that author's conclusions.

Considerations of Mr. Mellard Reade's theory.

Fortunately for the critic who has not unlimited space at his disposal the fundamental doctrine of "The Origin of Mountain Ranges" is easy to comprehend and tersely expressed; though unfortunately the argument is also terse, whilst the bulk of the book is taken up with descriptions and illustrations from many of the mountainous regions of the earth, which seem to me to be only sometimes relevant to the theories propounded, and with laboratory experiments, which I think are too artificial to be taken seriously as working models of the crust of the earth. With reference to the latter it is manifestly impossible to produce with the means at our disposal the condition of rocks at great depths and under the enormous pressure to which they must be subjected. Matter there must be in a state of which we have no experience, and attempts at imitation can at the best be but caricatures.

The key-note of Mr. Mellard Reade's book is that mountainous regions have been areas of great sedimentation, both vertical and horizontal—a sedimentation which is supposed to have raised the isogeotherms among the mass of those sedimentaries, thereby producing expansion by the increased heat. Thus it comes to pass that great sedimentation is the forerunner of upheaval, and also a factor in the *cause of it*. It must be noted here that the author gives no proof that sedimentation raises the isogeotherms, but merely states that "in 1834 Babbage . . . . pointed out that the addition of

"sediment to any part of the earth's crust must raise the temperature of "the portion of the crust it covers"[1]; and later, that Captain Dutton, of New Zealand, accounted for the anticlinal of the Weald through the rise of the isogeotherms caused by sedimentation.[2] Now, it is easy to see that, if a trough-like sea, of a certain depth, becomes gradually shallower and shallower as sediment is poured into it, there will be a rise in temperature of what was once the bottom of that sea; but all cases of great sedimentation cannot be considered in this simple form. No one will suppose that the accumulation of 20,000 or 30,000 feet of strata took place in a sea which was once of that depth and which gradually became silted up. Great sedimentation of this kind can only take place by concomitant sinking of the sea bottom; so that the rise of the isogeotherms being interpreted means merely the sinking of the floor on which the deposits were laid down. At page 266 the author recognises this when he says "the accumulation "of a great thickness and extent of sedimentary deposits pre-supposes "subsidence of large areas—regional subsidence as it may be called." If therefore great sedimentation is the cause of mountain-building, since subsidence is the cause of sedimentation, or rather its necessary accompaniment, then great depressions of the earth's crust must be looked upon as the ultimate condition or accompaniment of mountain-building; that is, a subsidence of the earth's crust is either the cause or accompaniment of a rising in the same locality, which is absurd As well might one say that the defeat of an army in one battle is the cause of its victory in the next; or that the greater the piles of dead in the one the greater the triumph that will follow.

Again, the author, in endeavouring to account for the subsidence, continues (page 270)—"If we assume, as we have reason to do, that "the heated interior of the earth below the crust, solid only by pressure, "is subject in large masses to change of volume by change of tempera-"ture, caused by re-combination [chemical combination?] of matter "taking place from time to time, many difficulties can be explained.

[1] Page 89.
[2] Page 90.

"An almost infinitesimal change of bulk, if the mass be large enough, "would explain what to our eyes seem stupendous movements." The author here asks for a great assumption, and one which, if granted, gives the necessary power to *upheave* as well as to *depress*. Change of volume by change of temperature is all that is wanted to account for the excrescences of the earth's crust which eventually form into mountain ranges. Where therefore, along with the assumption, is the necessity for the cumbrous machinery of great sedimentation, and rise of the isogeotherms, which the author makes the chief point in his argument? Even supposing great sedimentation had the enormous effect which the author advocates, it must cease to act when the sea level is attained. When, therefore, sedimentation has ceased, where is the power to urge those horizontal sedimentaries into the mountainous form? When they have attained the form of shoals or sandbanks, no further deposition can go on, and therefore (by the author's supposition that sedimentation is the great cause of upheaval) the isogeotherms would cease to rise, expansion of the lower beds would remain as it was, and there would be no further development of mountain-building forces. I see no way out of this difficulty unless it be by the rather grotesque assertion that mountains must therefore be formed subterraneously: a subterranean mountain, however, is somewhat of a contradiction in terms. I regard, therefore, this theory, that great sedimentation is the cause of mountain upheaval, as incompetent and self-contradictory.

Though it is like beating a corpse to say more, there is one simple way of refuting the theory which I may indicate. A thickness of eight miles of Cambrian and Silurian strata is urged by the author[1] as the sedimentation which brought about the upheaval of the mountains of Wales. Now, if eight miles of rock produced this effect, surely half that amount, or four miles, must have had an effect in some proportion; therefore, when four miles were laid down there ought to have been a mountain range asserting itself, not so high a one perhaps, but sufficient to stop all further sedimentation in that

[1] P. 30.

area. How then were the other four miles of strata deposited above them? Put briefly, the objection to the theory is this, that, if sedimentation had the effect claimed for it, it would very quickly defeat its purpose by stopping sedimentation in that area.

Again and again we find the author declaring with fresh assurance that it has been proved that mountain ranges have been areas of great sedimentation. In answer to this I would urge that it is only in mountainous parts that great thicknesses of strata can be actually observed by us; and that we frequently know nothing of the depth to which the sedimentaries reach beneath the flat or gently undulating areas of continents.

Finally, even if great sedimentation should be proved to be a characteristic mountain feature, I should rather regard it as the effect than the cause of the mountains. Denudation acts more powerfully on a mountainous region than elsewhere, for obvious reasons. Thus, the sedimentaries might be thicker in the neighbourhood than far away. When, therefore, further upheaval of the mountain mass goes on, these strata will be incorporated with it, and fresh ones then deposited. The core of the mountain range in a rising area is ever being converted and redistributed in the form of fresh sediment round about the flanks, which then once more are upheaved. So that, as in the case of the Himalaya, the range continues growing by fresh additions to itself, like a coral, by the incorporation of its offspring with itself.

But leaving these generalizations, which I have shewn to be fallacious, let us turn to more concrete statements regarding actual mountain ranges. In Chapter V, Mr. Mellard Reade writes—"It has "been a subject of wonder to more than one eminent geologist that "all the greatest mountain ranges are, geologically speaking, so com- "paratively modern. The Himalaya, the Andes, the Alps and the "mountains of the Caucasus have been to the larger extent upheaved "in Tertiary times." The reason he gives for this is that the youngest mountain ranges have been less exposed to destructive denudation, which has, on the other hand, almost levelled all the ranges of moun-

tains which were crushed up during the earlier periods of the earth's history. A few lines further he adds—"this great truth remains that "it is impossible to point to a range of mountains which have been "built up of old denuded rocks. Old rocks certainly accompany and "form part of all great mountain-ranges; but they are only discover- "able through the removal by denudation of the enormous masses of "more modern sediment with which they were originally covered. . . " . . . If we could point to *one* example where a mountain-range had "been built up solely of old rocks that had long suffered denudation, "and remained at their upheaval uncovered by newer sediment, the "significance of this association of great sedimentary deposits with "mountain-building would be considerably weakened."[1]

Among particular examples in illustration of the above principle he says, referring to India, that the "Tertiary [system] alone, "measuring 30,000 ft., has been upheaved and carved by denudation "into the greatest mountain system of the globe—the Himalaya."[1]

If it be borne in mind that the principle and the supposed facts alluded to here by the author form an important part of his reasoning throughout the whole of his work, it will be seen how necessary it is that there should be no doubt whatever of the validity of either the principle underlying his argument, or of the facts that he brings forward in support of it.

Now, with regard to the greatest mountain-ranges being, geologically speaking, comparatively modern; there is one consideration which the author does not seem to have taken any account of, namely, that to begin with a mountain-range must grow; and that we should therefore expect to find some mountain-ranges, not yet completed, which would be still more modern and of very low elevation. It has been pointed out by Prof. Judd that the life history of crystals in many respects bears a great resemblance to the life-history of animals and plants: they have their time of birth, of growth to maturity, and their ultimate decay and disintegration. And, without adopting

[1] Page 30.
[2] Page 73.

any theory or prejudicing any, it seems to me that a mountain-range must have in some sort a life-history, which may, in common with that of animals, plants and crystals, be divided into periods of growth, of maturity, and of decay. Long ago, as the result of the principles established by Sir Charles Lyell, cataclysms such as would heave a mountain-chain into immediate being have been discarded as preposterous fables only fit for the childhood of geology. Whatever be the view of the cause and the mode of working of the forces which wrinkle up the earth's crust into the majestic plications forming most of the larger ranges of the world, there is but one unanimous opinion that it came about gradually and not abruptly. But in this process of growth a mountain-range is opposed by the action of denudation. It therefore follows that, if a mountain-chain is to rise at all, it must be by its inherent growing forces, whatever they may be, ever becoming more and more intense and winning in the struggle with the opposing forces of denudation; and it also follows that, if ever a mountain-chain is to succumb to the levelling processes embraced by the general term denudation, it must be by the inherent growing forces of the mountain having reached their maximum, and having in turn become feebler and feebler until finally they are altogether extinct, and the once stupendous mountain is worn down to the level of the sea.

So far I have no doubt Mr. Mellard Reade will go with me; he, in common with every one, must admit that the loftier mountains of the world must be at, or near, their maturity; whilst those of less altitude must be either on their way to become more lofty, or must be declining after having reached their maximum of elevation:—*herein lies the real difficulty, namely, to distinguish between a mountain-range progressing towards full development and one retrograding towards extinction.*

It therefore seems in the highest degree improbable that the greatest mountain-ranges are, geologically speaking, comparatively modern. On the contrary, we should expect that being at the period of their fullest development they must be, geologically speaking, of

decidedly mature age. If we wish to see the aspect of a comparatively modern mountain, we have only to look at some cases which admit of no doubt, such as the chalk wolds of Yorkshire and Lincolnshire, which must have been elevated and slightly disturbed previous to the Post-Tertiary deposits of the low country nearer the sea. There we have an example of what can be accomplished in the lapse of time between the beginning of the Tertiary period and that of the glacial epoch. The Pennine Chain may next be cited as an illustration of a mountain-range which is older than the chalk wolds, but which is probably still in the process of growing. It has been subject to the elevatory forces of crushing and folding during Secondary and Tertiary times; and has been successively wrapped round on its east, west, and south sides by new formations; all of which have in turn been elevated, in order and degree, more or less directly proportional to their age. The Pennine Chain is more elevated and more folded than the chalk wolds; and this seems to be simply because the forces have had a longer time for working in in the former than in the latter case. Finally, the older Palæozoic rocks rise into the highest form of mountain structure which we have in England. On the other hand, much of the older Palæozoic country of Wales and the Lake district is lower than that of the Pennine Chain; and the reason for this is perfectly evident. High as are some parts of the Cambrian and Silurian area, it is probable they are not so high as they once were. These mountains would seem to be retrograding towards extinction; denudation is gaining on the forces of upheaval, so that in parts they have sunk to a lower level than the growing area of the Pennine Chain.

Let us now examine the next paragraph quoted by me. Mr. Mellard Reade says—"it is impossible to point to a range of mountains "which have been built up of old denuded rocks." I find it difficult to understand the form of thought which could induce such a statement. Unless there be some hidden meaning in the words "built," "old," or "denuded," I should regard the very opposite of this statement as the great residual truth. Using words in their plain significance,

I think few will doubt that every large mountain-chain is built up of a body of Palæozoic and crystalline rocks, merely flanked and sometimes partly covered by Secondary and Tertiary rocks; whilst, on the contrary, non-mountainous country is, as a rule, composed essentially of the younger formations. Continuing the quotation above, we learn that "old rocks certainly accompany and form part of all mountain-"ranges; but thay are only discoverable through the removal by denu-"dation of the enormous masses of more modern sediment with which "they were originally covered." He illustrates this by pointing to India and saying "the Tertiary (system) alone, measuring 30,000 ft., "has been upheaved and carved by denudation into the greatest moun-"tain system of the globe—the Himalaya."

To the uninitiated reader the above remark would at once raise the belief either that the only rocks found in the Himalaya were of Tertiary and Recent date, or that older rocks, if found at all, would only be discovered in the bottoms of ravines cut out by river erosion, or along anticlinal axes: it would most certainly invoke a vision of the Himalaya roughly blocked out of Tertiary strata. Now, what is the real state of the case? Over the greater part known to us it is this: the Himalaya, rising to about 25,000 feet in height, are composed chiefly of ancient gneissose granites, gneisses, granulitic gneisses, and crystalline schists down to a level of about 10,000 feet. Below that, over a vast area called the Lower Himalaya, there are chiefly quartzites, quartz-schists, traps and slates down to the 3,000 feet level. There is then a narrow band of rocks averaging only about 12 miles wide lying between the 3,000 feet level and the plains, which is in reality composed of Tertiary rocks, namely, those forming the subject of this memoir. If we could survey the Himalaya from some great height above them, and a cataclysm were to take place completely obliterating the Tertiary rocks, we should be quite unconscious of it. It would in fact be a mere flea-bite to the Himalaya as a whole.

Ridged one behind and above the other, the Tertiaries may be said to rise from the plains in height and distance according to their

antiquity, the oldest being highest and further away. They are a series of steps formed in a measure like the gravels of a river-bed which are left by the cutting of the channel, at heights proportional to their ages, but, unlike them, depending for their different elevations not on the sinking of the plains but on the further crushing up of the Himalayan area.

In Chapter V I have sufficiently disposed of the view that they can ever have extended to any appreciable distance beyond their present areas into the Higher Himalaya.

The intermittent deposition, therefore, of 16,000 feet of them at the margin of the Himalaya was certainly not the cause of the upheaval of the Himalaya. On the other hand, it was due to movements of the mass of the Himalaya themselves that they owe their present elevated and compressed state. They therefore were the sufferers by, and not the originators of (except in an indirect sense to be presently mentioned), a continuing upheaval of those mountains, be that movement due to whatever far-reaching cause it may.[1]

But I have already occupied too much space in this connection and must take leave of Mr. Mellard Reade's book, which, with the exception of the doctrine taught, is an admirable colligation of facts from many lands about mountain structure.

The Rev. O. Fisher's "Physics of the Earth's Crust."

There is one other recent work of a theoretical nature, about which I should like to say a few words. It is a pleasure to turn to the Rev. O. Fisher's "Physics of the Earth's Crust," a treatise published in 1881; for, as regards many of the subjects discussed in it, I feel myself entirely on his side. Opinion may be divided concerning some of the quantitive results that he has obtained by mathematical methods o treatment; but every one must admire his lucid and correct reasoning on the facts which he takes for granted. He makes two geological references to the Himalaya, which I may here quote, for it will be

[1] Since writing the above I find a somewhat similar position taken up by Dr. C. Ricketts (Geol. Mag., April 1889), with reference to Mr. Mellard Reade's theory. In addition, he concludes by expressing a belief in the permanence of the "core of the mountains" of Britain through many oscillations of upheaval and depression.

shewn that the views he enforces by these Himalayan examples are still more completely borne out by the results obtained by me.

His first reference is introduced by way of shewing that the crust of the earth in mountain regions has suffered lateral compression as distinguished from vertical up and down movements. He writes, p. 43,—"To take an instance of the mode of action of lateral pressure, "we may refer to the very instructive comparison between the Alps "and the Himalayas which has been made by Mr. Medlicott and pub- "lished in the 'Journal of the Geological Society'.[1] He there shows "that the reversed apparent faulting by which the older rocks of the "central chain of the Himalayas appear to overlap the younger of the "Nahan range, and these again the still younger rocks of the Siwalik "range, is due to lateral pressure, which must have compressed the "rocks horizontally, at least at two distinct epochs since the central "chain was first elevated." From what I have said in previous chapters on the subject of the five reversed faults in the Peláni R., and their formation at successive periods, it will be seen that at least in that locality five distinct compressions have acted, resulting in horizontal thrusts of the growing mountain mass towards the plains. The Sub-Himalayas, therefore, are really richer in examples of lateral pressure than Mr. Fisher supposed when he wrote his book. If he had produced it a few years later, he would have been able to add the very striking examples of horizontal thrusts that have lately been worked out with great patience and skill in the north-west highlands of Scotland by Prof. Lapworth, Messrs. Peach and Horne, and other officers of the Geological Survey of Scotland. Still, in drawing that inference from the Himalaya, he drew one which further work among those mountains has only succeeded in making the more apparent.

His second reference includes the Himalaya as evidence against the theory of the entire solidity of the earth. The instability of the earth's crust, the shifting of the crust towards a mountain range, and the sinking of deltas and other regions of deposition, go to shew

[1] Vol. XXIV, p. 34.

that the crust is in a "condition of approximate hydrostatical equili-"brium, such that any considerable addition of load will cause any re-"gion to sink or any considerable amount denuded off an area will "cause it to rise," and, therefore, that there must be a "fluid substra-tum" on which the crust floats. He writes, p. 80,—"The Himalayan "area presents some peculiarly interesting features in this connection. "The Sub-Himalayan range consists of tertiary strata which are now "highly disturbed. All, with the exception of the lower portion, which "is nummulitic and consequently marine, are composed of sub-aërial "deposits, formed by detritus brought down by torrents from the "Himalayas. These deposits are together between 12,000 and 15,000 "feet thick. The sandstones, which form the chief portion of these "beds, and the red clays which are intercalated with them, are exactly "like the alluvial deposits of the plains. 'Thus it was suggestive, and "not altogether misleading, to say that the Siwaliks were formed of an "upraised portion of the plains of India.'[1] The surface movements in-"dicated by this history suggest a level area at the foot of the Hima-"layan range, sinking continuously during the former part of the "tertiary period. Then a great movement of lateral compression and "elevation took place. Again it sunk, and unconformable beds were "deposited. These were again elevated and compressed. Such at "least appears to be the interpretation of the description given by "the surveyors. But the point which is material to our present subject "is the sinking of the land surface to the depth of nearly three miles, "while river deposits to that thickness were being laid down; the "whole being denuded off mountains whose spoils have in more recent "times provided materials for the great plains of India, and still "those mountains stand the highest in the world. That a sinking of "the area of the plains of a similar character is yet in progress, is "shown by the boring at Fort William, near Calcutta, in which to "the depth of 400 feet fresh-water deposits occurred. The con-"clusion seems irresistible that corresponding to the long, though "occasionally interrupted, depression of these plains, a correlative

[1] Manual of the Geology of India.

"elevation of the great range which has supplied the deposits has "been going on."

I need scarcely remark that the tendency of the general results which I have obtained is to strengthen this conclusion. I have shown indisputably that the margin of the Himalaya in all ages of the Tertiary period has been a line of weakness advancing slowly towards the south; on one side of which the strata have been thrust southwards and upwards, and on the other side of which they have been thrust northwards and downwards. And not only this but I have given proof in the section south of the Sanguri sót, and in those north of the Sára N., that the sinking of the plains and the rising of the hills was not an alternating phenomenon as if the one were the forward and the other the backward swing of a pendulum, but that both went on at one and the same time.

Therefore, by the regularity of the folds and the fold-faults which have affected the Sub-Himalaya, by their parallelism, and by the parallelism and uniformity of elevation and aspect of the different zones between them, by the regular succession of the fold-faults in time through all the ages of the Tertiary period, and by the presence of one in the act of forming between the Recent deposits of the plains and the edge of the hills, it is abundantly evident that further additions of sediment at the foot of the mountain-land was always accompanied by a sinking of that part and a rising of the denuded area, through the whole of the Tertiary period, and probably through the individual ages represented by each rock stage.

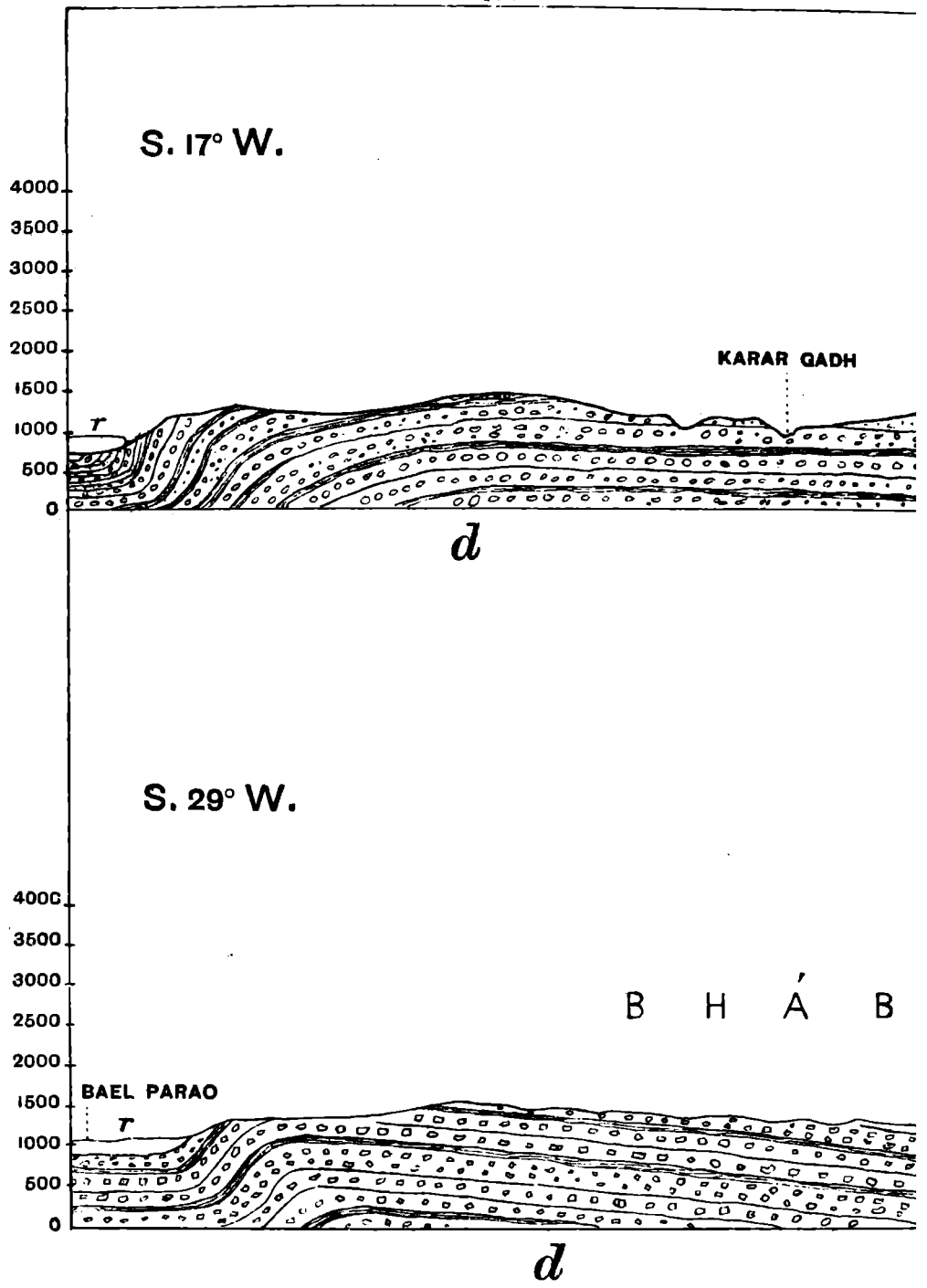
Recent Himalayan research, therefore, in this direction goes to establish the fact that the crust of the earth is extremely sensible to changes of load on it, that it rises when relieved, and sinks when over-burdened; and that, therefore, we must adopt some such supposition as that of the author of the "Physics of the Earth's Crust," namely, that a "fluid substratum" exists at some depth beneath the surface in which that crust floats in approximate hydrostatical equilibrium.

INDEX TO HORIZONTAL SECTIONS.

r = *Recent.*			
d = *U. Siwalik Conglomerate*	Siwalik series	SUB-HIMALAYAN SYSTEM	
c = *M. Siwalik sand-rock*			
b = *L. Siwalik Nahan sandstone*			
a = *Nummulitic*	Sirmur series		(TERTIARY).
n = *Tál series*	Mesozoic	YOUNGER HIMALAYAN SUB-GROUP	(MESOZOIC)
m = *Massive Limestone*	Age unknown		
x = *Purple slate*	Age unknown	OLDER HIMALAYAN SUB-GROUP	(PALÆOZOIC?)
y = *Volcanic breccia*	Do.		
z = *Crystalline schist*	Do.		
t = *Trap.*			

INDEX.

G. I. C. P. O.—No. 22 D. G. Survey.—1-5-90.—400.


S. 17° W.
4000
3500
3000
2500
2000
1500
1000
500
0
KARAR GADH
r
d
S. 29° W.
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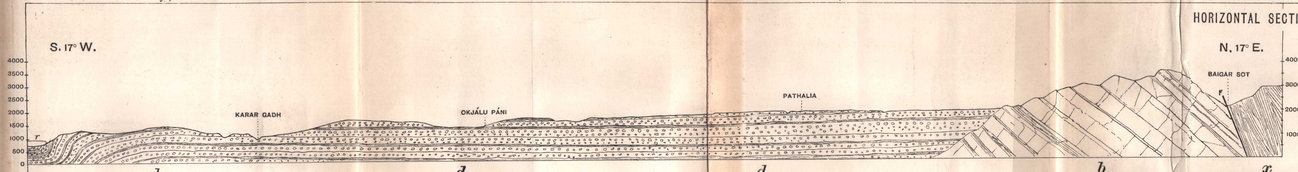
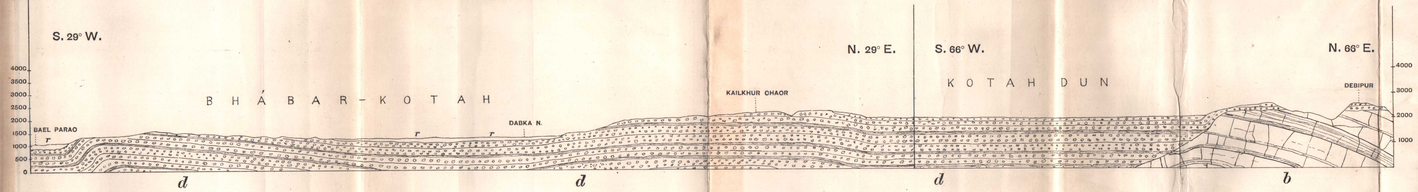
3500
3000
2500
2000
1500
1000
500
0
B H Á B
BAEL PARAO
r
d

HORIZONTAL SECTIONS, SHEET I.



SECTION I. ACROSS THE EAST END OF THE KOTAH DUN.



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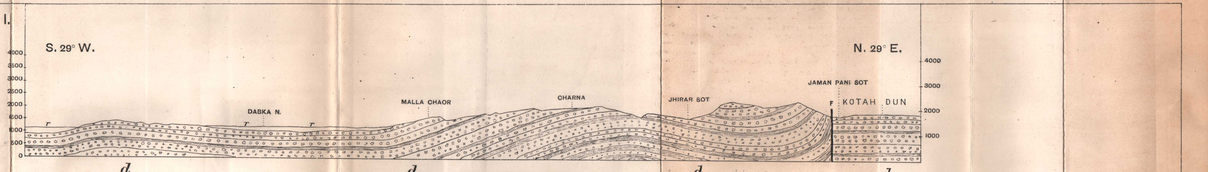
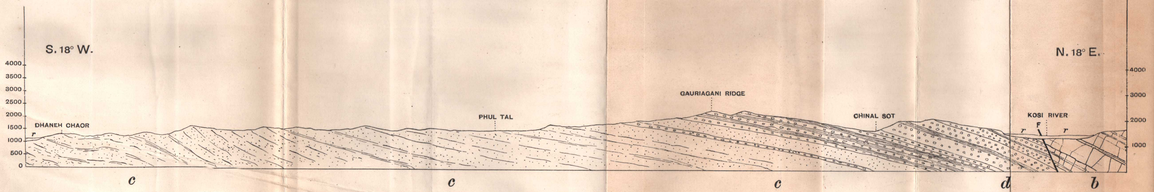


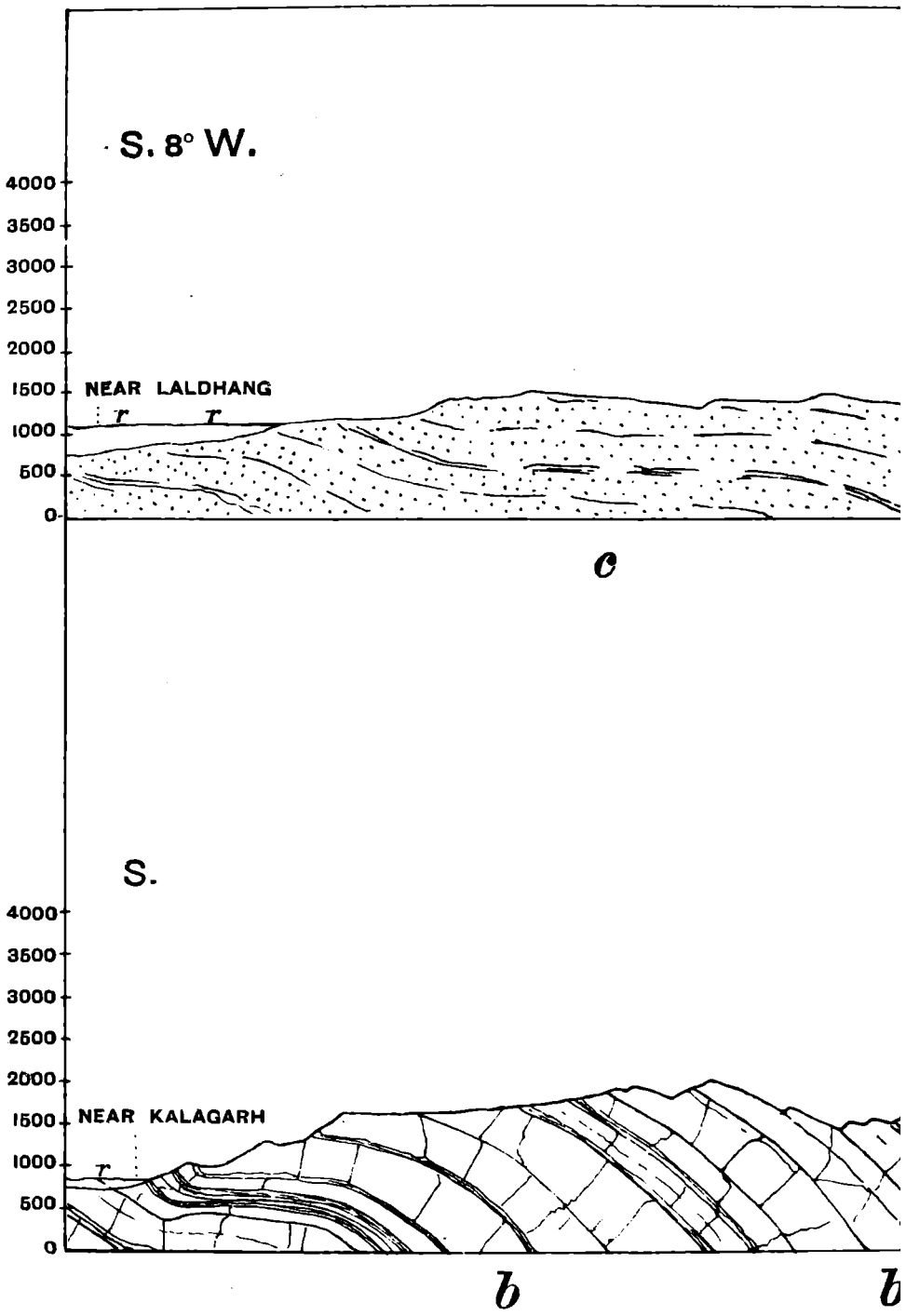
SECTION III. WEST OF THE KAILKHUR HILL.



SECTION IV. WEST OF RÁMNAGAR.

Horizontal and Vertical Scale, 2 Inches = 1 Mile.

Lithographed at the Survey of India Offices, Calcutta, December 1895.


S. 8° W.
4000
3500
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2500
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1500
1000
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0
NEAR LALDHANG
r
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c
S.
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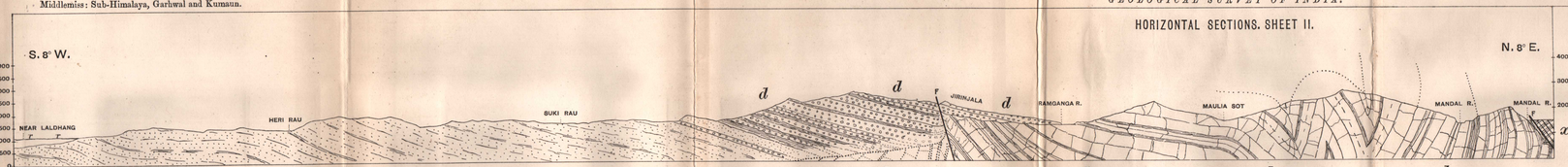
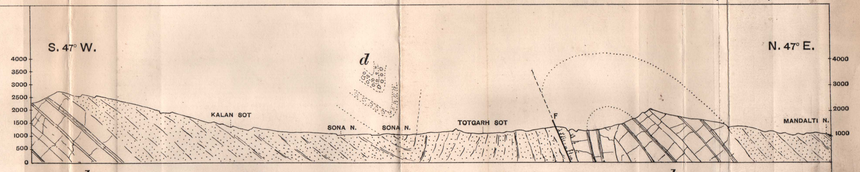
2000
1500
1000
500
0
NEAR KALAGARH
r
b
b

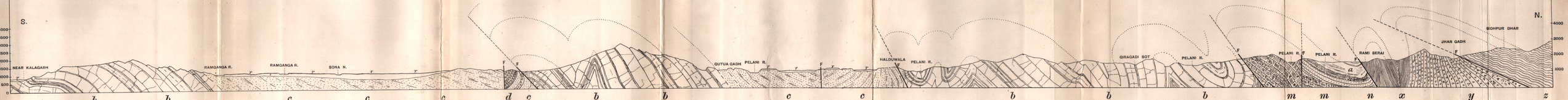
HORIZONTAL SECTIONS. SHEET II.



SECTION V. ACROSS THE COUNTRY BETWEEN THE KOTAH AND PÁTLI DUNS.



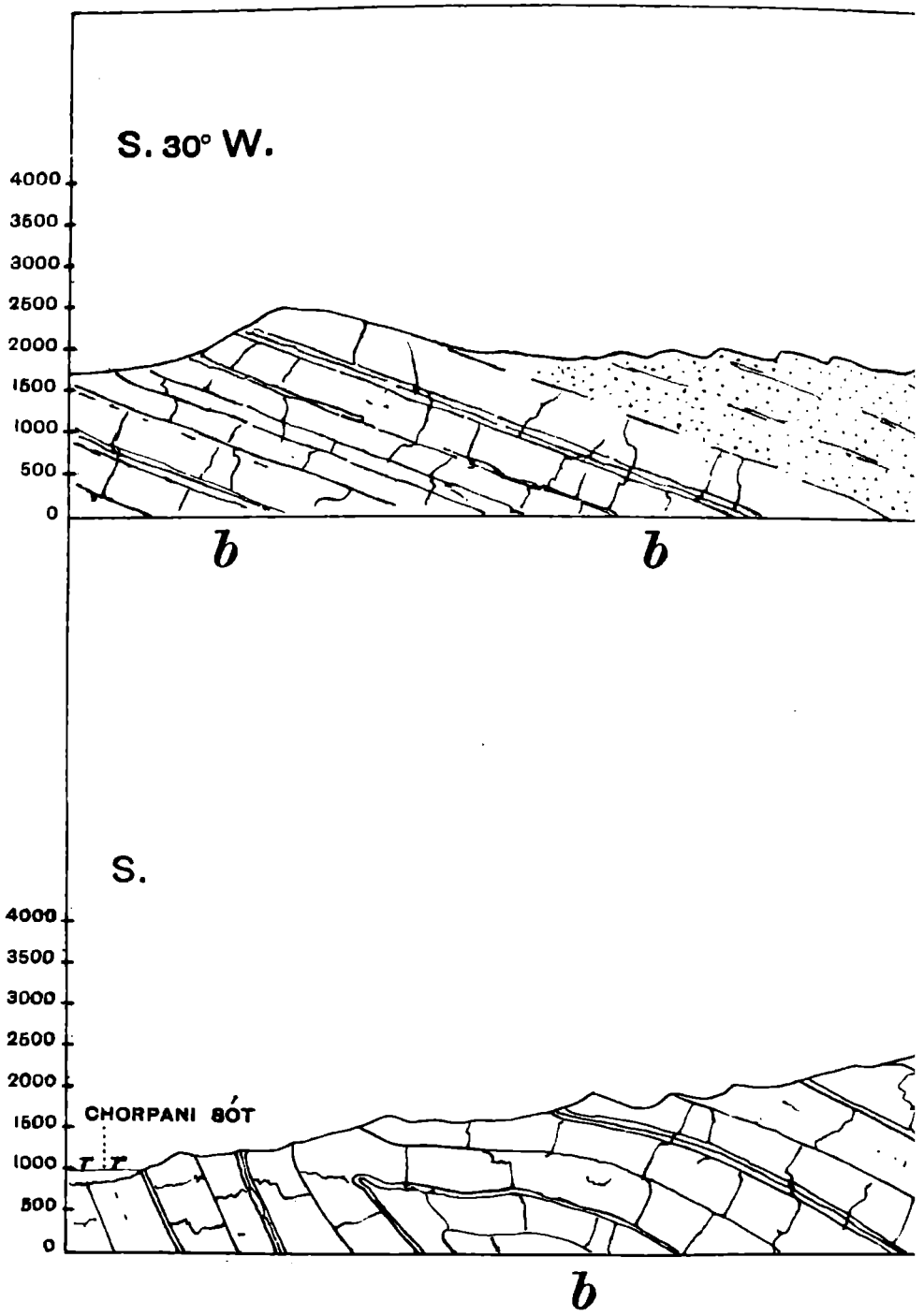
SECTION VII. ACROSS THE SONA N.



SECTION VI. ACROSS THE SUB-HIMALAYAN ZONE; EXHIBITING ITS RELATIONS TO THE OLDER ZONES.

Horizontal and Vertical Scale, 2 Inches = 1 Mile.

Lithographed at the Survey of India Offices, Calcutta, December 1893.



Reg. No. 2556, Geol. Sur.—18-7-89.—410.

HORIZONTAL SECTIONS: SHEET III.

Horizontal and Vertical Scale, 2 Inches = 1 Mile.

Litho., S. I. O., Calcutta.

Geological Map
OF THE
GARHWAL AND KUMAUN
SUB-HIMALAYA.

Scale 1 Inch = 4 Miles.

Miles

INDEX.

U. Siwalik Conglomerate.	Siwalik Series.	Sub-Himalayan System.	
M. Siwalik Sand-rock.			
L. Siwalik (Nahan).			
Nummulitic.	Sirmur Series.		
Tál.	Miocene.	Younger Himalayan Sub-group.	
Massive Limestone.	Age unknown.		
Purple Slates.	Do.	Older Himalayan Sub-group.	
Volcanic Breccia			
Crystalline Schists.	Do.		

NOTE.

The uncoloured portion to the North of the main boundary represents Himalayan rocks which do not come within the scope of this memoir.

Fault-lines represented.

Anticlinals

Synclinals

Ordinary dips 25°

Inverted dips are represented in their resolved directions by angles greater than 70°; thus S. 15° = inverted to the N. 75°

Surface geology is not depicted within the boundary of the hills; and the recent deposits of the Bhabar & Tarai, South of the hills, are left white.

Places referred to in Memoir but unnamed on map (20)

Taken from Sheets Nos. 53 S.E., 54 S.W., 57 N.E., 58 and 62 N.W., of the Atlas of India.

Reg. No. 2565. Geol. Sur.—8-11-89.—410.

Lithographed at the Survey of India Offices, Calcutta.