MEMOIRS

OF THE

GEOLOGICAL SURVEY OF INDIA.

VOL. XXVIII.

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

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SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY.
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MEMOIRS

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THE GEOLOGICAL SURVEY OF INDIA

Notes on the Geological Structure *of the* Chitichun region, *by* Dr. Carl Diener, *Professor of Geology at the University of Vienna.*

Mr. Griesbach [1] has shown that the structure of the Chitichun area corresponds, roughly speaking, to a complicated synclinal, formed by Spiti shales and Gieumal sandstones and bordered on three sides by triassic folds, "namely, the range which runs from the Lahur to Chidamu on the west, the high peaks and ranges which form the Chitichun No. II (19,550 feet) and Dharma peaks on the south, and the long ridges, with fine precipitous cliffs, which extend from the Chanambaniali peaks (18,360 feet) to northwards, and shut off the Chitichun ground from the widely extended hilly area, chiefly formed by mesozoic rocks, which are seen to stretch to north-east and north towards the Sutlej river."

Although the bedding of the mesozoic strata comprising the Chitichun area is considerably disturbed and much crushing, especially in the Spiti shales, may be observed locally, they all form an apparently normal sequence, without any distinct unconformity or break between them.

Jurassic beds.—Between the mighty system of upper triassic limestones and dolomites (Griesbach's rhætic system), which are the Himálayan representatives of the Alpine "Dachsteinkalk" (in the sense

[1] Records, XXVI. pp. 19—25.

of the Austrian geologists) and the jurassic Spiti shales, the dark brown or Indian-red pisolites of the Kelloway are exposed in most of the sections which we were able to examine during our visit to this part of the Himálayas. The best exposures of these pisolites have been met with on the western slope of Chanambaniali. For these beds the name "Sulcacutus beds" has been recently proposed on account of their leading fossil, *Belemnites sulcacutus*, Suess, of the *bisulcati* group. They were regarded as lias by Griesbach in his preliminary notes, but the fossils, which have meanwhile been examined by Dr. F. Suess, are all dogger forms. According to Dr. Suess, the Sulcacutus beds are most probably representative of the European Kelloway. Of the Spiti shales and Gieumal sandstones Griesbach has given an excellent description, to which I have but little to add. The three divisions, which, according to Griesbach, can be distinguished among the Spiti shales, are not equally well respresented in the Chitichun area. The upper horizon, for which the name Lochambel beds has been introduced, is most typically developed. It is near Lochambelkichak encamping ground (south-east of Chitichun No. I), that the beds of this horizon are richest in fossils of the youngest jurassic type (stage of Berrias).

Gieumal sandstones. Flysch.—The overlying Gieumal sandstones are connected with the Spiti shales by a gradual passage. In the vicinity of the Kungribingri Pass (18,300 feet) their lowest beds actually alternate with Spiti shales, from which it results that the main bulk of the Gieumal sandstones must be cretaceous, although Stoliczka considered them to be of upper jurassic age. Lithologically this mighty formation represents a typical Flysch development, strongly recalling in its chief characters the Alpine or Carpathian flysch. A few traces which might be crushed belemnites, are the only organic remains which have been hitherto found in this system along the Kumaon-Tibet frontier.

Diabase porphyrite.—Both the Spiti shales and the Gieumal sandstones are intimately associated with intrusive igneous rocks in the Chitichun area. Herr C. von John, Director of the chemical department of the K. K. Geologische Reichs-Anstalt in Vienna, who kindly examined the rock-specimens, which I collected near Sangcha Talla encamping ground, declares this igneous rock to be a diabase-porphyrite.

"*Klippen*" *or Crags.*—The younger mesozoic beds, which form the complicated synclinal of the Chitichun area, are capped here and there by massive limestones, which either seem to rest conformably on, or are imbedded in, the soft jurassic shales in the shape of detached blocks. Some of these masses of bright or reddish, often semi-crystalline limestone, are eroded into picturesque cliffs, or crags rising in sharp pinnacles and partly bordered by precipitous walls. By their material and outlines they differ remarkably from the dark, rather monotonous, undulating hills, composed of shales and sandstones, and thus form a very peculiar feature in the scenery of the country. These limestones do not rest normally on the mesozoic strata, but are partly of palæozoic, partly of triassic age, as has been proved by a careful examination of their fossil contents. It is their occurrence amidst much younger sediments and without apparent stratigraphical connection with the latter which makes the structure of the Chitichun area one of the most intricate and most remarkable in the Central Himálayas.

Mr. Griesbach in his preliminary note on this subject has called attention to the similarity of these limestone crags with like outcrops of older sediments (namely, of triassic and jurassic age) in the Alpine and Carpathian flysch, which have been described as *Klippen* in scientific literature. The correctness of this view has been doubted[1] but the doubts can no longer be maintained since the publication of the palæontological evidence.

The most northern of these peculiar limestone crags, which were examined by our expedition in 1892, are those situated between the Balchdhura and the Kiogarh-Chaldu pass (17,440 feet). Here the dividing ridge is composed of Gieumal sandstones and crowned by

[1] See foot note in Records, XXVI, p. 25.

a steep escarpment of limestones, which seem to overlie comformably the sandstones at their base. In 1879 Griesbach visited the Balchdhura and believed the limestone to be of upper-cretaceous age[1], corresponding to Stoliczka's Chikkim limestone, which in Spiti follows immediately above the Gieumal sandstone.[2]

We shared in this view, when passing along the southern slope of the range towards the head-waters of the Kiogadh river on the 12th and 13th of July, being likewise under the impression of an apparently normal position of the limestone cap above the underlying flysch. It was only after our discovery of the permo-carboniferous and triassic limestone crags near Chitichun encamping ground, that we began to doubt the correctness of our former opinion. We therefore resolved to revisit the Balchdhura on our trip from Laptal encamping ground to the Shalshal cliff, and succeeded in examining the most western of the limestone peaks which form the high range of mountains, extending northwards and eastwards into Tibetan ground, and culminating in the big rocky mass of Ghatamemin (18,700 feet).

This limestone peak overlooks the Balchdhura (17,590 feet) and is accessible from Sangcha Talla by a deep ravine, leading in an eastern direction. Its base is made up of Gieumal sandstones which show a very complicated dip and are penetrated by numerous veins of igneous rocks. In the upper portion of the mountain these igneous rocks and the tufa associated with them predominate. The limestone crag itself rests entirely on beds of a clearly igneous character, without coming into contact with the sandstone formation.

The highest crag forms a steep scarp and is likewise traversed by veins of a diabase-porphyrite. The limestone is of a white to reddish-white or red colour, without any distinct stratification, semicrystalline and partially altered, especially so where surrounded by intrusions of igneous rocks.

[1] Geology of the Central Himalayas, Mem. XXIII, p. 179, 1891.
[2] Mem. Geol. Surv. of India, VI, p. 113.

Fossils.—No fossils were found *in situ* in the limestone of the crag, but Griesbach was fortunate enough to find a loose block, full of sections of ammonites aud bivalves, near the end of the ravine which descends towards Sangcha Talla encamping ground. It is a red marble, apparently detached from the main mass of the crag, and exactly like some of the famous red Hallstatt marbles from the Salzkammergut in Upper Austria and Styria. The block has yielded a few specimens of ammonites, belonging to the family of *Tropitidæ*. Dr. E. von Mojsisovics, who examined them, believes them to belong to the genus *Jovites* of middle or upper carnian age (Aonoides beds or Subbullatus beds). In the main region of the triassic belt of the Central Himálayas neither of these two horizons is developed in a similar (Hallstatt) development, although the Aonoides beds were met with in the Shalshal cliff section near Rimkin Paiar encamping ground and the Subbullatus beds were found by Mr. Griesbach in the Teragadh near Kalapani (Byans).[1]

From the presence of the genus *Jovites* in the limestone crag to the east of Sangcha Talla encamping ground it results, that the great mass of limestones between the Balchdhura and the Kiogarh-Chaldu pass cannot rest in normal position on the Gieumal sandstones as appears to superficial observation. This is an indisputable fact, but it remains, of course, very doubtful whether the entire mass of limestones is of upper triassic age, or is composed of sediments belonging to very different geological periods, like in the range of Chitichun No. I. Considering the considerable thickness of the limestone cap, I am rather inclined to decide in favour of the latter assumption. As we could not prolong our stay at Sangcha Talla, and had to abandon altogether the survey of the remaining part of these mountains, we must be content with the evidence that part of the limestones at least are of an upper triassic age, and stand in a similar structural relation to the Gieumal sandstones

1 *E. von Mojsisovics,* Vorläufige Bemerkungen über die Cephalopoden Faunen der Himalaya Trias, Sitzungsb. K. Akad. Wiss. Wieu. Math Nat. Cl. CL., I. Abth., Mai 1892.

forming their base, as the limestone crags of Chitichun No. I, and near Lochambel-ki-chak encamping ground to the adjoining Spiti shales.

How far this mighty mass of limestone crags may extend to the north into Tibetan territory, we do not know. The other limestone crags of the Chitichun area are all of a considerably smaller size and in their strike exhibit a nearly semicircular arrangement. So far as we could get an idea of the grouping of these crags from our reconnaissance, they are arranged in three distinct rows or zones.

The first and most northern of these rows we only reconnoitred on our route from the Kiogarh-Chaldu pass (17,440 feet) to Lal Pahar encamping ground (on the western slope of Chitichun No. I). To this row of crags belong the top of Chaldu No. I (17,470 feet), and two lower cliffs of limestone, which face its eastern scarp. Mr. Middlemiss, who visited the Chaldu peak from Lochambel-ki-chak encamping ground, describes it as an isolated mass of a white semi-crystalline limestone with a north-eastern strike, apparently resting on Gieumal sandstones and on the igneous rocks associated with the latter. Lithologically it is perfectly like the limestone of Chitichun No. I, but has yielded no organic remains of permocarboniferous age.

The second or central row of crags is of much greater extent and contains by far the largest number of isolated blocks. It stretches from the prominent peak of Kungribingri (19,170 feet) towards the watershed of the Chaldu and Chitichun rivers. The first crag belonging to this central zone or row is situated to the south of the Kiogarh-Chitichun pass (17,960 feet). Although it was not visited, its outlines can be very distinctly traced from the top of Kingribingri, the bright coloured limestones standing out against the dark shales and sandstones as clearly as the Carpathian "Klippen" of jurassic limestones do against their mantle of eocene or cretaceous flysch. The very top of Kungribingri (19,170 feet) itself consists of a small block of white limestone, resting on greenish Gieumal sandstones, but as it has not yielded any fossils, I cannot say whether it is in normal position, corresponding to Stoliczka's Chikkim limestone or not.

Another limestone crag was discovered in the immediate vicinity of Chitichun encamping ground, in the ravine descending from the Kiogarh Chitichun pass towards the Chitichun river. This mass, as well as a second block of much smaller size situated to the east of the former, is almost entirely imbedded in the Spiti shales, or in the lowest beds of the Gieumal formation, and has only been brought to the surface by the denudation of the surrounding softer materials.

Neither here nor anywhere in the Chitichun region can a distinct boundary between the Gieumal sandstones and the upper Spiti shales (Lochambel beds) be fixed, as the two formations pass gradually into each other. In the vicinity of Chitichun encamping ground, slabs of a greenish sandstone are frequently met with, overlying the slopes of the dark Spiti shales. It is therefore simply a matter of personal taste, whether these sandstones are considered as belonging to the one or to the other system.

The next crag is situated near the low pass, west of the peak Chitichun No. I., on the route from the Kiogarh Chaldu pass to Chitichun encamping ground. A few sections of *Bryozoa* and corals were detected in the limestone, but no attention was paid to these very badly preserved organic traces, as at the time we visited this crag it was assumed to overlie normally the Spiti shales, by which the saddle leading over the range is formed. Close to this saddle a few loose blocks were found containing numerous though badly preserved ammonites of the genera *Monophyllites* and *Xenaspis* (?), pointing to a very low Muschelkalk horizon (Dinarian series).

Chitichun crag.—East of the abovementioned saddle rises the famous crag of Chitichun No. I (17,740 feet), with its rich permo-carboniferous fauna. It is rather difficult to say whether the limestone crag actually comes into contact with the Spiti shales or with the intrusive igneous rocks (diabase-porphyrites) and their tufa only, as the two are mixed up together so intimately, that a very detailed examination of the ground is necessary to fix the boundary between them. The intrusive character of the igneous rocks has been proved by the following important observation, which I shall quote in Griesbach's own words :—

"The base of the south-eastern slope of Chitichun No. I is covered with a mass of débris, and there is therefore no actual contact seen with the Spiti shales. But north-east a low saddle leads across the range between the crags of Chitichun No. I and the one immediately next in succession. The saddle is seen to be formed of the basic igneous rock, which also runs as a vein up the side of the crag, whilst the crown of the latter, a small level space, is entirely composed of that rock. The latter is therefore proved to be of intrusive character penetrating in succession the Spiti shales and the crag in question."

A distinct stratification has neither been observed in the limestone cap of Chitichun No. I, nor in any of the other crags, which I have personally visited. It is true that the limestone of Chitichun No. I appears to be bedded almost horizontally, especially if seen from the west or south-west, but the rock is crossed by so many planes of cleavage and thrust faults in nearly every direction, that it is extremely difficult to recognise its original stratification. So large indeed is the number of cleavage planes, that there is scarcely a fossil in our collection which is not traversed by one of them.

Triassic crag.—There is still another very remarkable crag immediately to the east of Chitichun No. I. It is about 130 feet in height and of a quite regular, conical shape. Its western, northern, and southern slopes are completely surrounded by intrusions of igneous rocks. Unfortunately there was no opportunity of examining its eastern slope. The surface of this cone is entirely made up of slabs of a yellow greyish limestone of a lithological character, which strongly recalls the topmost beds of the upper triassic limestones (Griesbach's rhætic system), corresponding to the Dachsteinkalk of the Austrian Alps.

The saddle north-east of Chitichun No. I, which is composed of intrusive igneous rocks, is joined by a long ridge, running along the Chaldu river in a north-eastern to northern direction. It is capped by masses of limestone, quite similar in their appearance to the crag of Chitichun No. I. They form the highest points of the ridge, and some of them exhibit quite picturesque outlines. That they are in reality only a continuation of the crag of Chitichun No. I, has been proved by an examination of the rocks of their most south-western promontory. But we could neither work out the details of their structure nor decide whether they form one continuous range or a row of smaller independent masses. It is however an indisputable fact, that their strike gradually passes from a north-eastern into a northern direction. The entire row or zone of crags, the centre of which is marked by the peak of Chitichun No. I, consequently describes a flat semi-circle with its convexity turned to S. E.

A third row of crags, considerably shorter however, is indicated by three small blocks to the west and north of Lochambel-ki-chak encamping ground, and by an outcrop of upper triassic limestones (Dachsteinkalk) in the Spiti shales west of the Chitichun river, and about 2 miles north of the last mentioned encamping ground. This latter outcrop may however turn out to be only an inlier of the upper-triassic limestones of the peak Chaldu No. II (17,110 feet), from which the overlying Spiti shales have been denuded.

Permian fossils.—Among the three small blocks to the west and north of Lochambel-ki-chak encamping ground, one has yielded *Productus semi-reticulatus*, and is therefore probably of the same age as the permocarboniferous limestone crag of Chitichun No. I. It is situated about half a mile to the north of the camping ground and is of sufficiently large size to exclude the probability of having rolled down from the eastern slope of Chitichun No. I. Half a mile further to the north, near the pass which leads into the valley of the Chaldu river, is a triassic crag with layers of shell-limestone, made up of *Monophyllites* and *Xenaspis* (?). The third block, situated in a narrow ravine on the eastern slope of Chitichun No. I, to the west-northwest of Lochambel-ki-chak encamping ground, has yielded the interesting triassic fauna, which has been described in Pal. Indica, ser. XV, Vol. II.

Hallstatt fossils.—Like the rocks of upper triassic age, to the east of the Balchdhura, this crag differs widely from the normal triassic sediments in the main region of the Central Himálayas, and represents the Hallstatt facies in the Indian triassic province. Its fauna is composed of the following species of cephalopoda :—

Orthoceras sp. ind.
Danubites kansa, Diener.
,, *ambika*, Diener.
Sibirites pandya, Diener.
Aspidites kossmati, Diener.
Monophyllites confucii, Diener.
,, *pradyumna*, Diener.
,, *hara*, Diener.
,, *kingi*, Diener.
,, *pitamaha*, Diener.
,, *nov. sp. ind. ex. aff. sphaerophylla*, Hauer.
Xenaspis nov. sp. ind.
,, *middlemissi*, Diener.
Procladiscites Yasoda, Diener.
Gymnites ugra, Diener.
Sturia mongolica, Diener.

Since the publication of my Memoir on the Cephalopoda of the Himálayan Muschelkalk (Pal. Indica ser. XV, vol. II. pt. 2), Waagen's[1] most important work on the ceratite formation of the Salt Range has been published, which has thrown new light on a number of geological and palæontological questions relating to the Indian trias. I had come to the conclusion that, judging from its general zoological character, the fauna of the triassic limestone of Chitichun can only be looked upon as a Muschelkalk fauna, but that the Muschelkalk types, which predominate in numbers, have all attained a stage of development pointing to a lower horizon than the main mass of the

[1] *W. Waagen*—Fossils from the Ceratite-Formation Pal. Indica, ser. XIII Salt Range Fossils, Vol. II, 1895.

Muschelkalk in the Central Himálayas (horizon of *Ptychites rugifer*). "The triassic limestones of Chitichun may therefore be considered as forming a lower division of the Indian Muschelkalk, corresponding probably to the horizon of *Sibirites prahlada* in the main region of the Himálayas."[1]

Hydaspian stage of Waagen.—It is only with some reserve that this view can be maintained, since Waagen has called attention to the geological importance of his "Hydaspian" stage, comprising the upper Ceratite limestone in the Salt Range, which he considers to be the lowest division of the "Dinarian" series.[2] The triassic limestones of Chitichun may eventually turn out to be homotaxial with the upper Ceratite limestone of the Punjab, not with the lower Muschelkalk (horizon of *Sibirites prahlada*) of the Central Himálayas. From the latter a small number of brachiopoda, but only a single ammonite, *Sibirites prahlada,* is known, and this is entirely different from any species of *Sibirites* described by Waagen from the upper Ceratite limestone. No direct comparison of the faunas of these two stratigraphical horizons is therefore possible.

From the upper Ceratite limestone of the Salt Range 41 ammonites have been described by Waagen, among which 35 are *Trachyostraca* and 6 only *Leiostraca.* In the triassic fauna of Chitichun on the other hand, not less than 12 among 15 ammonites are *Leiostraca.* Thus a direct comparison of the two faunas is likewise difficult. Although identical species are not present, the occurrence of a species of *Aspidites* in the Chitichun fauna is in favour of its being possibly homotaxial with the upper Ceratite limestone. Nevertheless its bathrological position is as yet very uncertain. This uncertainty is still strengthened by the rather conflicting characters which the Chitichun fauna exhibits. The occurrence of geologically old types

[1] Pal. Indica, ser. XV Himalayan Fossils, Vol. II, pt. 2, Cephalopoda of the Muschelkalk, p. 118.

[2] *E. v. Mojsisovics, W. Waagen, C. Diener,* Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems, Sitzungsber. K. Ak. Wiss, Wien, math. nat. Cl. Vol. CIV, Abth. 1, Dec. 1895, p. 1289.

(*Xenaspis*, *Gymnites ugra*) is counterbalanced by the presence of forms (*Procladiscites*, *Sturia*), which regarding their zoological character point to a higher stage of the Dinarian series.

Having described so far the structure of the Chitichun region, there remains the discussion of the difficult question whether the peculiar limestone-crags of this district do really correspond in their main characters to the structural features, known as "Klippen" in European geological literature. Before entering into this discussion a short analysis of the most remarkable types of Alpine and Carpathian Klippen must be given.

In the Carpathians and in the Alps of Switzerland the name "Klippen" was originally applied to isolated crags or outcrops, mostly of jurassic limestones, rising out of the surrounding flysch. The crags and the sandstones, in which these crags appear to be imbedded, lie, as a rule, quite unconformably to each other, but in many instances no unconformity can be observed between them.

Beyrich[1] was the first to prove the independence of the Carpathian Klippen of the surrounding belt of sandstones. E. von Mojsisovics[2] demonstrated the structural individuality of each separate crag. Paul[3] believed the different ranges of Klippen to correspond to anticlinal folds. Neumayr[4] gave the following definition of the Carpathian Klippen (more precisely of the Piennine chain).

"The Carpathian Klippen are the fragments and remains of a crushed anticlinal, which have been forced by pressure unconformably through and into younger, originally overlying, strata in the shape of blocks, or of upturned edges of strata shorn off from the original rocks *in situ*."

[1] *E. Beyrich*—Ueber die Entwicklung des Flötzgebirges in Schlesien, Karsten's Archiv XVIII, 1844, pp. 1-86.

[2] Verhandl. K. Geolog. Reichs-Anst. 1867 p. 213.

[3] C. *M. Paul*—Die nördliche Arva, Jahrb. Kk Geol. Reichs-Anst. XVIII, 1868, pp. 201-247.

[4] *M. Neumayr*—Jahrb. Kk Geol. Reichs-Anst., XXI, 1871, p. 526.

Stache[1] however explains the mode of formation of the Carpathian Klippen in a very different manner. He considers them to be the fragments of a geologically older chain of mountains which, in latter geological periods, were unconformably overlaid by younger sediments, which are different from this older (infra-cretaceous) mountain range, both by their stratigraphical and structural conditions. The results of the recent detailed surveys of Uhlig[2] in the region north of the Tátra (Piennine chain) are in favour of Stache's view. According to Uhlig the Piennine klippen, which are composed of triassic, jurassic and neocomain rocks, correspond to fragments of an older mountain chain, with a structure independent of the adjoining belt of sandstones, and are distinguished by the presence of littoral deposits of locally considerable thickness in their immediate vicinity.

In the western Alps chains of Klippen play likewise an important part in the structure of their north-western sedimentary belt. Among the Swiss geologists two theories prevail regarding the explanation of their mode of formation. These theories closely resemble those which have been proposed by Neumayr and Stache for the explanation of the Carpathian klippen, and are similarly contradictory. One of them, advanced by Studer and Mösch, tries to explain the phenomena in question by the assumption of outcrops of crushed anticlinals. The other (Renevier[3]) prefers the assumption of a folding process, anterior to the deposition of the younger sandstones which have been deposited on the eroded surface of the fragments of an older mountain range.

Recently, however, a third hypothesis has been advanced by Bertrand and has been developed more fully by Maillard, Schardt,

[1] *G. Stache*—Die Geologischen Verhältnisse der Umgebung von Unghvär in Ungarn, Jahrb. Kk Geol. Reichs-Anst., XXI. 1871, 405.

[2] *V. Uhlig.*—Ergebnisse geologischer Aufnahmen in den westgalizischen Karpathen, 2. Theil, Jahrb. Kk. Geol. Reichs-Anst. 1890, XL, pp. 559-824.

F. Renevier, Matériaux pour la carte géologique de la Suisse, livraison XVI, Berne, 1890, pp. 112, 128, 133, 189, 457.

Lugeon,[1] Kilian, Haug, and other French geologists to explain the formation of a number of Klippen in the Provence and in the Western Alps.

The Klippen, to which this explanation applies, are considered neither as outcrops, shorn off from a crushed anticlinal (Neumayr, Studer), nor as fragments of an older mountain range (Stache, Uhlig, Renevier), but as the last isolated relics of enormous recumbent folds[2] (plis couchés) or overthrusts. In this way, for instance, the presence of a triassic crag in the cretaceous basin of Le Beausset is explained by Bertrand.[3] He proved this crag not to be an outcrop of older rocks, but to rest on the younger cretaceous strata, which on every side dip below the triassic beds and are separated from the latter by a quaquaversal thrust plane. The term "*lambeaux de recouvrement*" has been introduced to designate crags of a similar structure, the origin of which widely differs from that of the Carpathian Klippen. In the cretaceous coal basin of Fuveau the superposition of the triassic (Muschelkalk and Keuper) crags on the cretaceous strata has been actually proved by the construction of a tunnel, which traversed the cretaceous rocks underneath the triassic "*lambeau de recouvrement*."

A similar explanation has been given by Kilian and Haug for a number of crags in the Ubaye region.[4] But the structure of these crags seems to be altogether different from that of the Carpathian Klippen. The Ubaye crags consist of deposits of the so-called Brianconnais facies resting on Dauphiné facies, and their mode of

[1] *M. Lugeon,* La région de la Brêche du Chablais, Bull. des services de la carte géologique de la France, VII, No. 49, Paris 1896.

[2] *B. Willis.*—The mechanics of Appalachian structure, XIII Annual Report of the U. S. Geological Survey, p. 221.

[3] *M. Bertrand.*—Coupes de la chaîne de Ste. Beaume, Bull. Soc. Geol. sér iii, XIII, 1885, p. 115, and: Ilôt triasique du Beausset, analogie avec le bassin houiller franco-belge et avec les Alpes de Glaris, ibid XV, 1886-87, p. 667-702.

[4] *E. Haug.*—Les chaînes subalpines entre Gap et Digne, Bull. des services de la carte géologique de la France, III, 1891-92, No. 21; *W. Kilian* and *E. Haug,* Esquisse de la structure géologique des environs de Barcelonnette (Basses-Alpes), Travaux du laboratoire de géologie de la faculté des sciences de Grenoble, 1894-95, III, 2, fasc. p. 6.

origin is clearly indicated, either the crest (charnière), or the connection with the arch limb or roof[1] of the ancient recumbent fold having been partially preserved.

I shall not enter into the controversy on the intricate structure of the Chablais district in Savoy, but shall close this review of the Alpine Klippen and "*lambeaux de recouvrement*" with a short description of the crags in the Helvetian region between the lakes of Brienz and Walenstadt, which offer some very remarkable analogies with our Tibetan limestone crags. This region has been studied in detail by Kaufmann, Mösch, Stutz, and quite recently by C. Schmidt Steinmann and Quereau.[2] I shall follow the views as exposed by the latter author.

The crags under consideration are the following:—Gyswilerstöcke, Stanserhorn, Buochserhorn, Mythen, Zweckenalp, Iberger Klippen (Grosse and Kleine Schyn, Roggenstock). The area where these crags are situated is composed of rocks, which are all developed in the Helvetian facies, the predominating mode of development in the northern sedimentary belt of the Swiss Alps. The sequence of beds in the crags themselves is entirely different. It has been designated as Vindelician facies by Steinmann and Quereau, and it is much more closely related to the Austrian (Tyrolese) than to the Helvetian development of Alpine rocks. All the crags rest on the tertiary flysch, the youngest member of the Helvetian sequence, and in their occurrence are confined to synclinal depressions in the strike of the folds, making exception, however, of the two crags of Roggenstock and Mördergrub, which are placed on a recumbent anticlinal fold of the Helvetian sequence. Kaufmann and Mösch believed the crags to be anticlinal outcrops, forced and squeezed through the originally overlying sandstones, but from more recent investigations they seem actually to rest on the underlying sandstones, the folds and flexures

[1] *B. Willis.—loc. cit.*, p. 220, 221.

[2] *Quereau*, Die Klippenregion von Iberg, Beiträge zur geologischen Karte der Schweiz, 33 Lieferung.

of which pass underneath them quite unchecked in their development or direction. In the crags of Iberg the rocks are completely squeezed and crossed so intensely by thrust planes that the true stratification can be made out but exceptionally. In the Roggenstock crag the sequence of beds is totally inverted as has been shown by Quereau. Every single crag seems to be separated from the underlying flysch by a quaquaversal thrustplane, and may consequently be considered as a relic of an ancient recumbent fold, the larger portion of which has been carried off by subsequent denudation. These crags, like those of le Beausset or of the Ubaye district ought therefore rather to be classed among the *lambeaux de recouvrement* (Bertrand), than among the true Klippen, of which those of the Piennine chain must be regarded as the prototype.

The Tibetan crags of the Chitichun area form a special type of structural features, which differ both from the Piennine Klippen and from the Alpine "*lambeaux de recouvrement*" of the Ubaye or Iberg type. They are distinguished by five peculiar characters, which must be taken into consideration by any theory that may be advanced for the explanation of their origin. These five characters are the following :—

1. The difference of the rocks, both in the crags of Chitichun and in the main region of the sedimentary belt of the Central Himálayas.
2. The almost semicircular direction of their strike, which is arranged diagonally to the direction of the Himalayan folds outside the Chitichun area.
3. Their occurrence within a synclinal region, consisting of Spiti shales and Gieumal sandstones.
4. Their intimate association with intrusive igneous (basic) rocks of cretaceous or tertiary age.
5. The absence of any distinct littoral deposits in their vicinity.

These points will be separately taken into consideration.

1.—In the Tibetan crags of the Chitichun region the presence of the following rocks has been established.

(*a*) White or reddish limestones of permian (permo-carboniferous) age, with a rich fauna closely allied to the faunas of the Virgal and Kálábagh beds (middle Productus limestone) of the Salt Range and of the Artinski horizon of Russia.

(*b*) Red limestone with cephalopoda of muschelkalk age, pointing to one of the lower horizons of the Dinarian series.

(*c*) Red limestone with cephalopoda of upper triassic (Carnian) age (subbullatus or aonoides beds).

The series (*b*) and (*c*) represent the Hallstatt development of rocks in the Indian triassic province.

(*d*) Upper triassic (?), unfossiliferous limestone, corresponding in its stratigraphical position probably to the Dachsteinkalk of the Austrian Alps and to Griesbach's "rhætic system" in the Himálayas.

Among these rocks only the last-mentioned is developed with similar characters in the Chitichun crags and in the main region of the sedimentary belt of the Central Himálayas. The Hallstatt development is not known in the latter region, where the triassic beds have all been deposited as normal sediments, spread equally over a large area. Nor have any equivalents of the permo-carboniferous limestone of Chitichun No. I been discovered as yet. The faunistic relations to the Productus limestone of the Salt Range are remarkably closer than to any member of the palæozoic series in the main region of the Himálayas of Kumaon and Gurhwal.

2.—The structural relations between the rows or zones of our Tibetan crags and the principal Himálayan folds may partly be seen from Griesbach's maps (Memoirs XXIII, 1891, and *Records*, XXVI, pt. I., 1893).

In the vicinity of the Niti Pass and in the district of Rimkin Paiar, the folds and thrust-faults (Painkhánda fault) strike almost directly north-west to south-east. In the frontier part of Painkhánda, Johár and Hundes they approach more nearly to a north to south direction. This meridional direction is most clearly indicated in the strike of the narrow synclinal of Spiti shales from Laptal to the Kiangur Pass with its continuation into the permo-triassic synclinal of the Utadhura, in the parallel anticlinal of the Lahur, with the adjoining synclinal of Kungribingri, and in the broad anticlinal of the Chanambaniali range. In the Dharma ranges, in Eastern Johar and Byans, the folds of the Himálayan system have again a north-west to south-east strike, as in Painkhánda.

The strike of the chain of crags, to which Chitichun No. I belongs, is quite independent of the direction of the Himálayan folds. This chain runs obliquely across the fold of upper-triassic limestones, which gradually rises from out of the Chitichun synclinal, in the peak Chitichun No. II, 19,550 feet, and transversely across the narrow synclinal of Dharma, which is enclosed between the anticlinal folds of Chitichun No. II and Chanambaniali.

The independence of this Tibetan chain of crags from the neighbouring folds of the Himálayan system is one of the chief characters by which these crags differ from the Carpathian Klippen of the Piennine type. In the Piennine chain the strike of every single row of Klippen almost invariably follows the direction of the zone of folds, of which this chain forms a part. A deviation from the normal direction of the folds is a great exception. The only instance on a larger scale, which has been noticed by Uhlig[1] are the Klippen of Falstin, which for a distance of 2 kilometres strike transversely across the direction of the entire chain. But this instance scarcely allows any comparison with the structural independence of the

[1] *V. Uhlig* —Ergebnisse Geologischer Aufnahmen in den westgalizischen Karpathen, II. Theil, Der Pienninische Klippenzug, Jahrb. K. k. Geol. Reichs-Anst. Wien. XL. 1890, p. 797.

Tibetan crags from the Himálayan folds, the independent strike of the chain of crags to which Chitichun No. I belongs, having been ascertained for a distance of 13 km.

3.—A certain analogy of the Tibetan crags with those of the Iberg type in the Helvetian region between the lakes of Brienz and Walenstadt cannot be denied. Like the latter crags they are confined to a synclinal area. The crags of the Chitichun region rest on a synclinal of Spiti shales and Gieumal sandstones, fringed on three sides by triassic anticlinals. The Swiss crags rest in exactly the same manner on a synclinal of eocene flysch, forming a sort of trough between an outer (Pilatus-Autrig) and an inner range (Brienzer Grat-Brisen-Bauenstöcke-Räderten) of anticlinal folds.

4.—A feature, which is quite peculiar to the Tibetan crags and has as yet not been discovered in any of the hitherto known chains of Klippen or *lambeaux de recouvrement*, is their intimate association with intrusive igneous rocks. The local occurrence of eruptive materials within the zone of Carpathian Klippen is of a very slight importance only, if compared with the predominant part taken by intrusive igneous rocks (diabase-porphyrites) in the structure of the Chitichun area.

In the preceding description it has been demonstrated that the largest of our Tibetan crags are nearly imbedded in eruptive materials, that neither in the crag east of Sangcha Talla encamping ground nor in Chitichun No. I, a direct contact of the limestone crag with the apparently underlying sandstones or shales has been observed, but that an intermediate layer of igneous rocks and of their tufa is inserted between the two formations. The igneous rocks cannot be of older than at least cretaceous age, having penetrated both the shales and sandstones and the crags in succession. Nor can the formation of the crags as structural features be younger than the eruption of the diabase-porphyrites which must have intruded them *in situ*, at the place where they are at present situated.

5.—There is no indication of any deposits of a littoral character in the Spiti shales, which surround the Tibetan crags. The condition of the sediments remains unaltered over a large area, and is not influenced in any distinct way by the vicinity of the crags. The nature of the Spiti shales themselves as well as of their organic remains prove, that they must not be considered either as a pelagic nor as a littoral formation. Professor Uhlig, who is working out the fauna of the Spiti shales, has kindly forwarded the following notes on this subject :—

"The Spiti shales are certainly not littoral sediment, as for instance is the Carpathian 'Klippenhülle,' *i.e.*, the complex of rocks in the immediate vicinity of the Carpathian Klippen (red clay, sandstones, and conglomerates with *Inoceramus*). With regard to their lithological character, the Spiti shales are undoubtedly very similar to the 'Terrain a géodes' (Dogger) of the Caucasus and to the Wernsdorf and upper Teschen beds of Silesia. In the latter beds the iron occurs in layers, but is not concentrated in concretions. In the Wernsdorf beds remains of terrestrial plants are frequently met with; their presence in connexion with the clastic condition of the sediments seems to prove that the latter are not truly pelagic deposits. The same reasoning might be applied to the origin of the Spiti shales. In this respect the fact is of some importance, that the state of preservation of the very numerous ammonites completely excludes the possibility of their having been rolled or abraded near an ancient coast-line. As in the Wernsdorf beds, specimens with entirely preserved mouthborders (peristomes) are not at all rare. Their state of preservation is indeed so perfect that they cannot be supposed to have been rolled or damaged in any way. The Spiti shales ought therefore to be considered as sediments, which, having neither been deposited in the vicinity of the ancient coast-line nor in the open sea, are certainly not littoral, though not strictly thalassic."

The difference in the stratigraphical sequence between the main region of the sedimentary belt of the Central Himálayas and the Tibetan crags of the Chitichun area is equally consistent with an explanation of the latter as true Klippen (in a structural sense), or as *lambeaux de recouvrement.* As has been pointed out by Griesbach, this change of the lithological character of the rocks in these two separate regions can easily be accounted for by the appurtenance of the crags to a sedimentary zone which was more distant from the ancient coast-line of the Gondwana continent (peninsular area of India) during the permian and triassic epochs.[1] There is consequently nothing astonishing in the fact, that in the Chitichun area a change in the development of sediments is met with, both palæontologically and lithologically.

As a direct structural connection between the Tibetan crags and the neighbouring folds of the Himálayan system has not been observed, these crags cannot be explained as the fragments of crushed anticlinals. The theory advanced by Paul and developed more fully by Neumayr for the explanation of the origin of the Carpathian Klippen of the Piennine type is therefore not admissible. Nor are we justified in considering the crags of Chitichun as the relics of an older mountain range, as the Piennine Klippen to the north of the Tátra have been proved to be by Stache and Uhlig, seeing that littoral deposits of the character of the Carpathian "Klippenhülle" are absent in their vicinity. In the Spiti shales of the vicinity of Chitichun No. I at least, which was more closely examined during our visit to this part of the Himálayas, we failed to discover any similar deposits pointing to the existence of a jurassic coast-line within the Chitichun region.

Regarding the differences which exist between the Tibetan crags and the Carpathian Klippen of the Piennine type, the question might

[1] The difference in the development of the upper-triassic strata of the Himálayas and the Salt Range is explained in a similar manner. The geographical position of the Salt Range is an intermediate one between the Gondwana continent in the south and the pelagic area of the Himálayan system in the north. Waagen and E. v. Mojsisovics justly compared its position to that of the German triassic basin between the Atlantic continent and the Alpine region (*E. v. Mojsisovics,* Beiträge zur Kenntniss der obertriadischen Cephalopoden-Faunen des Himálaya, Denkschr. K. Akad. Wiss. Wien. math. nat. Cl. LXIII. 1896, p. 689).

be raised if these crags ought not rather to be considered *lambeaux de recouvrement* of an origin similar to that of a good number of so-called Klippen in the Western Alps.

There are several arguments of no slight importance, which seem to be in favour of such a view.

Like the Alpine *lambeaux de recouvrement* the Tibetan crags are confined to a synclinal area, and apparently rest on geologically younger strata. I should not, however, like to insist on the latter argument, as I am too well aware of the difficulty of deciding, whether in similar cases one has to do with a real superposition or with outcrops of older rocks.[1] Nor must it be forgotten that some of these Tibetan crags appear to have been perfectly imbedded in the soft Spiti shales of the igneous materials associated with them, and to have been laid bare by subsequent denudation only. A stronger argument in favour of an explanation of the Tibetan crags of the Chitichun area as *lambeaux de recouvrement* is their structural independence of the Himálayan folds. This peculiar feature of theirs might be easily accounted for by the theory advanced by Bertrand, Schardt, Quereau and Lugeon for the explanation of the majority of the so-called Klippen of Switzerland and Savoy.

Nevertheless I believe that the latter hypothesis must also be dismissed on account of the very grave objections which might be urged against it. The objection against this explanation of the Tibetan crags as *lambeaux de recouvrement* is two-fold.

Supposing these crags to be really the relics of an enormous recumbent fold, the mountain range, part of which has been carried across the Himálayan system into the Chitichun area by means of this hypothetical fold, must exist somewhere in the neighbourhood of the latter region. But nowhere in Southern Hundés has a large belt of sedimentary strata of the Chitichun development been discovered.

[1] *Vide* the triassic crags of Beausset and Fuveau, considered formerly—and not only by casual observers—as outcrops; or the controversy, which is still going on between Heim and Vacek on the structural condition of the Verrucano-caps in the Alps of Glarus.

Against this evidence, it is true, not only our very superficial knowledge of the geology of Southern Hundés may be urged, but the probability of the existence of a sedimentary zone north of the Kailas mountains is supported by the following arguments.

Thanks to the geological reconnaissances of Godwin-Austen, Stoliczka and Lydekker the structure of the Western Himálayas has been made pretty well known. On the important papers of these authors the masterly description of the mountain-system of Kashmir and Ladakh by Eduard Suess (Das Antlitz der Erde, I Bd., pp. 559-565) has been based. He proposes the following structural division of the Western Himálayas :[1]—

a. Sub-Himálayas (tertiary with outcrops of older rocks).
b. Pir Panjal (anticlinal of crystalline and metamorphic rocks).
c. Synclinal of Kashmir (mesozoic and palæozoic).
d. Zanskar (crystalline zone, corresponding to the main axis of the Central Himálayas).
e. Synclinal of Spiti (palæozoic and mesozoic).
f. Eocene zone of Leh (Upper Indus Valley).
g. Crystalline zone of the Ladakh Range.
h. Sedimentary belt of Baltistan (upper palæozoic and mesozoic).
i. Gneissic zone of the Mustagh Range (Karakorum).

Whilst the outer crystalline zone of the Pir Panjal and the synclinal sedimentary belt of Kashmir come to an end before reaching the Sutlej river, both the crystalline zone of the Zanskar and the sedimentary belt of Spiti find their continuation in the Central Himálayas of Kumaon and Gurhwal. To the crystalline mass of the Zanskar correspond the enormous gneissic masses of the Kedarnáth peaks, of the Nanda Devi (25,660 feet) and Nampa. The sedimentary belt on the northern slope of this crystalline masses, which has been followed by Griesbach from the Hop Gádh to Kalapani for a distance of 130 miles (210 km.), is a direct continuation of the

[1] *Vide* also *Godwin-Austen*,—The mountain-systems of the Himálaya and neighbouring ranges of India, Proceedings of the Royal Geograph. Soc., London, new ser. V, 1883, p. 610; VI, 1884, p. 83.

mesozoic synclinal of Spiti. This sedimentary zone of fossiliferous deposits, ranging from the silurian into the cretaceous formation, is one of the most important features in the structure of the Himálayas. In the district of Chitichun it is intimately connected with the tertiary belt of the Upper Indus Valley in Ladakh, our Tibetan crags forming part of these two united zones (*e* and *f* of the foregoing scheme).

Having been able to follow the sedimentary belt of Spiti as an almost uninterrupted zone from the Suru river in Kargil to the frontier of Nepal and Byans, we must consequently look on the crystalline mountain ranges to the north of this zone as a structural continuation of the gneissic Ladakh range. The Kailas mountains, the southern slopes of which have been reconnoitred by Strachey, belong to this crystalline zone of Ladakh. None of the fossiliferous beds of the Bhot Mahals of Johár and Painkhánda have been found, neither in the Kailas range nor in the vicinity of the Mánásarowar lakes. Nor are we justified in expecting their discovery so far as we may judge from the structural analogies with the Western Himálayas. If any sedimentary zone exists beyond the valley of the Sutlej river in Hundés, we must suppose it to form a continuation of the sedimentary belt of Baltistan. The regularity in the arrangement of the structural zones in the Western Himálayas is a strong argument in favour of this supposed continuation of the palæo-mesozoic belt of Baltistan into Hundés. But this sedimentary belt must by all accounts be looked for on the northern slopes of the Kailas range.

This problematic continuation of the zone of Baltistan to the north of the Kailas mountains is the only possible source of the hypothetical *lambeaux de recouvrement* in the Chitichun area.[2] An

[1] The existence of a sedimentary synclinal along the northern slopes of the crystalline anticlinal of the Kailas range has also been advocated by Griesbach (Mem. Geol. Survey Ind. Vol. XXIII, p. 40).

[2] I need scarcely dwell on the fact, that the few fossils, which were collected in the sedimentary belt of Baltistan near Shigar by Godwin-Austen, are certainly not sufficient to prove an identity of the development of sedimentary strata in Baltistan and in the Chitichun area.

advocate of this hypothesis must admit the existence of an ancient recumbent fold, by which part of the abovementioned sedimentary zone has been carried across the crystalline Kailas range into the Chitichun area. Now the shortest distance between the crest of the Kailas range (north of Tirthapuri) to Chitichun No. I is nearly 50 miles (80 km.). It would be difficult to explain, I believe, the mode of formation of such enormous recumbent folds, in comparison to which any fold, which has hitherto been actually observed, is ridiculously insignificant. I am well aware that several geologists, like Schardt or Lugeon, suppose the region of the "Brêche du Chablais" in Savoy to have been formed by a recumbent fold of similar dimensions, but I humbly confess my inability to understand the mechanics of an overthrust of entire structural zones for a distance of 50 miles.

The second objection, which to me appears to be still more cogent, is based on the intimate association of the Tibetan crags with intrusive igneous rocks, which penetrate both the crags and the geologically younger shales and sandstones in their proximity. The localisation of the igneous rocks to the crags along their entire line of strike seems to prove the coincidence of the eruptions with the structural movements, by which the crags themselves have been brought into their present position. This fact excludes any mode of explanation, by which the crags are assumed to have been brought into their present position from some distance, by recumbent folds or overthrusts, but naturally involves the assumption, that they have been brought to the surface from underneath, either as fragments of a squeezed fold, or by faulting.

The independence of the strike of the crags from the folds of the Himálayan system in the Chitichun area is opposed to the existence of a squeezed fold. Thus the explanation, given by Griesbach in his preliminary notes (Records of the Geological Survey of India, Vol. XXIV, p. 24) remains the most plausible. He explains the occurrence of the crags in association with the diabase porphyrites in the following manner:—

"We have seen, that this limestone (which forms Chitichun No. I and the neighbouring crags) lies apparently on Gieumal beds in one section and on Spiti shales in another; further that the crags are accompanied more or less along their entire line of strike by igneous intrusive rocks, and in one instance at least the latter penetrates the permocarboniferous limestone, which is partially converted into a semi-crystalline limestone.

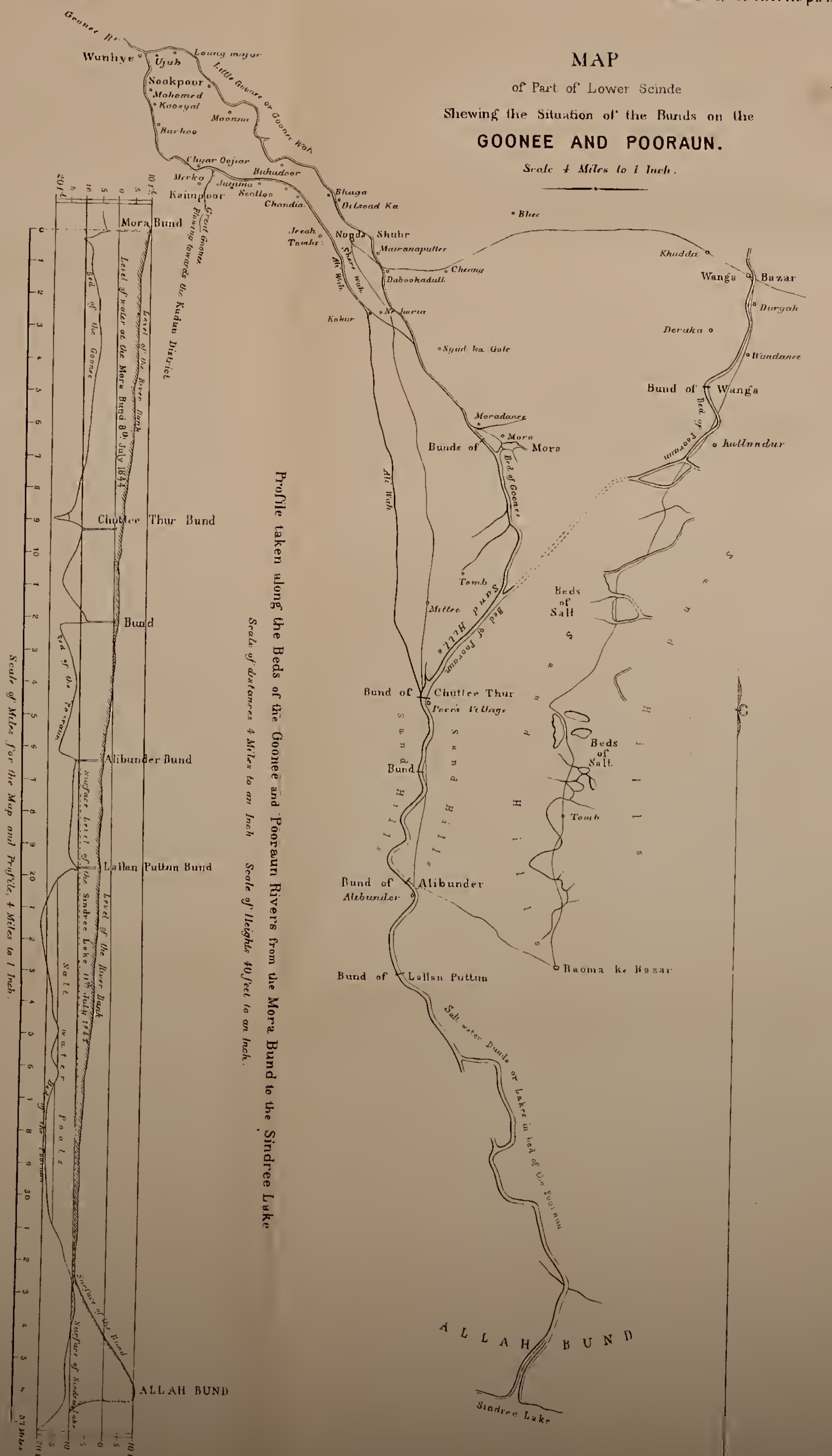
"I advance therefore the theory that these older rocks have been brought to the surface by faulting. The latter is not directly visible, which, indeed, is rarely the case in a complex of soft shales, such as the jurassic beds are in this region, but a fault may be inferred not only from the existence of palæozoic rocks above jurassic, but also from the fact, that the former rest on different divisions of the latter in adjoining sections.[1] The assumption of a fault explains also the presence of intrusive rocks, which may have most probably intruded along a line of fissure."

According to Griesbach these Chitichun faults may belong to the system of dislocations, which affects the Hundès plain in the vicinity of the Mánásarowar lakes and has enabled the basic rocks of Eastern Hundés to intrude. This system of dislocation is however purely hypothetical, being based only on Strachey's reconnaissances, which though very meritorious in many respects, are of no value for a discussion of the complicated question of our Tibetan crags.

If I should be asked an explanation of the origin of these crags, I could give no better than the above quoted, which has been advanced by Griesbach, at least for the present moment, although positive proofs of the supposed faults are yet absent. After all, this opinion may yield to reconsideration, when the details of the struc-

[1] This fact, however, is equally well consistent with the hypothesis of a fault or of a recumbent fold or overthrust.

R. D. Oldham.


MAP
of Part of Lower Scinde
Shewing the Situation of the Bunds on the
GOONEE AND POORAUN.
Scale 4 Miles to 1 Inch.
Profile taken along the Beds of the Goonee and Pooraun Rivers from the Mora Bund to the Sindree Lake
Scale of distances 4 Miles to an Inch   Scale of Heights 40 feet to an Inch.
Scale of Miles for the Map and Profile, 4 Miles to 1 Inch.
Mora Bund
Chuttee Thur Bund
Bund
Alibunder Bund
Lallan Puttun Bund
ALLAH BUND
Level of water at the Mora Bund 8th July 1844
Level of the River Bank
Bed of the Goonee
Surface Level of the Sindree Lake 11th July 1844
Salt water Pools
Surface of the Bund
Wunhye
Sookpoor
Kainpoor
Great Goonee Flowing towards the Kudun District
Shuhr
Wanga
Bazar
Bund of Wanga
Bunds of
Mora
Bed of Goonee
Beds of Salt
Bund of
Chuttee Thur
Bund
Bund of
Alibunder
Bund of
Lallan Puttun
Raoma ka Bazar
Salt water Bunds or Lakes in bed of the Pooraun
ALLAH BUND
Sindree Lake

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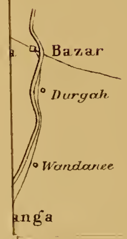


ture of the Chitichun area and adjoining portions of Hundés have been worked out more fully by a new exploration of this exceedingly interesting country. I scarcely need say that it would be of special interest and well worthy the expenditure of money and time to further explore a territory exhibiting such peculiar structure. For the present we must be satisfied with the discovery of the latter, which had not previously been recognised in India, but must leave its thorough explanation to our successors.

A note on the Allah-Bund *in the north-west of the* Rann *of* Kuchh,[1] *by* R. D. Oldham, A. R. S. M., F. G. S., *Superintendent, Geological Survey of India* (with plate I.)

All who have read Sir Charles Lyell's Principles of Geology will be familiar with the account of the great earthquake of Kuchh in 1819, by which a considerable area of the Rann of Kuchh was depressed, and a strip of land, known as the Allah Bund, was supposed to have been elevated.

In 1872, the Memoir on the Geology of Kuchh, by Mr. A. B. Wynne, of the Geological Survey of India, was published,[2] in which it was argued that the Allah Bund was not in fact an elevated tract, but that it merely had the appearance of such when viewed from the south, and represented the comparatively steep slope connecting the area which had been depressed from that which had remained unchanged in level. This view was subsequently adopted by Professor Suess, who threw over his original view that the Allah Bund was the manifestation of a deep seated fold at the surface,[3] and in his Antlitz der Erde unreservedly accepted Mr. Wynne's suggestion.[4] During the recent move of the offices of the Geological Survey, a tracing of

[1] Wrongly spelt Cutch, Kutch, Kuch, and Kuchchh.

[2] *Memoirs*, Vol. IX, pt. i.

[3] Die Entstehung der Alpen, 1875, p. 152.

[4] Das Antlitz der Erde, Vol. I, 1885, p. 61.

Captain Baker's original map, referred to by Mr. Wynne,[1] was discovered; and as this survey is most distinctly at variance with Mr. Wynne's view, which the classic authority of Professor Suess' work is likely to make universally accepted, it has been thought worth being published, that the evidence may be appreciated at its true value.

The accounts of the various examinations of the Allah Bund need not be repeated here, as full references will be found in Mr. Wynne's memoir, but a brief abstract will enable what follows to be better appreciated. On the 16th June 1819, the great earthquake occurred, by which a large portion of the Rann north of Lakpat was depressed and immediately flooded by the inrush of the sea. At the same time the inhabitants of the fort of Sindri, on the margin of the Rann, saw a long elevated mound, where the surface had once been a plain, extending east and west for a considerable distance, and separating, as it were, the waters of the Puran from the sea.

So far there is no difficulty; of the depression of the Rann and of the appearance of what looked like an elevation, there can be no doubt; but the question to be decided is whether this apparent elevation was in reality a barrier, as implied by the name Allah Bund, or Dam of God, or whether the appearance was deceptive.

Owing to feuds between the Governments of Sind and Kuchh the former had, after several unsuccessful attempts, succeeded, about 1802, in permanently blocking the channel of the Indus, which once flowed by Lakpat and out by the Kori mouth. As a consequence of this there was no water flowing in the channels across which the Allah Bund was raised, and there was nothing to show whether there was an actual elevation of the ground or not. In 1826, however, there was a great flood of the Indus, which broke through all artificial barriers, and forced its way along the old channel, cutting a passage for itself through the Allah Bund.

Such, briefly, is the history of this interesting feature, but of all the

[1] Memoirs IX, p. 36.

accounts and examinations of it one alone is based on such a survey as would render it possible to say whether there had been any elevation or not. This one is the report by Captain Baker, of the Bengal Engineers, in 1844,[1] whose statement is very precise, that the bund rises some 20 feet above the water of the Sindri lake and that from this elevation it gradually slopes to the northward till it becomes undistinguishable from the plain.

Against this definite statement the only argument which can be brought is that of Mr. Wynne, that if there had been such an elevation, the floods of 1826, instead of forcing their way through the Bund, should have accumulated on its northern side and found their way round, and not through, the supposed barrier. He urges that the recorded facts become intelligible only on the supposition that the fall which existed originally between the northern margin of the elevated tract and its southern boundary of maximum elevation, was great enough to leave a slope sufficient to enable the stream to follow its old direction. As the width of the Allah Bund is put at 10 miles and the elevation of its southern face at 20 feet, this would necessitate an original fall of more than 2 feet per mile, or double that of the whole Indus from Attock to the sea.[2]

This argument is a telling one, but it must be remembered that though the height of the dam is given by some authorities as 20 feet, the statements of different accounts not only vary greatly, but in every case represent the total apparent elevation on the south side of the barrier, and consequently represent the sum of the depression on the south and the elevation, if any, on the north. According to Captain Baker's survey, of which a reduced copy will be found on plate I, the total elevation on the north could not have been more than 10 feet at the place where the Puran cuts through the bund. Supposing this to have been the amount of the elevation, and the channel to have had this depth—as might well have been the case

[1] Trans. Bombay Geol. Soc., VII, 186-188. (1846.)
[2] Memoirs IX, p. 42.

in spite of the long period during which it was dry—it would have been quite possible for the flood waters to have forced their way through the old channel instead of forming a new one round the end of the elevation, said to be some 50 miles long. There would certainly be some ponding up of the flood waters above the barrier, but this might easily have been regarded as a natural accompaniment of the flood, or have escaped notice altogether, as the country had been depopulated.

On the other hand, and opposed to the arguments which can be urged against an elevation, we have the map and section, and the very definite statement, evidently based on careful levelling, that there was an actual upward slope of the ground immediately behind the southern scarp of the Allah Bund. There seem, consequently, good grounds for maintaining the older view that the Allah Bund was an elevated tract, but there can be no doubt that the estimates of its height do not correctly represent the amount of elevation, but of the sum of this and the depression which certainly took place to the south. The former cannot have exceeded 10 feet, the latter amounted to as much or more, and the two together represent the estimates of the height of the barrier as seen from the south, estimates which range up to 20½ feet.

Geology *of* parts *of the* Myingyan, Magwe *and* Pakokku Districts, Burma, *by* G. E. Grimes, *Assistant Superintendent, Geological Survey of India.*[1] (*With Pls. 2 and 3*).

Part 1.—Geology of the Yenangyat Oil-field and its extension.

Area described.

In the Myingyan district, upper Burma, in the country south of the village of Kanthit-kon (Lat. 20° 42′ N., Long. 94° 56′ E.) a range of hills, formed of miocene and pliocene beds, bent into an anticlinal arch, rises up from the

[1] Mr. GRIMES died of cholera, at Thayetmyo, Burma, on the 11th April 1898.

G. I


GEOLOGICAL MAP
OF THE
YENANGYAT OIL FIELD
PAKOKKU DISTRICT
by
G. E. Grimes,
Asst. Supdt. Geol. Survey.
Scale
16 inches = 1 Mile
INDEX OF COLOURS
Post Pliocene & Recent
Plateau Gravel
Pliocene
Upper Miocene
Lower Miocene
Contour of Oil Sands at the depth they occur in Well No. 6
Circle boundary
TAUNBON
SEIKTAWA
TAUNGBON
LANYWA
IRRAWADDY
IRRAWADDY R.
Letpan
Tangyi
Chaung
Seikkwa
Ayadaw C
Ywaya C
Yenangyat
Ywathit Yo
Kodaung C.
Kyoukwaung C
Lanywa
Singu
Chauk ywa
Salemyo

G. E. Grimes.

Memoirs Vol. XXVIII. Pl. III.

surrounding low country and runs northwards in a direction 18° W. of N., E. of S. At Singu, where these hills come up to the Irrawaddi, there is a considerable break in them, but on the other side of the river they continue northwards in a direction which is now slightly turned to 10° W. of N., E. of S. In the Myingyan district the length of the hills is about sixteen miles, and they are locally known as the Singu hills, but on the other side of the river, in the Pakokku district, they are known as the Tangyi hills, from the well-known and conspicuous Tangyi pagoda, which is built on one of the highest points of the range. Of these Tangyi hills I have examined a length of twenty-four miles, but I did not reach nor see the end of them, and so I cannot say how far they extend towards the north. In direction the Singu-Tangyi hills are parallel to, but not in the same line as, the Yenangyaung hills, and an examination of the surrounding parts of the Myingyan district shows that the range is one of a number of roughly parallel ranges of hills, which are formed of rocks bent in approximately parallel anticlinal folds. The Yenangyaung hills form one of these parallel ranges but the Yenangyaung anticline and hills sink down into the plain and become covered up by recent deposits in the country to the south-east of Sale, and the Singu-Tangyi range begins at Kanthit-kon, which is a considerable distance east of the northern end of the Yenang-yaung hills. Other roughly parallel ranges of hills are the Pagan hills and the Gwegyo hills. From their southern end the Singu-Tangyi hills rise rapidly in height towards the north as far as Singu, where the Irrawaddi breaks through. But on the other side of the river the hills continue, still rising in height, until at Yenangyat and Seikkwa they reach a maximum of nearly 900 feet above the Irrawaddi. From here northwards they gradually sink down, at first slowly and then more rapidly, until, near Myigyaundwe (Lat. 21° 18′ N., Long. 94° 47′ E.), which is the most northerly point I have visited, they are much lower than near Yenangyat, and looking from this place towards the north one sees that they are rapidly becoming lower still and tending to die down entirely.

Maps available.

The Singu hills and the southern part of the Tangyi hills have been demarcated into blocks of one square mile each, and these blocks have been mapped on the scale 8″ = 1 mile. The Singu hills have been marked out as blocks of the Yenangyaung oil-field, and here the miocene beds are exposed in blocks 50 N to 59 N; they are not, however, as we have seen before, on a continuation of the Yenangyaung anticline, and they are really not part of the Yenangyaung oil-field at all, but might more properly be called the Singu oil-field. This line of demarcated blocks, too, does not run parallel with the axis of the anticline, but in a somewhat inclined direction, so that it is only in the northernmost blocks that the crest of the anticlinal arch comes into the mapped area at all, being first seen in the south-east corner of block 58N. South of this it is to the east of the maps. The Tangyi hills, from their southern end on the Irrawaddi, are demarcated into blocks of one square mile on the Yenangyat oil-field, numbered 1 to 21 A to G, and these blocks extend seven miles north of Yenangyat.

Of the country round and north of these mapped blocks, the only maps available were the ¼″ = 1 mile Frontier maps.

Previous observer.

Previous to my examination of the Singu and Tangyi hills, parts of them had been visited by Dr. F. Noetling, and they have been described by him in Vol. XXVII of the Memoirs of the Geological Survey of India.

Physical features.

Coming now to the physical features of the country, we find that those parts of the hills, which are composed of miocene beds, are very different in appearance from those composed of pliocene sandstones, as their outward shape is governed by the weathering of beds dipping at various angles, which resist the disintegrating influences at different rates. The miocene hills are steep and rise sharply from the surrounding country. They are composed of interstratified sandstones and shales which resist weathering unequally. On the east side of the anticlinal arch, where the beds are dipping at high angles, the hills take the form of a number of narrow parallel ridges, but on the west side of the anticline, where they have only gentle dips, the ridges have a dip slope on the west side and a steep scarp facing towards the east. The pliocene area, as a rule, rises more gradually from the surrounding country and tends to form broad plateaux, which are, however, cut into by innumerable stream-beds.

Very numerous stream-beds drain the Singu-Tangyi hills, with courses both to the east and to the west, but the watershed is not at the crest of the anticlinal fold; in the Singu hills it is the ridge of pliocene beds on the eastern side of the arch, and in the Tangyi hills it is the ridges of miocene beds about half-way between the crests of the fold and their western boundary. In the hills the general course of the main streams is at right angles to the axis of the anticline and the strike of the beds, and here, flowing over the miocene rocks, the tributary streams largely run along the strike, but in the pliocene hills they radiate in all directions. Many of the larger streams have cut deep nullahs and valleys in the hills, which often have lofty and precipitous sides; but in some places, especially amongst the pliocene hills and where aided by numerous tributary streams, they have worn out broad valleys and deposited alluvium in them. Most of these stream beds were quite dry during the whole of the time, November to April, which I spent in the country, and in no case was the water flowing into the Irrawaddi. The only exceptions to the rule of being perfectly dry in the cold and hot seasons were a few stream-beds in the Tangyi hills, where the nullahs have been cut through miocene beds, in which small pools are found in places, and the water sometimes flows for a short distance before sinking again underneath the sands, but in no case does the water flow on the surface of the ground into the Irrawaddi.

The Yaw-Chaung, which flows along the base of the Tangyi hills on their western side, roughly parallel to the Irrawaddi for several miles, has a considerable stream of water flowing in it all the year round, and this stream enters the Irrawaddi at the southern end of the hills. Its source is in the hill country to the west.

The slopes of the Singu-Tangyi hills are usually very rough, and the surface is mostly covered with pieces of the hard concretions from both the miocene and pliocene beds. They are, as a rule, barren and uncultivated, and but little grass grows on the ground. Practically the only vegetation on the hills formed of pliocene beds is the low, almost shrub-like acacia (*Acacia ferruginea*), and on the hills of miocene beds the great majority of trees are either this same thorny acacia or a thick-leaved euphorbia. This range is in the dry zone of upper Burma, and the smallness of the rainfall and the steepness of the hills probably largely account for this barrenness.

Stratigraphy.

The rocks which are exposed in the Singu-Tangyi hills are miocene and pliocene beds, bent into an anticlinal fold, and recent deposits. The miocene beds, which are exposed in the centre of the anticline, consist almost entirely of upper miocene (Yenangyaung) beds, with interstratified shales and sandstones, whilst of the lower miocene (Prome) beds there are only a few small exposures. The pliocene beds, the exposure of which surrounds that of the miocene beds, are soft coarse sandstones with interstratified layers of red ferruginous conglomerate. On the flat tops of some of the hills are patches of red ferruginous gravel (plateau gravel), and in the lower ground there are deposits representing an older alluvium and modern stream-sands.

Miocene beds. Prome stage.

Along the Singu-Yenangyat anticline the lower miocene beds (Prome stage) are only exposed in a few small patches. One is on the north side of Moksoma-kon, in block 58 N of the Yenangyaung oil-field, where the anticlinal arch rises to a maximum, and here there is a small exposure of lower miocene sandstone. Another exposure is in the bed of the Magyi Chaung, in block 2 of the Yenangyat oilfield, where a small patch of Prome sandstone can also be seen, and besides this there are more exposures in the stream-beds amongst the hills to the north of the demarcated blocks. From these exposures alone we should not learn much of the Prome beds in this part of the country, but fortunately our knowledge is somewhat supplemented by information obtained from wells and borings, and even then it is very imperfect. From the evidence we have, we see that the lower miocene (Prome) beds consist of interstratified layers of shale and sandstone, the shales predominating.

Where the boundary between upper and lower miocene should be placed is not very definite, as the beds in the two stages are in many ways similar in character, and they are apparently conformable to one another. The difficulty in fixing the boundary is also increased by the smallness of the exposures of Prome beds, and by the way in which these exposures are obscured and covered up by loose material. In the Singu and Tangyi hills I have, as Dr. Noetling did, taken the junction as just on the top of the first oil sand, as the Prome beds below differ from the Yenangyaung beds above, in the different colour of their sandstones and in places of their shales and in the absence of gypsum in the shales. The Prome sandstones are massive, fine-grained and greyish in colour, many of them are glauconitic, and then their colour is somewhat greenish; the uppermost sandstone is in some places bluish-grey. The shales are soft, and bluish-grey to black in colour, and they may be distinguished from the Yenangyaung shales in not containing any gypsum. Between the shales and the sandstones there is every gradation of shaly sandstones and sandy shales besides beds composed of alternate thin layers of shale and sandstone. Of the total thickness of the Prome beds in these parts, there is no evidence, only the uppermost beds being exposed, and although over eight hundred feet have been bored through, the base has nowhere been reached.

From an examination of the boring records we see that the beds vary very greatly in thickness and character within a comparatively short distance, shales replacing sandstones and sandstones shales and fresh beds coming in or others dying out. So rapid is this change that no two records of bores, however close together, are the same, and I have only with difficulty been able to correlate the beds shown by the boring records of the wells, on the hills to the south of the Yenan-C Chaung at Yenangyat, with those of the wells on the hills to the north of that Chaung. Notwithstanding this rapid change we see that there is a fairly regular succession of beds, and the following would be a typical section, the thicknesses given being the average of those observed in the wells :—

Sand	30 feet.	1st oil sand.
Shale	50 ,,	
Sand	21 ,,	2nd oil sand.
Shale	27 ,,	
Sand	16 ,,	3rd oil sand.
Shale	24 ,,	
Sand	10 ,,	4th oil sand.
Shale	54 ,,	
Sand	20 ,,	5th oil sand.
Shale	76 ,,	
Sand	40 ,,	6th oil sand.
Shale	60 ,,	
Sand	75 ,,	7th oil sand.
Shale	32 ,,	
Sand	20 ,,	8th oil sand.
Shale	45 ,,	
Sand	23 ,,	9th oil sand.
Shale	35 ,,	
Sand	9 ,,	10th oil sand.
Shale	18 ,,	
Sand	20 ,,	11th oil sand.
Shale	91 ,,	
Sand	10 ,,	
Shale	25 ,,	
Sand	15 ,,	12th oil sand.
Shale	13 ,,	
Sand	39 ,,	

Most of the sandstone beds near the centre of the anticline at

Oil sands.

Yenangyat contain petroleum oil, or water, or both. The oil-bearing sandstones which have been met with in the bored wells are twelve in number, and there are probably more lower down, in the strata which have not yet been reached by the boring tools, but whether they will be rich in oil or not it is impossible to say. Most of the known oil sands only contain small quantities or traces of oil, and the great bulk of the oil extracted from the bored wells comes from only three or four of these sands.

The following is a list of these oil sands in descending order:—

The *first oil sand* is from 15 to 50 feet in thickness, average thickness 30 feet. In two wells it is under 15 feet thick and in two wells it is apparently wanting, but in these four cases the shale above is thicker than usual; in the two wells, where the first oil sand is not recorded, the shale above is referred to as sandy, and in three of the four wells it shows signs of oil, and so part of this shale ought to be included in the first oil sand which it evidently replaces.

The *second oil sand* is from 4 to 40 feet in thickness, average 21 feet. This sand is thickest in the wells south of the Yenan-C Chaung, indeed in one of these wells 151 feet of sandstone is recorded, but this is due to lower beds of shale being absent, so that it is a union of several sandstone beds. This sand is absent in three wells, and in one bore hole, No. 6, it is divided by a clay band.

Third oil sand.—This when separate varies from 5 to 35 feet in thickness, average 16 feet; but in seven wells the next bed of shale is wanting, and so this and the fourth oil sand are united, when as great a thickness as 88 feet has been recorded.

The *fourth oil sand*, where separated from the third, is quite a thin layer of average thickness, 10 feet, and where thickest it is only recorded as 15 feet thick.

The *fifth oil sand* is from 5 to 50 feet in thickness, average 20 feet. This is an important sand as several of the wells draw their oil from it. In one well the shale below contains two layers of sand, which gave signs of gas and oil, and which might be included in this fifth oil sand.

The *sixth oil sand* is from 10 to 93 feet in thickness, average 40 feet.

The *seventh oil sand* varies from 60 to 107 feet in thickness, average 75 feet. In four of the wells in the Yenan-C-Chaung it is largely replaced by shale, and is divided into two sands by this shale, which in these wells is from 39 to 55 feet in thickness, but it is absent in the majority of the wells.

The *eighth oil sand* is 5 feet to 45 feet in thickness, average 20 feet. In one well it is joined to the seventh oil sand.

The *ninth oil sand* is from 15 to 33 feet in thickness, average 23 feet. This is a most important sand as several of the wells draw their oil from it. In one well it is divided into two by a bed of shale 5 feet thick.

The *tenth oil sand* is mostly only a few (2 to 7) feet in thickness, but in one well the next shale is missing, and so it is joined to the eleventh oil sand, when the recorded thickness is 60 feet.

The *eleventh oil sand* is only reached in three wells, and in one of these it is largely replaced by slate. Its average thickness is 20 feet.

The *twelfth oil sand* is only reached in one well, and it is there 13 feet thick.

Where sandstone beds, which show any signs of petroleum, are exposed, the rock is found to be much hotter than the air and the surrounding strata.

Yenangyaung stage.

The upper miocene beds (Yenangyaung stage) consist of interstratified sandstones and shales, the latter being predominant. Along the Singu-Yenangyat anticline they are continuously exposed, with only a break where the Irrawaddi crosses them, from the Themathank Chaung, at the south-east corner of block 50 N of the Yenangyaung oil-field, seven miles south of Singu, to the farthest limit of my survey, which is twenty-eight miles to the north of Singu, and the exposure probably extends some distance beyond. The sandstones are mostly fine-grained, soft, and yellow, brown, grey or white in colour. The shales are greyish or greenish and are likewise mostly quite soft. Between the sandstones and the shales there is every gradation, and rocks composed of alternate thin layers of shale and sandstone are quite common. In both sandstones and shales there are hard calcareous bands strings and nodules, which are greyish in colour. These nodules are often of considerable size and are commonly three or four feet across, mammilated or kidney-shaped, and when weathered they break along the original planes of bedding. These nodules and pieces of the bands are everywhere found lying on the surface of the ground, and the slopes of the hills are covered with them. Subordinate bands of conglomerate too are found in several places, but they are never of any great thickness, nor are the pebbles of large size, and some of the calcareous bands contain rounded pebbles of limestone derived from other beds. The beds of shale and clay, and in places the uppermost sandstone, contain numerous flakes of gypsum scattered through them, the quantity of which varies greatly in different localities, but it is never entirely absent, and its presence is one of the distinguishing characteristics of the shales of the Yenangyaung stage. In the shales, and occasionally in the sandstones, there are also nodules of marcasite, which in the days of the Burmese kings were collected and used in the manufacture of gunpowder, and in some of the lower beds one finds calcite crystallized in the crevices.

All my attempts to subdivide the upper miocene beds by their lithological characters were without success, as they change very rapidly, both in thickness and character along the strike, and it is quite common to see sandstones changing into shales, or *vice versâ* within a short distance. Dr. Noetling, in his Memoir,[1] has divided up the bottom 500 feet of these beds, which are exposed on the eastern side of the anticline at Yenangyat, but an examination of the country to the north and south of this place shows that, owing to the rapid changes in the beds, this subdivision only holds good for the immediate neighbourhood of Yenangyat. Many of the beds, however, are very persistent, and one of the sandstones, which was named Signal hill sandstone by Dr. Noetling, I have mapped in order to show the structure of the country better; this at Yenangyat is a soft yellowish-brown sandstone, which, when traced along its outcrop, shows very great alterations, both in character, varying from fine-grained rock to conglomerate, and thickness, sometimes almost dying out and at other times 30 or 40 feet thick.

The uppermost bed of the upper miocene is, however, when present, quite distinct from the beds below, and it can be easily identified, especially as its colour is so conspicuous, that it can often be distinguished at a considerable distance off. In the southern part of the Yenangyaung oil-field it is a very soft sand-rock of a brilliant white colour, sometimes tinged with blue, red, etc., and it is in striking contrast to the dull yellowish-brown sandstones below it. It usually contains pieces of gypsum, and in a few places, fragments of wood partly replaced by oxide of iron, etc., these last are very friable and so quite unlike the fossil wood in the Pliocene beds above. This upper sand is of very variable thickness; it is exposed all along the western miocene boundary on the Singu-Yenangyat anticlinal arch, but, with the exception of a small length at the southern end, it is not present on the eastern side.

The thickness of the upper miocene beds varies, I believe, very considerably, but this I was unable to thoroughly test owing to the limited area of my maps, as only at one place—3 miles south of

[1] Memoirs, G. S. I., Vol. XXVII, Part 2, p. 127.

Singu—was the whole thickness of the beds exposed in the mapped country, and here I measured it as 2,450 feet.

Fossils are not uncommon, and I have obtained them from several localities, especially in the blocks to the south of Singu. They are not, as a rule, scattered through the rocks, but are largely confined to certain calcareous bands, rarely more than a foot thick, which are crowded with shells. In places, however, shells or casts are scattered through the shales, and a few casts of mollusca, some sharks' teeth, the vertebra of a fish, and a few fragments of bones were found in some of the sandstones. Most of the specimens were obtained from five definite horizons, which are characterised by certain species, but a few were found in intermediate beds, which could not be definitely assigned to either of the horizons. Dr. Noetling is examining the fossils I brought back with me from Burma, but as yet he has only finished the Pelecypoda, of which he has furnished me with the following lists ; there are also about as many species of gastropoda, besides corals, etc. The following are the horizons, with their pelecypoda, in ascending order :

(1) Basal beds of Yenangyaung stage, resting on the 1st oil-sand of the Prome stage. Most of the specimens obtained are casts, which were scattered through the shales.

(2) Shales just above and below the Signal hill sandstone, about 350 feet above the base. These beds are characterised by a *Cytherea*.

Cytherea, sp. nov.
Cardium, sp. nov.
Corbula semitorta, Boessg.
Tellina, sp.
Lucina, sp. nov.
Pecten, sp. nov.

3. A band of argillaceous sandstone, mostly conglomeratic and in places calcareous, between 500 and 600 feet above the base. This is characterised by a *Meiocardia*, and is the same as the Cypricardia bed of Dr. Noetling.

Meiocardia, sp. nov.
Pecten, sp. nov.
Cardita (1 new species).
Nucula (1 new species).
Lithodomus.
Crassatella (1 new species).
Cytherea lilacina, Lin.
Paracyathus cœruleus, Duncan.

4. A very hard band, six inches to one foot in thickness, about 900 feet above the base. This is a very persistent and conspicuous band and has been discovered in several places. It is characterised by a *Mytilus*.

Mytilus nicobaricus, Reeve.
Modiola, 2 new species.
Meiocardia, spec. nov.
Cytherea lilacina, Lin.
Cytherea (*Dione*) (2 new species).
Tellina, (2 new species).
Metis, spec. nov.
Gari, spec. nov.
Pecten, spec. nov.
Vulsella, spec. nov.
Cardita cf. mutabilis, d'Arch.
Paracyathus cœruleus Duncan.
Lima, spec. nov.
Corbula rugosa, Low.

5. Another calcareous band higher still, containing *Cardita tjidamarensis*, Martin. A glance at the fossils brought back shows that they are shallow-water marine forms. A large proportion of them are gastropoda, and the lamellibranchiata consist of forms like *Mytilus*, *Pecten*, *Cytherea*, etc., which are found in the shallow waters close to land.

It will also be noticed that the fossiliferous bands are in the bottom 1,000 feet of the upper miocene beds, and in the higher beds fossils are wanting or rare. This want of fossils may be due to the dying out of the mollusca, owing to the water gradually becoming brackish as pliocene times are approached, when fresh-water beds were deposited on the top of these miocene beds, and some support is given to this suggestion by the greater prevalance of gypsum in the upper beds than in the lower.

Unconformity between miocene and pliocene.

Between the upper miocene beds and the overlying pliocene (Irrawaddi) beds there is an unconformity, and in places a great thickness of miocene beds was removed before the pliocene sandstones were deposited on them. The uppermost bed of the miocene series is a sandstone of a brilliantly white colour, and this is seen in both the Yenangyaung and Singu-Tangyi ranges of hills, in places 60 miles apart. Of this bed a varying thickness is exposed all along the western side of the anticline, but, with the exception of a few small patches south of Singu, it is absent from the eastern. Even where it is continuously exposed, there are signs that it has suffered somewhat from denudation before the pliocene beds were deposited on it, as, when the boundary is traced on the 8″ = 1 mile maps, the surface of the white sandstone is seen to be very irregular. On the west side of the anticline the dip and strike of the adjoining miocene and pliocene beds are apparently the same, but it is impossible to test this rigidly owing to the adjacent rocks not having very definite bedding planes. On the eastern side of the anticline we find that not only has the uppermost white sandstone been denuded away, but several others of the upper miocene beds also, and there is a great difference between the thicknesses of the miocene beds on the opposite sides of the anticlinal arch; this difference gradually increases from the extreme southern part of the miocene exposure, south of Singu, to a maximum at Seikkwa (2 miles north of Yenangyat), whilst at Yenangyat we have only 500 feet of miocene beds on the eastern side of the anticline, and about 3,000 feet on the western side. The miocene and pliocene beds on the east side of the anticline at Yenangyat also have apparently the same dip and strike, but when mapping the Signal hill sandstone I found that this is not so, and that the exposure of it is not parallel with the boundary; and besides, at one place, for a distance of one and a quarter miles, the Signal hill standstone is cut out and the pliocene sandstones are resting on still lower Yenangyaung beds. This great difference in the thickness of the miocene beds on the two sides of the anticline, and the change of the miocene beds next to the boundary, show that it must either be faulted or unconformable. That it is not faulted is, I think, evident from the very steep, almost vertical, dip of both series, so that if the differences in thickness of the miocene beds were due to faulting the throw of the fault must be very great, and so much so as to be out of the question. Another piece of evidence against a fault is the occurrence, at one place, of the *debris* of the miocene in the basal beds of the pliocene, so that there is an apparent transition between the two. North of Seikkwa we see, at the top of the series, miocene shales and sandstones, apparently somewhat broken up and fragmentary, passing down into ordinary miocene beds and upwards into a whitish sandstone, containing miocene *debris* and pieces of gypsum. This white sandstone contains fossil wood, and can only be distinguished from ordinary Irrawaddi sandstone by the presence of the pieces of gypsum, and it passes gradually into the typical pliocene sandstone by the decrease of this gypsum. From these two considerations we see that the boundary is not a faulted one, and so between the miocene and pliocene there must be here a considerable unconformity. On the western side of the anticline this unconformity is not very great, and the interval between the deposition of the miocene and pliocene beds was possibly of short duration. On the east side of the anticline the beds show a much greater unconformity, and the interval between miocene and pliocene was probably greater, and there is one piece of evidence, which tends to indicate that here the denudation of the miocene beds was still proceeding, while the pliocene beds farther west were being deposited, as on the western side of the Tangyi hills the basal pliocene beds resemble those at Yenangyaung, and they have, interstratified with them, the typical bands of ferruginous conglomerate, which contain vertebrate remains; but on the eastern side of these hills the basal Irrawaddi beds are wanting, and we have, at the base, sandstones like those higher up in the series on the other side of the hills.

Pliocene beds, Irrawaddi series.

To the east and west of the exposure of Yenangyaung beds, and resting on them unconformably, as we have seen, are the Irrawaddi beds. On the eastern side of the anticline they dip towards the east at angles varying from 60° to 90°, and on the western side at angles varying from 20° to 25°. The area, on the east side of the hills, in which they are exposed, is quite narrow, as south of Singu they become covered up by recent deposits at the foot of the hills; then along the southern part of the Tangyi hills, to within 2 miles of Yenangyat, they are not present, and the miocene beds extend to the Irrawaddi, but from this place to the north there is a narrow strip of them, which at Yenangyat and Seikkwa is bounded by the Irrawaddi, and farther north their area, to the west of Mitchi, is again bounded by flat alluvial country. On the western side of the hills they cover a large area, and their exposure extends for a great distance into the Yaw country. The Irrawadi (pliocene) beds are soft, whitish and yellowish sandstones, full of fossil wood and calcareous concretions, and containing layers of ferruginous conglomerate. The basal band of conglomerate is not so constant here as at Yenangyaung,[1] and in the country south of Singu it is almost entirely wanting, there being only small patches of it; farther north, however, in the Yaw valley, west of the Tangyi Hills, it is more prevalent, and here again it is found as a fairly constant band, although very variable in thickness, running along the boundary between the miocene and pliocene. Dr. Nœtling[2] has made a zone of this band of conglomerate, but I am inclined to include the next 150 or 200 feet of sandstone in the basal zone, as they contain inter-stratified layers of ferruginous conglomerate, in which I have found

[1] Memoirs, G. S. I., Vol. XXVII, Pt. 2, p. 59.
[2] *Ibid*, p. 55.

typical vertebrate fossils. From two localities, one south of Singu and the other in the Yaw valley west of Lanywa, I have obtained vertebrate remains, teeth and bones from this basal zone, from near Singu remains of *Tetraconodon* sp., *Crocodilis* or *Guvialis* sp., *Trionyx* sp. and *Bos* sp., and from the Yaw valley to the west of Lanywa, *Dinotherium* sp., *Hipparion* sp., *Crocodilis* or *Guvialis* sp. and *Trionyx* sp.

Recent beds.

In the southern blocks of the Yenangyat oil-field, and in the country south of Singu, some of the hills are capped with a plateau gravel. On the Pakokku side of the Irrawaddi this gravel is lying on the up-turned edges of the upper miocene beds, but on the Myingyan side it is on pliocene beds. In blocks 18, 19, 20, 21 D, E, F and G of the Yenangyat oil-field, where it is on the miocene rocks, the tops of the hills are all flat and form a plateau, in which the streams have cut the present nullahs ; this plateau is about 150 feet above the Irrawaddi River, and so the gravel is at a lower level than that at Yenangyaung.[1] As in other places it consists of rounded pebbles of quartz, and pieces of fossil wood, in a red highly ferruginous matrix. The size of the pebbles in the gravel on the southern end of the Tangyi hills is not so great as in the gravels on the Yenangyaung hills, which were described by Dr. Nœtling, but the gravel on the other side of the river, in the country south of Singu, which is apparently a continuation of that on the Tangyi hills, contains pebbles and pieces of fossil wood as large and as well rounded as any found near Yenangyaung. On the Tangyi hills this gravel is only present along a narrow strip of country, which is bounded on the east and south by the Irrawaddi, and on the west and north by more lofty hills, and it is probably part of the bed of the Irrawaddi or some other stream in former and post-Pliocene times.

On the eastern side and around the southern end of the Singu Hills, and on the east side of the Tangyi hills near Aingy and

[1] Memoir, G. S., I., Vol. XXVII, Pt. 2, p. 59.

Mitchi, the country is covered by recent alluvial beds, which are often of great extent, and the thickness of which it is impossible to tell, but it must be very considerable, as deep stream beds have not reached the base of them. The beds consist of clayey sands, with small nodules of kunkar in places, and gravels with rounded pebbles of quartz and fossil wood. The deposits are, I think, part of an older alluvium of the Irrawaddi.

The valleys amongst the hills have mostly deposits of stream sands, many of which are of considerable breadth.

In the beds of several of the streams, and in a few other places where the ground is slightly damp, there is a layer of a white efflorescent salt on the surface of the lower beds of the upper miocene, which when tested proved to be almost entirely composed of sulphate of soda. I am indebted to my colleague Dr. Walker for the following analysis :—

Na_2O	34·89
K_2O	·24
CaO	1·25
MgO	1·80
Cl	·32
SO_3	48·09
Loss on ignition	4·65
Insoluble	10·00
	101·24
Less Oxygen equivalent	·08
	101·16

It contains therefore about 78% of Na_2SO_4, with smaller quantities of $CaSO_4$ and $MgSO_4$. The solution gives a distinctly alkaline reaction with litmus. The origin of this sulphate of soda may possibly be due to the sulphuric acid from the petroleum bearing beds below.

Structure.

Considering now the structure of the country we find that the axis of the anticline follows somewhat, but not quite, the same up and down course as the heights of the hills; from Kanthit-kon it gradually rises and reaches a maximum in block 58 N, about three miles south of Singu, where a patch of lower miocene beds is exposed, then there is a slight sinking of the axis between this block and the Irrawaddi. On the other side of the river the axis is at first apparently horizontal, and then it very slowly and gradually rises to a maximum at Yenangyat, where the lower miocene beds are again at the surface; from here towards the north it sinks again, at first gradually, and then more rapidly as far as block 5, where it again begins to rise so rapidly that, in the south-west corner of block 2, the first oil sand of the lower miocene is close to the surface. The rise then continues slowly with slight oscillations, to as far as where the road from Sabe to Gonledaing crosses the hills, and at this place the first oil sand is 250 feet above the bottom of the Chaung, but after this the anticlinal axis sinks continually as far as I have been towards the north.

The beds in these Singu and Tangyi hills are folded in an unsymmetrical anticlinal arch, the dip on the east side being very much steeper than on the west side. Near the southern end of the Singu hills, close by Trinzan, we find the pliocene beds on the east side of the anticline with a dip of 36° to the east, and on the west side it is only a very low westerly dip. As one goes north the anticlinal axis rises and so the dips steepen, but they are always much steeper on the east side than on the west, thus west of Teingan we find in the pliocene beds a dip of 60° on the east side and only low dips on the west side. In the section from Kyeni westwards, where we have miocene beds exposed in the centre of the anticline, we have, advancing west, first, pliocene beds with a steep dip and then miocene beds, the uppermost of which has a dip of 69° to the east; this dip decreases somewhat towards the centre of the anticline, where the beds turn over rather sharply to a dip of 10° west, which gradually increases to 27°, and then decreases until, at the western boundary of the miocene beds, it is only 15°. A little farther north, where the anticlinal axis rises to its first maximum at

Moksomakon, a section shows miocene beds close to the centre of the anticline with a dip of 57° east, which turns sharply to one of 6° west, and then gradually increases to 20°, at the western miocene boundary. From here towards the north the anticlinal arch sinks and close to Singu we find that, on its eastern side, the beds close to the centre have a smaller dip than in the last case. On the other side of the Irrawaddi, near Lanywa, we find the miocene beds on the east side with a dip of 48°, and on the western side with dips varying from 13° to 20°, within the limits of my map. At Yenangyat the crest of the anticline is close to the Irrawaddi, and here we have very steep dips on the eastern side, and the bend at the centre is very sharp; an examination, however, of sections constructed from boring records shows that deeper down the bend at the crest is not so sharp; on the western side the dip gradually increases from 7° at the centre to 24° at the edge of my map, and beyond this as far as the Yaw Chaung ; then it remains constant at about the same angle in both miocene and pliocene beds. Both north and south of Yenangyat we find the same structure, almost the only variations being in the dips near the centre, and also, to some extent, of the miocene beds on the eastern side of the anticline. A few miles north of Yenangyat the dip of these beds increases until they are vertical, and for a short distance they are bent over so as to have a steep westerly dip.

Petroleum.

At Yenangyat the petroleum in the oil sands of the lower miocene (Prome series) is worked both by drill and wells. The dug wells, which are in the three Chaungs, the Yenan-C-Chaung, the Ok Chaung and the Ywaya Chaung, are worked by natives in the same manner as those at Yenangyaung, described by Dr. Noetling ;[1] here they are generally quite shallow and limited in number and are not producing a great quantity of oil. Of the drilled wells of the Burma Oil Company there were seventeen at the time of my visit. Regarding the

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2, p. 164 *et seq.*

occurrence of petroleum at Yenangyat there is little to add to what has been previously written, as to the oil being accumulated in the higher parts of the anticlinal arch—a rule which applies also to occurrences in other places. There is, however, a slight modification of this at Yenangyat, as the wells a short distance, about 400 feet, west of the axis give a greater yield than those at the very crest of the arch, this possibly being due to the beds at the centre being somewhat broken up, so that the oil is partially diffused through the adjoining beds. The wells too are mostly bored from sites on the hills, as it was found that those sunk in the valleys gave a poor yield. With the oil there is often gas at a considerable pressure, which, especially when the oil sand is first pierced by the boring tools, causes the oil to rise to a considerable height up the bore-hole, often some hundreds of feet, and sometimes up to the surface. In most cases this rise ceases in two or three days, but in two of the wells it has been continuous ever since the bore-holes were made. Owing to the great variability in the thickness of the oil-bearing sandstones and to the enclosing beds of impermeable soft shale, which often completely encases the sands, so that they are merely lenticular masses embedded in shale, the separation of the gas, oil and water, and the collection of the gas at the top of the anticlinal arch, then oil at a lower level and below this the water, does not take place in the neighbourhood of Yenangyat; and in the case of well No. 6, which is the one farthest back from the crest of the anticlinal arch, and which yields only a small quantity of oil, this oil is forced up by gas from an oil sand 1,100 feet from the surface, whereas the oil from wells close by and nearer the centre, has to be pumped. This encasing of the sandstones in the shales, and the presence of bands of shale or shaly sandstone in the sands themselves, also impede any flow of the oil within the beds, so that neighbouring wells do not interfere with or draw oil from one another, at least not to any extent.

It has been shewn before[1] from the cases of Yenangyaung, Yenangyat, etc., that in Burma, as in other countries, the workable deposits of oil are only found in those parts of the oil-bearing beds, which occupy the highest and most elevated points of the anticlinal folds. In Burma the oil is obtained from lower miocene (Prome) beds, and so the only places where we can look for it with any chances of finding it in workable quantities, are where the miocene beds are exposed near the crests of anticlines, and then the higher the lower miocene beds are elevated, and the nearer they are brought to the surface, the greater the probability of finding petroleum. In other places, where the miocene beds are overlaid by pliocene sandstones, there is no hope of there being an exploitable area, as even if oil were present in the sands below, it would be at too great a depth from the surface, and besides it is very improbable that there is workable oil in the lower lying part of the sandstone.

Applying these conditions to the Singu-Yenangyat anticline we find that there are three known separate places along it, where the crest of the arch rises to a maximum, and where the resulting dome-like elevations of the Prome beds are at, or close to, the surface of the ground, and these three places are Moksoma-kon near Singu, Yenangyat, and in the hills near Sabe.

First, I will take the case of Yenangyat as it was known previously. At Yenangyat the first oil sand of the lower miocene is close to the surface in the beds of the Yenan-C-Chaung, the Ok Chaung and the Ywaya Chaung, in places which are not much elevated above the level of the Irrawaddi river. By mapping one of the sandstone beds (the Signal hill sandstone) of the upper miocene, which is about 350 feet above the first oil sand, I have been able to trace the up and down movement of this oil-bearing bed as one goes to the north and south. This Signal hill sandstone becomes entirely covered up by newer beds in block 15, to the south of Yenangyat, and in block B to the north, and so for a distance of at

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2, p. 139 *et seq.*

least six miles to the south and four-and-a-half miles to the north, the first oil sand of the lower miocene at its crest is within 350 feet of the surface of the ground, and as the places where the Signal hill sandstone disappears are amongst the hills, the crest of the first oil sand is at a less depth below the level of the Irrawaddi river, especially in the case of the northern extension. The area which can be exploited with any good chances of success does not extend far north, and also narrows rapidly both to the north and to the south. Taking well No. 6 as on the edge of the exploitable area, as it is the farthest west, and yields only a small quantity of oil; and then, by means of mapped Signal hill sandstone, finding places in the other blocks where the first oil sand is at the same depth as in this well, I have been able, by joining up these places, to trace a line on the west side of the anticline, which is an approximate limit of the area within which the oil can be exploited with hopes of success. This line can only be regarded as approximate, as we do not know if the small yield of oil in well No. 6 may not be due to some local cause, or to the same influences which have acted in the case of the other wells sunk at the bottom of the Chaung; and also there is no means of knowing what variations there are in the thickness of the beds between the Signal hill sandstone and the first oil sand of the Prome stage. The line, however, will, I think, be found to be fairly correct as a limit, but, if anything, it is more likely to be a minimum than a maximum limit. Tracing this line to the south we see that the exploitable area rapidly becomes narrower owing to the sinking of the anticlinal arch, but the crest of the anticline itself sinks somewhat less rapidly, as the downward movement of the anticline as a whole is, near the centre, partly compensated by a narrowing of the arch and consequent increase of dip, which brings the crest itself higher and so nearer the surface. A continued sinking, however, makes the area very narrow in block 12, and in the northern part of block 13, about three miles south of Yenangyat, it dies out. North of Yenangyat we find a similar contraction, and the area ends in the northern part of block C, three-and-a-half miles north of the Yenan-C-Chaung.

A second place, where the crest of the anticlinal arch rises to a maximum, is in block 58 N of the so-called Yenangyaung oil-field, which is about three miles south of Singu in the Myingyan district. There the first oil sand is exposed, on the north side of Moksoma-kon, at an elevation above the Irrawaddi certainly greater than that of the beds of the Chaungs near Yenangyat, and so the crest of the anticlinal fold of the oil-bearing sandstones is at a somewhat higher level than near Yenangyat. At Yenangyat we know that the oil sands are workable, and as the two places are only a few miles apart and on the same anticline there are strong reasons for regarding this and the neighbouring blocks, to the north and south, as possibly part of one oil-field. Oil is found south at Yenangyaung and north at Yenangyat, and there is absolutely no reason to think that possibly this area is beyond the oil bearing zone, but on the contrary there is strong presumptive evidence that it is within the oil area, and this the presence of a distinct smell of petroleum gas, which comes from the exposure of Prome sandstone, corroborates.

The third maximum in the height of the crest of the anticline is between Sabe and Gouledaing, about four or five miles north of the demarcated blocks of the Yenangyat oil-field, and here the first oil sand is at an elevation of 250 feet above the bed of the Chaung, through which the road from Sabe to Gouledaing passes, and consequently it is at a considerably higher elevation above the river Irrawaddi, and so it is much higher than the crest of the anticline at Yenangyat. On the outcrop of the first oil sand, on the south side of this ravine, there are several patches of black and burnt earth surrounding small holes in the ground, and the villagers tell me that from these holes last year there issued flames three feet high, which continued to burn for several months. At the time of my visit the ground here was quite hot and there was a strong smell of petroleum from the sand, and when stones lying on the surface are turned over a film of oil and water is seen on their under side. The Burmans call this hill the Yenan Daung (earth-oil hill). Besides this place there are other exposures of the first oil sand, with indications of oil, but at a lower level, in other stream beds, both north and south, the most southerly being in the Magyi Chaung in block 2 of the Yenangyat oil-field, where the oil sand is just under the stream sands. The arguments, which I have used in the case of the Singu oil-field, apply here with, if anything, greater force, and it is most probable that this will be found to be a new and profitable oil-field also. Of its extent it is impossible to speak accurately at present, as there are no detailed maps north of the demarcated blocks of the Yenangyat oil-field, but I may say that the exploitable area will most probably extend from the north part of block B (Yenangyat oil-field) to about six miles north of the mapped blocks. This is only a rough estimate, and possibly the limits may have been taken too far to the south or too little to the north, but it is impossible to say accurately until we have larger and more detailed maps, wherewith to geologically examine the country here.

Amber.

When working a few miles north of Yenangyat one of the villagers brought me two small pieces of amber, which he said he had obtained from the Kyun Chaung. I went with him to this place, which is in block 5 of the Yenangyat oil-field, and the beds which he pointed out to me as having contained this amber were thin bands of yellow sandstones in the shales of Yenangyaung age. These bands were full of fragments of partially fossilized wood, partly converted into coal or replaced by oxide of iron, and of strings of coal. I could not myself find any amber, but I observed several holes, where the Burmans had been digging for it. The villager said that when found it is always in small round balls, and so it may possibly have been derived from beds of the Prome stage, in which it is known to occur.

PART 2.—*Notes on the Geology of the Western Part of Myingyan District and of a small area in the north of Magwe District, Upper Burma.*

Physical features of the area examined: hills of anticline with intervening plains.

The physical features of the western part of Myingyan and the northern parts of Magwe districts, upper Burma, may be roughly described as a number of ranges of hills having an approximately N. N. W. and S. S. E. direction and between these ranges of hills more or less flat country. The hills which are due to a number of anticlinal folds are formed of miocene and pliocene strata, the miocene beds in some cases forming the centre of the hills with pliocene beds along the sides or the anticlinal arch may not be sufficiently raised or sufficiently denuded for the miocene beds to be exposed and then the hills are composed of pliocene sandstones only. The plains are mostly covered by recent deposits.

Hlils composed of pliocene and miocene strata.

Hills of miocene beds different in aspect from those of pliocene age.

The ranges of hills composed of miocene beds are, however, very different in appearance from those composed of pliocene sandstones. The first are steep and rise sharply from the surrounding country, and being composed of alternate beds of sandstone and shale which unequally resist weathering, the form of the hills is governed by the weathering of these beds when dipping at various angles ; where the beds are steeply inclined the hills take the form of a number of narrow parallel ridges, but where they have only a gentle dip the hills have a dip slope on one side and a steep scarp on the other. In contrast with the hills composed of miocene beds those which are formed of pliocene beds rise, as a rule, but slowly from the surrounding country and they tend to form broad plateau-like elevations with only a gentle slope to the sides. On both kinds of hills the rocks are almost everywhere exposed the ground being quite barren and little

Hilly ground barren.

or no grass growing on it; on the pliocene hills almost the only vegetation is the low almost shrub-like thorny acacia-trees (Acacia ferruginea) and on the miocene hills the great majority of the trees are either this same thorny acacia or a thick leaved euphorbia.

Plains between the hills: With recent alluvial deposits,

Between the ranges of hills, however, there are large areas of flat or slightly rolling country which are covered with recent deposits of an alluvial character and here the appearance of the country is strikingly different from that in the hills; a great part of it of which the surface is covered by a sandy soil, is under cultivation being divided into fields or plantations of toddy palms, of which many hundreds may often be seen at a time; in fact over a large part of the country covered by recent beds the cultivation of the toddy palms and the manufacture of jaggery from its juice is the staple industry.

and abundance of toddy palms.

The Irrawaddi.

Along the western side of these districts the Irrawaddi river flows in a bed which is in most places about three miles wide, but which is only filled by the river at the end of the rainy season. At other times the river only occupies a small part of its bed, the remaining part of it, which is filled with alluvial sands, being largely under cultivation, and these river deposits form the best agricultural land in the districts as the crops on them do not suffer to such an extent as those in the adjoining country from the long drought during the dry season. Numerous temporary villages are everywhere built on the sand-banks, which are only deserted by the inhabitants when the floods rise up to them.

Tributaries to the Irrawaddi; mostly dry.

Running into the Irrawaddi there are very numerous stream beds which with one exception were all perfectly dry during the whole of the time, November to April, that I was in the country. The only permanently flowing stream was the Pin Chaung which has its sources on Popa mountain and the hills to the east of Myingyan district, and along the greater part of its course it receives no permanent tributaries only flood streams during the rains. Although quite a large stream the Pin Chaung for several miles of its course across the plain in the centre of Myingyan district has an underground course during the dry season, which is so deep that the Burmans who live near have not been able to reach it by means of wells, neither do they get any water under the sand in the stream bed above, and in consequence during the long drought in the last dry season the villagers living near the Pin Chaung in this part of its course suffered so severely from the water famine that they had to leave their own villages and crowd into those on the banks of the Irrawaddi.

Water often obtainable by digging into dry beds of small streams.

In many of the nullahs and sometimes apparently the driest of them, water could be obtained at a few feet from the surface by digging a hole in the sand and this was in places the only water obtainable. This storage of water under the sand was particularly common where the water-courses run over miocene beds, which are largely composed of soft shales, but it is by no means confined to the miocene areas and was not unfrequently found where the underlying rocks are alluvium or even ordinary pliocene sandstones.

Where the streams flow over the hilly country, the nullahs are mostly cut down pretty deep and they often have lofty precipitous sides, but where aided by numerous tributary streams the torrents which flow during the rainy season have in places worn out quite large and broad valleys in which they have also deposited beds of alluvium over considerable areas.

Geology of the area—rocks tertiary and recent.

Coming now to the geology of the area we find that the rocks are all of tertiary or recent age, none older being represented.

Recent deposits occupy the ground between the hills.

As before mentioned the recent (post-pliocene) deposits consisting chiefly of sand and gravel cover the flat or slightly rolling country between the hills, and the areas they occupy are often very large, the chief being that of the plain stretching eastward from the foot of the Yenangyaung hills and the plain extending southwards and eastwards from Pagan.

The hills which are formed of beds bent in anticlinal arches are composed of pliocene beds with, as a rule, miocene beds exposed by denudation in the centre of the anticline, the pliocene beds consisting of soft yellowish sandstones mostly coarse and containing hard concretions and layers of red ferruginous gravel and the miocene beds being interstratified layers of shale and sandstone. The chief of these ranges of hills which I examined are those formed by the Yenangyaung anticline, the Singu anticline, the Pagan anticline and the Gwegyo anticline. Besides these there are other ranges of less importance composed entirely of pliocene beds.

Pliocene and miocene beds compose the hills.

The Principal hill ranges examined :

The Singu hills I have described in another paper, and it will perhaps be convenient if I divide the rest of the area into several portions and describe each in turn in the following order :—

Area under examination exclusive of the Singu hills, divided, for purposes of description, into 4 parts.

(I) The Yenangyaung range of hills.
(II) The Pagan " "
(III) The Gwegyo " "
(IV) The intermediate country.

(*I*) *The Yenangyaung anticline and range of hills.*—The range of hills which runs close to Yenangyaung extends northwards into Myingyan district for about fifteen miles, and southwards I have traced them for ten miles, but had not reached the end of the hills. These hills are formed of beds bent into an anticlinal arch the axis of which north of Yenangyaung has a direction 20° W of N, E of S, but at the Yenangyaung oil-field the direction bends to 40° W of N, S of E and to the south it continues in this direction as far as the limits of my survey.

The Yenangyaung range of hills, their extent,

and direction.

The anticlinal arch rises to its greatest height at Khodaung between two and three miles east of Yenangyaung and towards the north and south it gradually sinks down so that at Lebingon and

Position of summit of anticline.

Nyamigs about fifteen miles to the north it has disappeared and become covered up by recent deposits.

Miocene beds exposed in the centre of the anticline: their extent.

In the centre of the anticline near Khodaung, Iwingon and Minlindaung, miocene beds are exposed in an area 5½ miles long by 1 mile broad in the centre. With the exception of a small part of the area in blocks 3 S and 4 S of the Yenangyaung oil-field this exposure of miocene beds has been mapped and described by Dr. Fritz Noetling, and so I will only give a few notes on the southern part of this area which was not mapped by him.

Most of the miocene exposure described by Dr. Noetling.

Southern portion of the miocene area.

At Minlindaung at the south of blocks 1S and 2S of the Yenangyaung oil-field, where Dr. Noetling's survey ends, the exposure of miocene beds is about ¼ mile wide, but in the next block to the south it widens out to ¾ mile wide. In the northern part of blocks 5S and 6S, however, a little over a mile south of Minlindaung the miocene beds become covered up by Irrawaddi sandstones, and as the axis of the anticline is sinking towards the south I did not find any more exposures in that direction within the limits of my Survey (Memoirs, G. S. I., Vol XXVII, Pt. 2, p. .)

The miocene beds: only the top beds of the upper miocene exposed.

Of the miocene strata only the upper beds of the upper miocene are exposed and like those described by Dr. Noetling they are olive-coloured shales and sandstones with very numerous pieces of gypsum scattered through them. The uppermost bed is a sandstone of a brilliant white colour; in places this is stained red, etc., but its colour is always brilliant and in striking contrast with the dull colour of the Irrawaddi sandstones above. Like the other miocene beds below it contains numerous pieces of gypsum and it gradually passes into the underlying strata. The thickness of this sandstone even within the limits of this small area varies very greatly, and where the Thi ho Yo Chaung in block 3S crosses the boundary of the miocene beds it

The uppermost bed, a remarkable white sandstone.

is not present at all. In the northern part of the Yenangyaung oil-field it is absent, but twenty-eight miles to the north in the Singu exposure of miocene beds there is a very considerable thickness of it. This varying thickness of the uppermost miocene bed within a small area points to an unconformity of erosion between the miocene and pliocene. The upper miocene beds and the pliocene beds overlying them have approximately the same dip and strike, but owing to the want of definite bedding planes it is impossible to observe this accurately.

Its varying thickness indicates erosion-unconformity.

With reference to the occurrence of petroleum in lower miocene beds Dr. Noetling has shown[1] that in Burma as in other countries, it is only found in workable quantities at the crests of anticlinal folds and where the crests are most elevated.

As to the possibility of occurrence of petroleum in lower miocene beds.

In the Yenangyaung anticline we find the crest of the fold at its highest level at Twingon, Khodaung and Beme and gradually sinking both to the north and to the south, and so as the limits of the workable area have been reached in the Yenangyaung oil-field there is no hope of finding other workable areas along the Yenangyaung anticline at least within the limits of my survey.

Surrounding the miocene area and resting on its strata with, as we have just seen, unconformity of erosion, are the beds of the Irrawaddi series, which are of pliocene age.

In the neighbourhood of Yenangyaung, where the anticlinal arch riess to its greatest height, the Irrawaddi beds have a fairly steep dip on both sides and between the oil-field and the town of Yenangyaung Dr. Noetling has measured[2] dips from 50° to 32°. Towards the north, owing to the sinking of the anticlinal arch, the dips steadily decrease until in blocks 25N and 26N the Irrawaddi beds, where they become covered up by more recent deposits, are lying almost horizontally and the dips

The Irrawaddi (pliocene) beds.

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2.
[2] Memoirs, G. S., I., Vol. XXVII, Pt. 2, Map.

to each side are very slight. On the south side of Yenangyaung oil-field the sinking of the anticlinal arch and the consequent decrease of dip is not so rapid as towards the north, and in blocks 13S and 14S, eight miles south of Khodaung and the farthest limit of my survey, the dips are still considerable.

Their characters.

The Irrawaddi (pliocene) beds consist of current-bedded soft sandstones or rather sand rock, which is usually so friable that pieces of the rock can be easily broken up between the fingers; these beds are whitish or yellowish in colour but are in places stained red by iron, and scattered through them are concretions of two kinds.

Concretions in the Irrawaddi beds.

The larger concretions which are nodular, mammilated or kidney-shaped are siliceous and calcareous; they are greyish in colour, very hard and often of considerable size, two or three feet in diameter or even more, and in the rock they are usually arranged in strings; besides the nodules there are layers and bands of hard rock which is similar to that forming the nodules. The smaller concretions which are scattered irregularly through the sandstones are calcareous, are rarely more than three or four inches in length, they are whitish or yellowish in colour like the rock in which they are imbedded, of various irregular and fantastic shapes resembling roots of trees, sponges, bones, etc., and often hollow in the centre.

Irregular conglomeritic bands in the upper and lower parts of the series.

In the lower and upper parts of the series there are irregular bands of ferruginous conglomerate of varying thickness, most of which when their outcrop is traced are seen to die out within a short distance; the bed, however, at the base of the series is fairly constant within the area of the Yenangyaung oil-field. Quite subordinate to the other beds are some bands and lenticular patches of argillaceous beds, clays and sandy-clays, which as a rule do not extend far and soon die out, and they are also rarely more than four or five feet in thickness.

Thickness of the beds.

The thickness of the Irrawaddi beds it is impossible to tell from my last season's work as the top of the series is nowhere to be seen, besides I have not measured a greater thickness than the 4,530 feet, which Dr. Noetling measured at Yenangyaung.[1]

Division of the Irrawaddi into four zones.

Owing to the uniformity of the series it is impossible to definitely divide it into zones, but an examination of the beds shows that certain characters are more or less confined to different horizons, of which I have distinguished four. It is, however, impossible to map these as they pass gradually into one another so that no boundary between them can be distinguished. The following are the horizons in ascending order, but as I am not acquainted with the uppermost beds of the series there are probably higher zones:—

Zone 1. Sandstones with numerous bands of ferruginous conglomerate containing vertebrate remains.
„ 2. Sandstones with large rounded concretions and much fossil wood.
„ 3. Sandstones with numerous small root-like concretions and little fossil wood.
„ 4. Sandstones with ferruginous conglomerate and much fossil wood.

The lowermost zone.

Zone 1. The lowermost zone consists of the ordinary yellowish white sandstones containing numerous pieces of fossil wood and it is full of very hard concretions which are both calcareous and silicious, and these are either in globular or mammilated masses or in definite layers in the sandstone. Pieces of the concretions and of the fossil wood are everywhere seen lying on the surface of the ground. Scattered through these sandstones are numerous layers of red ferruginous conglomerate, which with the exception of the basal bed are very inconstant and rapidly die out when traced in any direction.

The basal conglomerate band.

The basal band of conglomerate is fairly constant within the area of the Yenangyaung oil-field and is very conspicuous; it varies somewhat in composition and greatly in thickness within a short distance, and at one place in the southern part of the Yenangyaung oil-field it dies out entirely for a short distance. Dr. Noetling has mapped[2] this as a separate zone, and as my work on the southern part of the Yenangyaung oil-field was a continuation of his,

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2.
[2] Memoirs, G. S., I., Vol. XXVII, Pt. 2, Map.

I have done likewise. I am, however, inclined to include in this zone the next 150 to 200 feet of sandstones which contain bands of ferruginous conglomerate, as in other parts of the country I have obtained some of the typical fossils of the lower bed in a higher layer of ferruginous conglomerate. Dr. Noetling would, I understand, welcome this inconclusion, but the impossibility, in that case, of mapping the upper limit of the zone and the great help the mapping of a basal zone is in the interpretation of the structure of the Yenangyaung oil-field induced him to confine the zone to the bottom bed of conglomerate. From this lower conglomerate Dr. Nœtling has obtained a number of fossils, but as I had only a small area of the bed to map and the season was far advanced, I was unable to spend much time in searching the bed on the southern side of Minlindaung. I obtained, however, part of the jaw of a *Cervus* sp. and fragments of bones of *Crocodilis* sp. or *Guvialis* sp. and of *Trionyx* sp., and I saw numerous very much broken fragments of the bones of very large animals, but of these I was unable to get any fragments sufficiently well preserved to take away.

Fossils.

2. The above bottom zone passes gradually up into the second zone which is composed of similar sandstones, but has no ferruginous bands. Especially in the lower part it contains numerous concretions, like those in the beds below, and pieces of fossil wood; pieces of these concretions and of the fossil wood are scattered over the surface of the country. In the upper part of the zone these concretions and the fossil wood become less and we find present the smaller calcareous concretions, which occur in many fantastic shapes like roots, sponges, bones, etc., and in this way the beds pass into the zone above. From this zone the only vertebrate remains I have found are vertebræ of a crocodilian animal which were lying on the surface of the ground.

Zone 2. Its character.

Fossil remains.

3. In the third zone there are the same white and yellowish-white current bedded sandstones, but the concretions are chiefly the calcareous ones resembling roots,

Zone 3. Character and fossil contents.

etc., which are often hollow in the centre ; the larger rounded concretions and fossil wood are much less common than in the zone below.

Zone 4. Character of the component beds.

4. In the fourth zone we have conglomeratic beds coming in again. At first it is simply small pebbles scattered through the sandstone, but this gradually passes into beds of conglomerate in which the pebbles are at first small, but increasing in size as we get into the higher beds until at last we have conglomerates with big pebbles like those near Nyounghla. At the same time as this increase in the size of the pebbles we have an increasing quantity of oxide of iron in the beds; at first they are only stained by it, but it increases until we have beds, of conglomerate or pebbly sandstone of a deep red or reddish brown colour. In these conglomerate beds there is usually a large amount of fossil wood, which is mostly much more highly silicified than that in the lower Irrawaddi beds. It was from conglomerate beds of this zone that Mr. Crawford, Dr. Oldham, and in late years Dr. Noetling have obtained numerous fossil vertebrate bones, but I was unable myself to find any such remains in this zone.

Fossil wood and vertebrate remains.

These last three zones of mine Dr. Noetling has included in one zone, his zone of *Mastodon latidens* and *Hippopotamus irravadiensis*. Higher than this Dr. Noetling has another zone, but I did not have any opportunity of examining Irrawaddi beds of later age than those of my fourth zone.

Plateau gravel (post-pliocene). Its extent.

Resting horizontally on the upturned Irrawaddi beds on the plateau-like top of the Yenangyaung hills, and consequently of post-pliocene age, there are some patches of gravel which at one time were evidently continuous, but the denudation of the hills and the deep cutting into them of the stream beds has left only a few remnants. Dr. Noetling mapped some of this plateau gravel, and I have found several more patches farther north on the tops of the hills in blocks 10N, 12N, 14N, and D of the Yenangyaung oil-field, which extend to the north as far as the Gwe Chaung, but on the north

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2.

side of the broad valley of this stream I have not detected any more on the Yenangyaung hills. In the southern blocks there is no trace of this gravel, but west of them on the tops of the hills at Nyaunghla close to the Irrawaddi it is found, but is at a different level from that of the gravel near Yenangyaung and farther north. Plateau gravel is also found on the top of the Tangyi hills and in the country round Pagan also at the different levels. Besides being found on the hills similar gravel is also found in the neighbourhood of the Yenangyaung oil-field, amongst recent deposits in the valleys and near the Irrawaddi river. These beds of plateau gravel consist of large well-rounded pebbles of quartz and fossil wood, which are mostly bound together by a red ferruginous matrix of clay, sand and smaller pebbles ; the lower beds of the gravel, however, have not so much cementing material as those on the tops of the plateau. The fossil wood and the majority of the smaller pebbles were evidently derived from the Irrawaddi beds, but I do not think it is possible that the larger pebbles could have been derived from these beds, for although in a few places I have seen pebbles as large as the average big pebbles of the plateau gravel, these were comparatively scarce and there were none so large as the largest of the pebbles in the gravel. The fossil wood in the gravels is mostly highly silicified like that scattered through the conglomerates of the uppermost of the zones in which I have divided the Irrawaddi beds.

Nature of the components of plateau gravel.

Origin of the pebbles.

The recent deposits at a lower level, called by Dr. Noetling[1] the lower silt, I shall not describe here as they may better be considered when I come to deal with the extensive deposits of a similar nature, which cover the country between the ranges of hills, and of which these are merely parts.

The lower silt of Dr. Noetling.

Besides this lower silt, but very difficult to distinguish from it, there are deposits of stream sands from the present streams and rain-

[1] Memoirs, G. S., I., Vol. XXVII, Pt. 2.

wash; when these, especially the latter, are in juxtaposition to the lower silt it is impossible to distinguish between them.

Relative age of the lower silt and the plateau gravel.

To the relative age of the plateau gravel and the lower silt I had better refer here. The plateau gravel was deposited on the tops of the hills before denudation had moulded the country into its present form and when the tops of the hills were a flat plateau, and it has suffered from the same denudation which has carved out the present valleys and stream beds, but the lower silt has been deposited at a lower level in the valleys, carved out by this denudation, and so I think the plateau gravel is certainly of greater age than the lower silt.

The recent and post-pliocene beds near Yenangyaung divisible into three groups.

The post-pliocene and recent deposits in the neighbourhood of Yenangyaung may, I think, be divided into three divisions:—

1. The plateau gravel representing the former river beds of either the Irrawaddi basin or a predecessor of it.
2. The lower silt being part of an older alluvium of the Irrawaddi.
3. The rain-wash and stream sands being a newer alluvium.

The Pagan range of hills.

The position, extent and direction.

II. *The Pagan anticline.*—Five miles south-east of Pagan and Nyoungu we come to a range of hills rising for their whole length quite suddenly out of the surrounding country, which are generally known as the Pagan hills and which run in a direction 25° W of N, E of S for a distance of 14 miles to the south-east.

Beds of upper miocene.

These hills are composed entirely of upper miocene (Yenangyaung) beds of which neither the top or bottom beds are exposed, and which are bent into an anticlinal fold.

The anticlinal fold unsymmetrical.

In this anticline the fold is unsymmetrical, being much steeper on the east side than on the west, but owing to the anticline being

Fault.

faulted close to its crest, or else to very extensive denudation, only in two or three places is a small thickness of the beds on the east side exposed, and everywhere else along the eastern side of the hills we have a steep scarp of the westerly dipping beds. Where exposed the beds on the east side have a dip of about 80° to the east, and the dip of the rocks on the westerly side of the anticlinal arch is fairly constant at about 35° all along the hills with the exception of the extreme ends. At their northern end the hills end quite abruptly in a vertical cliff which shows a section across the anticline, but at the southern end they sink more gradually but still somewhat rapidly underneath the alluvium which surrounds them.

Character of the beds.

The upper miocene beds which are exposed in these hills consist of thick massive beds of sandstone with layers of shale, and as at Yenangyaung but unlike the beds at Singu and Yenangyat the sandstones predominate. The thickness of beds exposed I measured as between 2,000 and 2,500 feet. The sandstones which occur in thick massive beds are greyish, yellowish and brownish in colour and are mostly very fine-grained; the shales are greenish and greyish in colour and in one band near the base there were streaks of coal. In the centre of the range of hills towards the base of the beds exposed, the shales have a distinct bluish-tinge, and this may perhaps indicate that the Prome beds are not very deep below the surface. I did not see any lower miocene beds exposed or find any traces of petroleum or hear of any being noticed by the villagers at other times, but it is possible that oil-bearing rocks may be present at no very great distance from the surface. As there are no means of knowing the thickness of the upper miocene beds in this part of the country or how great a thickness at the top is concealed beneath the alluvium of the surrounding country, it is impossible to make even an approximate guess at the depth of the Prome beds or the likelihood of their being oil bearing, but when other sources of supply are exhausted this range of hills might be tested by boring on their eastern side with some hopes of success.

Streaks of coal in a shale band.

No petroleum found.

Where to test for oil by boring.

III. *The Gwegyo anticline.*—In a south-westerly direction from the end of the Pagan hills we see the northern end of another range of hills formed by beds bent into an anticlinal fold whose axis has a similar direction to the axis of Pagan anticline, but is not in the same line with it. Like the Pagan hills, the Gwegyo hills are composed of upper miocene Yenangyaung beds, but here the pliocene beds are exposed in the surrounding country to the northern part of the hills; around the southern part of the range, however, the country is entirely covered by recent deposits. This anticlinal arch is also faulted close to its crest, not by a single fault but by a series of faults in different directions, consisting of one main fault in a direction varying from 5° E. of N., W. of S., to 5° W. of E., N. of S. and of several smaller cross-faults; in the hills close by Nyaunigyin the shifting caused by one of these faults may be distinctly seen and different beds are exposed in the cliff on the two sides of the fault. Owing to this faulting along the eastern side of the hills the beds on the east side of the anticlinal arch are only exposed in a few places, and then it may be seen that the anticline is somewhat unsymmetrical, but not so much so as that in the Pagan hills; on the east side I have measured dips of 62° to the east, whilst the general westerly dip is about 40°. Along the greater part of the hills the eastern face is a scarp of the westerly dipping beds.

The Gwegyo range of hills.

Position and direction.

Upper miocene beds compose the hills.

Faults.

The upper miocene beds in these hills are similar to those elsewhere, greyish and brownish sandstones with interstratified beds of greenish or greyish shale. Unlike the rocks in the Pagan hills the shales are here predominant and the beds much more like those at Singu, but the uppermost bed of white sandstone is here wanting. I did not find any Prome beds exposed or any traces of oil, but amongst the basal upper miocene beds, which are exposed, there are some shales which are very like those in the Lower Miocene at Yenangyaung. The villagers too

Characters of the beds.

Petroleum : none seen.

tell me that oil has been seen at different times in places which they pointed out to me ; these are near the faults, and although I had excavations made I could not find any indication of it.

Site of its possible occurrence near the surface.

It is quite possible that Prome beds are brought near the surface on the eastern side of the hills, and the chances of finding oil by boring between Ayadaw and Gwegyo are not hopeless.

Pliocene beds of the area.

Around the northern part of the hills the pliocene beds are exposed overlying the miocene rocks. These are of the usual type like those described before, and from one of the conglomerates near the base I obtained a tooth of *Sus* sp.

To the recent beds I will allude in the next section.

The intermediate country.

IV. *The intermediate country.*—The country between the main ranges of hills may be divided into two portions, *viz.*, (i) low ranges of hills and (ii) flat or rolling country, and this division roughly corresponds with the geological one of pliocene and alluvial country.

Low ranges of hills.

Composed of pliocene beds.

(i) The low ranges of hills which are approximately parallel to the main ranges are mostly formed of lesser folds in the rocks by which only the pliocene beds are elevated above the rest of the country. These areas, where the pliocene beds are exposed, are like those in the Yenangyaung hills, rugged and barren and so much cut into by innumerable stream beds as to be very difficult to traverse; almost the only vegetation on them is the low thorny acacia-trees (*Acacia ferruginea*) and the bare ground is covered with loose pieces of the hard concretions. Of the nature of the beds there is nothing more to say as they are exactly like those described before.

The flat or rolling ground.

Much cultivated.

(ii) The flat or rolling country is quite different in character, being largely cultivated and having on it innumerable toddy palms. This country is covered by a deposit of recent alluvial beds, which is often of great extent, and the thickness of

The country covered by recent alluvium.

which it is impossible to estimate, but which must in places be very considerable as deep stream beds have not reached the base of it. The beds consist of sands, clayey sands and gravels and vary somewhat with the locality. At Oubintwingwa they are white clayey sands with subordinate clay bands and containing numerous but small nodules of kankar, which are rarely more than ½ inch in diameter; farther east towards Gwegyo they are gravelly and contain numerous small rounded pebbles of quartz and fossil wood, which shows that they were derived from the pliocene beds, and at Pagan these beds of gravel, which cap the low hills, are ferruginous and cannot be distinguished in character from the plateau gravel on the tops of the Singu and Tangyi hills; in the cliffs of the Irrawaddi too between Yenangyaung and Kyaukye and in other places one finds interstratified with ordinary alluvial beds, which Dr. Noetling has called the lower silt,[1] beds of gravel with pebbles and pieces of fossil wood like those in the beds of plateau gravel on the hills above, the only differences between the gravels being the quantity of iron in the matrix between the pebbles, the lower beds being as a rule less ferruginous than the beds on the hills.

The alluvial beds at Oubintwingwa.

Near Gwegyo.

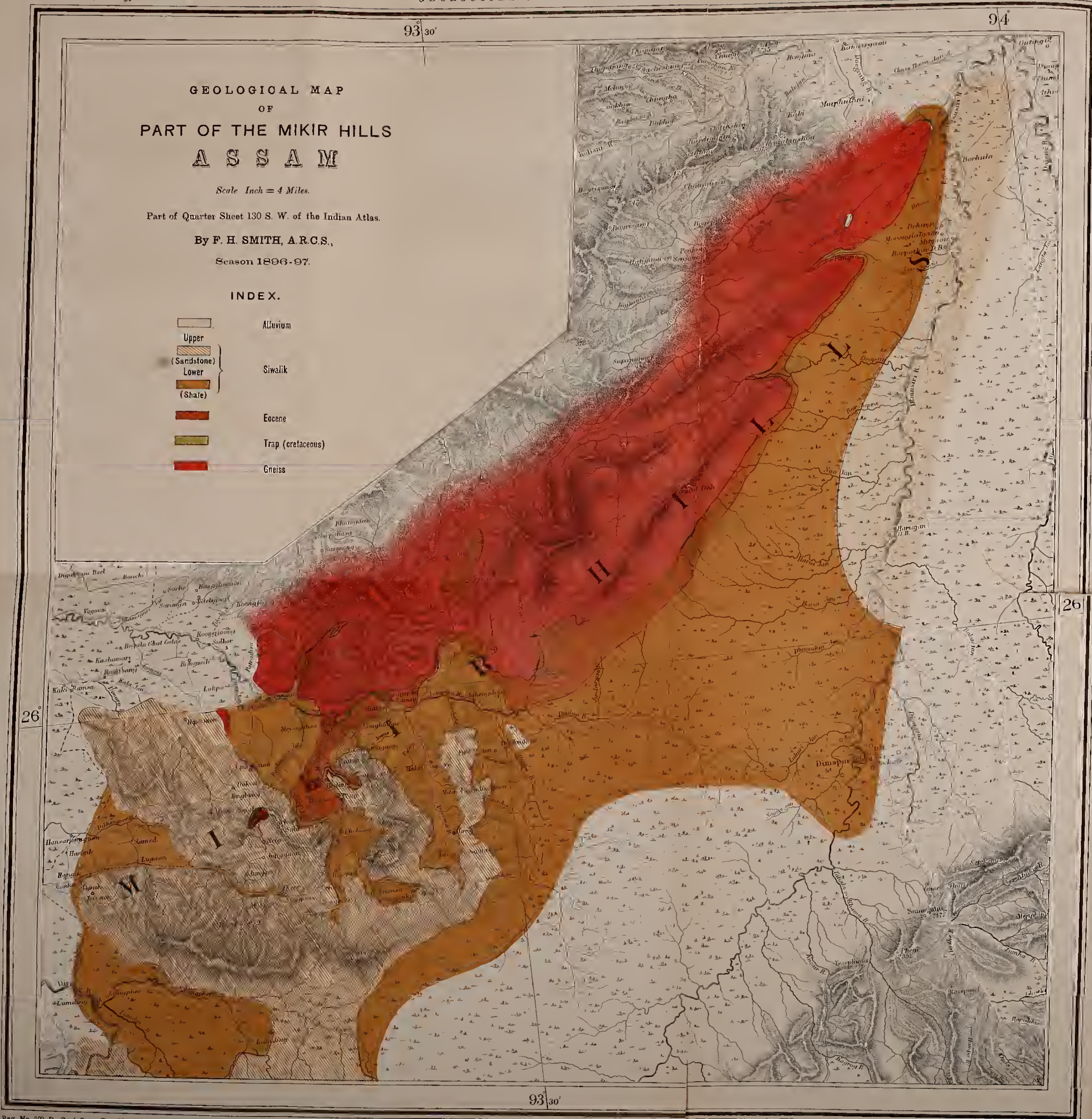
Between Yenangyaung and Kyaukye.

Around the Gwegyo hills and between them and Kyaukpadaung there are in the sandstones and gravels numerous spherical nodules of ironstone, which when broken are seen to be concretions round a nodule of clay or some other centre; formerly these nodules were smelted for iron by the Burmans in rude furnaces, and remains of these furnaces and slag heaps may still be seen in several places, *e.g.*, at Nyaunigyin, Kyauktan, etc.

Ironstone nodules as a source of iron.

The nature of the beds is, I think, undoubtedly alluvial, they are post-pliocene in age resting in places on the upturned edges of

[1] Memoir, G. S., I., Vol. XXVII, Pt. 2, p.


GEOLOGICAL MAP
OF
PART OF THE MIKIR HILLS
ASSAM
Scale Inch = 4 Miles.
Part of Quarter Sheet 130 S. W. of the Indian Atlas.
By F. H. SMITH, A.R.C.S.,
Season 1896-97.
INDEX.
Alluvium
Upper (Sandstone)
Lower (Shale)
Siwalik
Eocene
Trap (cretaceous)
Gneiss
MIKIR HILLS
93°30'
94°
26°
Dimapur
Lumding

denuded Irrawaddi beds, and the country over which they are deposited shows they must have been the alluvium of a very large river. This river was most probably the Irrawaddi, and the level of these alluvial beds is not much above the present level of that river, of which they are probably an older alluvium.

The Geology *of the* Mikir Hills *in* Assam, *by* F. H. Smith, A.R.C.S., *Deputy Superintendent, Geological Survey of India.* (With Pl. 4).

The Mikir hills occupy a tract of country lying to the south of the Brahmaputra, between Nowgong and Golaghat. They are separated from the Naga hills, on the east, by the Dhansiri valley or 'Nambor forest', and from the North Cachar hills, on the south, by the Lumding plain.

The Jamuna river, with its tributary the Deolao, cuts through the hills from east to west, some 20 miles north of Lumding, dividing them into the north and south Mikir hills, the former also being known as the Rengma hills.

I started for the Mikir hills from Silchar, and thus had to traverse the North Cachar hills *en route*. I followed the course of the Assam-Bengal railway through these hills, ascending the Jatinga valley to the small station of Haflong, and thence turning northwards across the hills to Lumding, which is situated at the southern corner of the Mikir hills.

North Cachar Hills.

The geology of the North Cachar hills, as seen along the railway line, appears to be very simple, the visible rocks being confined to the upper Tertiaries.

At the mouth of the Jatinga valley, one mile north of Balicherra, there is a low ridge composed of rounded sandstone boulders, sometimes loosely cemented together in a sandy matrix. The Jating river-bed is full of exactly similar pebbles, so the ridge probably represents merely a sub-recent river deposit.

Along the Jatinga valley soft clay-shales and shaley sandstones, shewing much disturbance, are seen to be overlaid, in the ranges to north and south, by a great thickness of massive sandstone.

Good sections are frequent in the railway cuttings, the shaley rock taking the following forms: nodular, grey clay-shales; finely laminated shales and shaley sandstone, with thin, micaceous layers; blue, splintery shales, with sandy beds and irregular bands of blue, micaceous, calcareous sandstone; dark blue-grey clay-shales, with thin bands of greenish sandstone and gypsum. Occasional threads and bands of lignite, up to an inch or two in thickness, occur in the shales.

Great disturbance is seen throughout, the beds dipping steeply in all directions, and in several cases they are seen to be torn off suddenly by small faults.

The difficulties of making a railway over this sort of rock are great. For instance, near Dumcherra a tunnel had been cut through a spur along the strike of the shales. When the excavation was complete, the slab of vertical shales over the tunnel slipped bodily down into it, obliterating the tunnel, and leaving a corresponding cutting over the surface of the spur.

Several thin bands of coal occur in a tunnel to the south of Kayeng, but they are only a few inches each in thickness, and of no economic importance.

Approaching Haflong the shales gradually die out and are replaced by more and more massive sandstone, showing frequent false bedding and ripple-marked surfaces.

Along the crest of the range, to the north of the upper Jatinga valley, great thicknesses of this massive sandstone are seen horizontally bedded; and along the Burrail range, to the south of the valley, similar beds occur dipping away 20° to 30° S. E. Haflong is situated on this sandstone, which is a softish, fine-grained rock, grey-green in colour, with occasional bands of fine shale. It is roughly horizontal, but considerable disturbance is frequently seen in the finer beds.

To the north-east of Haflong another small exposure of the crushed shales occurs in the Phoiding valley; but otherwise, north of Haflong, only massive sandstone, grey to buff in colour and generally horizontal, is seen as far as the Lumding plain.

At Boila, about 3 miles north of Mupa, there is a reported occurrence of limestone in a nala amongst the hills. I saw no trace of any limestone band, but I had no time to examine the country. From subsequent information, I have learnt that the exposure is a layer of calcareous tufa, forming a low cliff in a nala bed. It is only a foot or two in thickness, and it must come, I think, from a deep-seated spring, as there is no limestone near this horizon.

Several wells had been sunk in the neighbourhood of Hathikali by the late Mr. F. Wilde, Executive Engineer of that district. From figures, which he kindly gave me, it appears that the sandstone reaches down to 50 or 60 feet below the ordinary river levels, and that it is underlaid by blue clay-shale of unknown thickness.

To the north of Hathikali massive sandstone is seen in all the railway cuttings. In some of the sections thin partings of dark carbonaceous shale occur in it. The dip is usually roughly horizontal, but here and there it changes to a steep southerly inclination.

The sandstone dies out before reaching the Lumding plain, where a few small exposures of the underlying, horizontal grey clay-shale are seen.

Summary.

The geological 'plateau' of the Shillong hills evidently stretches eastwards as far as Haflong, and the 'uniclinal flexure', which terminates the plateau along its southern edge, turns north-eastwards, up the Jatinga valley, exposing along its axis the crushed and contorted shale-series, and leaving the overlying sandstones horizontal and undisturbed to the north, but dipping down steeply along the Burrail range to the south-east.

Mr. H. B. Medlicott has already noted this sudden turn of the great flexure[1]; it is probably continuous along the foot of the Burrail range far to the north-east, into the Naga hills.

The massive sandstone continues northwards from Haflong, with a very gentle general northerly dip and a gradually decreasing thickness across the North Cachar hills. In the Jatinga valley and surrounding high ranges, the shales and sandstone attain a great thickness. The visible section must contain 5,000 feet of rock, of which fully 3,000 feet belong to the massive sandstones.

Northwards the thickness decreases greatly. Near Lumding the total is certainly under 2,000 feet. It is evident that a great increase in the development of the series takes place from north to south—a fact which, as frequently pointed out by earlier observers, occurs all along the southern margin of the Shillong plateau.

No trace of nummulitic beds is met with across the North Cachar hills, and as these are very constant throughout the Shillong and Mikir hills at the base of the tertiary, it is almost certain that the Jatinga shales and sandstones are of younger tertiary age—a view already adopted by Medlicott. No hard and fast line can be drawn between the shales and sandstone, but it is probable that they represent the lower and upper Siwaliks, though it is also probable that the younger-pliocene beds are absent in the Haflong section.

Mikir Hills.

The Mikir hills present several difficulties to the geologist, the chief of these being the great lack of rock-exposures of any kind, to say nothing of any visible length of section. The country is made up of low undulating hills, densely covered with jungle and tall grass, the latter often 30 feet in height. The rainfall is moderate, and so a very substantial coating of soil covers the whole country. On the hill-tops occasional boulders give evidence of the rock below, but they are seldom actually *in situ*.

The hill-slopes and valleys are usually absolutely bare of any rock-exposures. The larger nalas form the chief hunting-ground of the

[1] Mem. Geol. Surv., Ind., Vol. IV, Art. 3, pp. 44-48.

geologist, and occasionally the smaller ones shew a few yards of rock *in situ*.

The great mass of the north Mikir hills is composed of gneiss, and the ranges are higher and steeper than those of the southern hills. The jungle is almost as thick, however, on the northern hills, but they present a fair number of rock-exposures.

Several peaks in the north Mikir hills reach 4,000 feet in height, while in the south Mikirs only one range touches 1,500 feet.

General Geology.

All round the foot of the north Mikir hills, sedimentary rocke overlie, and abut against, the gneiss. These younger rocks stretch away, southwards, over the south Mikir and north Cachar hills, and eastwards, across the Dhansiri valley into the Naga hills.

They were evidently deposited on the ancient surface of the gneiss, which, being naturally uneven, has frequently given the beds immediately overlying it a gently undulating dip, but the general lie of the beds is horizontal.

Very few of the sedimentary rocks contain fossils, but there is fortunately a fairly constant band of nodular, earthy limestone, full of nummulites, which is always found at or near the junction of the sedimentary rocks with the gneiss. This band supplies most of the evidence as to the age of the younger beds.

At several places decomposed trap and some doubtful beds of small extent intervene between the gneiss and the limestone, probably representing the cretaceous; but the mass of the sedimentary rocks in the Mikir hills is undoubtedly of tertiary age. The chief divisions with their probable approximate ages and thicknesses are as follows:—

Alluvial Deposits.

		feet.
	Soft mottled clays, sandy soil and loose gravels.	100

Tertiary.

1. *Pliocene*	. Soft yellow sandstones, locally and superficially highly ferruginous: with silicified wood, rare	1,000

	calcareous bands, and local conglomerates at the base. Passing down into	feet
2. *Miocene and Oligocene.*	Finely laminated grey clay-shales, with hard, concretionary, calcareous bands, rare shell-beds, and thin coal-seams. Resting with apparent conformity upon	800
3. *Eocene* .	. Nodular, earthy limestone, highly nummuliferous, with associated unfossiliferous sandstones.	300

SECONDARY.

Cretaceous	. Doubtful coal-bearing shales, overlying white chalk-like argillaceous bed, associated with decomposed, mottled, earthy trap.	50

MASSIVE GNEISS.

Age unknown.

It will be convenient to treat the different divisions in detail, before dealing with the general arrangement of the beds.

CRYSTALLINE ROCKS.

Nearly the whole mass of the north Mikir hills appears to be composed of massive gneiss, or foliated granite. The rock varies in texture from a coarse-grained, porphyritic, slightly foliated granite, to fine-grained strongly banded gneiss. The colour frequently changes, from black and brownish-grey, through intermediate tints, to salmon-pink; but the composition alters only very slightly. There is one interesting occurrence at Miji of foliated charnockite—hypersthene-bearing gneiss—interbanded with the ordinary gneiss of the Mikir hills. It is similar in all respects to the Madras hypersthene bearing rocks. I only met with one or two layers of the charnockite, and the exposures are somewhat obscured, but it occurs intimately interbanded along the foliation strike of the gneiss, though the two rocks are quite distinct and do not pass into one another gradually. The bands of charnockite are only 20 to 30 feet in thickness.

In the south Mikir hills only two small exposures of gneiss occur: one in the peak of Longloi hill, and the other two miles south of

Bokula Ghât. The general foliation strike of the gneiss is very inconstant, but the dip is usually either vertical or inclined at a high angle. The strike is continually changing, but the most frequently observed direction of foliation was east and west.

Occasional veins of quartz are seen in the gneiss. Near the junction of the Jamuna and Langapoo nalas, one of these takes the form of quartzose schist, becoming in places garnetiferous and micaceous.

Under the microscope, the various specimens of gneiss appear very similar. They are nearly all fresh, uncrushed rocks, one or two only showing some signs of crushing. They are composed of quartz; plagioclase felspar, shewing frequent lamellar intergrowths; rare orthoclase; brown biotite and green hornblende; grains of magnetite, sometimes passing into hæmatite, and granules of apatite, zircon, and occasionally brown rutile. One or two bright yellow-green crystals in one section are probably epidote. Graphic and micro-pegmatitic structure is frequently seen amongst the quartz and plagioclase.

The charnockite under the microscope is a coarse-grained fresh looking rock, shewing little crushing. The groundmass is chiefly composed of quartz grains, traversed by thin lines of inclusions, and slightly decomposed plagioclase felspar, with much hypersthene—pleochroic light-green to pink—scattered through it. Brown biotite is common, and many grains of magnetite occur, some of which are associated with a dark-green isotropic mineral, apparently a spinel (hercynite). Small granules of apatite and zircon are also seen.

Trap-Dykes.

There seems to be a remarkable absence of trap-dykes in the gneissic area; in fact, I have only seen one undoubted dyke. A few exposures of soft, green, hydrated trap occur in some of the rivers, but they do not appear to descend to any depth. When at Pangso, on the Nambor river, I was taken by the natives to a reported thick seam of coal, in the hills between the Nambor and Doigrung rivers. When I reached the spot, I found a vein of very curious dark trap—the 'coal' of report—about 20 feet wide, running east and west in the gneiss. The trap was a remarkable, coarse-grained rock shewing a distinct ophitic structure. Under the microscope it is seen to be composed of light-green to colourless hornblendes, with large brown biotite crystals ophitic round them. It contains also some plagioclase felspar, and a few quartz grains, with a fibrous mineral of high double refraction—apparently an altered hornblende.

Cretaceous.

Between the gneiss and the definite nummulitic band, some doubtful beds of intermediate age occur, here dealt with as cretaceous.

The only occurrence of pre-tertiary sedimentary rocks, in the south Mikir hills, is on the flanks of Longloi hill. The peak of the hill is of gneiss, lapped round by sedimentary rocks. Thick jungle obscures everything, however, and it was only with the help of the neighbouring villagers that any rock exposures could be found.

Longloi hill.

About one mile west-south-west of Bihar the following section is seen in a small nala, which traverses the outcrop of the beds. The section is presumably in regular descending order, approaching the gneissic core of the hill.

The first exposure of rock seen in the nala is a barrier of 15 feet of scft earthy, sandy limestone, full of nummulites, dipping 60° N.W. For 100 yards above this barrier no exposure is seen, except where a small landslip shows a few yards of soft, sandy clay of recent appearance. Then, with no trace of overlying beds, the following section is found, dipping 10° to 20° N.N.W., in descending order :—

	Feet.	Inch.
Brownish-black coal, with many grains of fossil resin, slightly shaly at the base	9	4
Similar brownish-black coal with specks of resin . . .	2	8
Purple to black carbonaceous shale	4	0
Similar coal to above	0	7
Purplish to light-grey clay-shale with plant remains . . .	5	0
White argillaceous rock, stratified above, massive below, with small quartz-grains included, visible for	35	0

The section in the nala-bed becomes obscured, above this, by recent dèbris and boulders of soft sandstone. The next exposure is that of the massive gneiss on the hill-top.

A fairly good section is seen near Silbatta, a small trading station, consisting of one grass hut, at the Jamuna Falls.

Silbatta.

At the foot of the Falls, and again about a quarter of a mile above them, the gneiss is seen to be overlaid by a band of decomposed and hydrated earthy trap. The trap presents a mottled appearance, dark-red and dull-green in colour, and seems to be some 20 feet in thickness.

It is overlaid by a bed of white argillaceous rock, very like chalk in appearance, but neither calcareous nor fossiliferous. The white rock is slightly nodular below, but stratified above, with a dip of 5° S.E. It has about the same thickness as the mottled trap.

Above the argillaceous rock the section is obscured, both above and below the Falls; but the next exposure in both cases is of nummulitic limestone dipping gently north to north-west.

Beds of decomposed trap are seen overlying the gneiss in several of the river-beds, where sections are exposed. In the Jamuna river, north of Miji, two bands of hydrated trap cross the river-bed, apparently resting on the gneiss. The trap is of a light blue-green colour when freshly broken, with brilliant grey grains scattered through it, very like graphite, but it usually changes into the dull coloured mottled trap near the surface.

Other localities.

I attempted to cut sections of several of these trap bands, but the rock was too rotten to hold together. The grey grains, however, turned out to be a titaniferous iron-ore.

On the Haria Jan a band of dull-green trap is seen resting directly on gneiss, and underlying the nummulitic rocks, but no contact-section with the latter is visible.

A similar band is seen on the north bank of the Deopani, where a small tributary nala flows over a considerable sheet of mottled brick-red and greenish trap, which can be traced for about 150 yards. It rests on the gneiss, and the only rock visible above it is sandy nummulitic limestone.

The last exposure of trap that I saw, in a northerly direction, was a low bank of mottled pale-blue and ochreous trap about 20 yards below the Nambor Falls, resting on the gneiss and immediately overlaid by a series of grey clay-shales and shell limestones. Medlicott states that "there is no trace of trap under the (supposed) cretaceous beds on the Namba."[1] The fact remains, however, that this small exposure occurs; though, as it is almost on the river level and very like the grey waterworn gneiss superficially, it might easily escape observation.

Summary.

The fairly constant occurrence of the mottled earthy trap at the gneiss-sedimentary junction suggests the probability that the exposures belong to a continuous trap-flow. I have never seen any trace of real bedding in the trap, but it can only be a thin band some 30 feet in thickness, with probably no stratification.

If there be a definite trap-flow between the gneiss and the nummulitics, its nearest relation should be Medlicott's 'Sylhet Trap', which he considers intimately connected with the cretaceous.

The same age would apply to the white chalk-like rock associated with the trap. The former seems to resemble a rock described by Mr. Theobald[2] from the Arakan, which he considered to be cretaceous. The white rock of Longloi hill corresponds closely to Theobald's description, but the Arakan rock is calcareous, and the Mikir rock contains only a small amount of carbonate of lime.

The coal bearing shales of Longloi, which immediately overlie the white rock, must also be cretaceous, if the nala-section shows a regular sequence of beds. In this case they are the only representative of definite, cretaceous, sedimentary rocks seen in the Mikir hills.

[1] Mem. Geol. Sur., Ind., Vol. VII, Art. 3, p. 38.
[2] Manual Geol. Ind., p. 297.

OLDER TERTIARY—NUMMULITIC.

A fairly strong band of nummulitic strata occurs constantly at the base of the tertiary rocks. It consists of highly nummuliferous, earthy limestones, generally nodular in appearance, associated with siliceous, unfossiliferous sandstones and grit.

The section varies very considerably both in thickness and composition. Some of the upper sandstones are of doubtful age, and may be post-eocene. But as they always occur closely associated with the limestone, probability and convenience unite in grouping them with the nummulitics.

I have never met with any trace of eocene coal either in the limestone or sandstone.

South Mikir hills.

The isolated band of nummulitic limestone on Longloi hill has been already referred to. No other exposure is to be found connected with it. From Silbatta nummulitic rocks can be traced southwards, down the Meyongdisa river, as far as the Dogaon hill, 3 miles east of Longloi. No rocks of eocene age are seen south of this, until they reappear near the Kopili Hot-springs, in the North Cachar hills. At the Jamuna Falls nodular, earthy, nummulitic limestone is seen, somewhat massively bedded, with a gentle dip 7° N.W. The hills immediately to the south are composed of similar limestone, but rather more compact. The total thickness is about 200 feet.

A fair section is seen in the nala running from Megik into the Meyongdisa. Hard, nummulitic limestone is overlaid by coarse purple sandstone, interbedded with hard, white, quartzitic sandstone with a general dip 3° N.W. On the Dogaon hill massive, coarse, white sandstone overlies the nummulitic limestone. On the southern face of the hill, both are seen dipping 30° to 40° S.W.

North Mikir hills.

From Silbatta the nummulitic band can be traced cotinuously north-eastwards, along the eastern flanks of the north Mikir hills, to the Boro Neoria. Two outlying exposures also occur. On the Disobai nala a broken section is seen of nummulitic limestone, overlaid by coarse sandstone, resting, with a gentle northerly dip, apparently on the gneiss. Up the Langhit river also three isolated patches of these rocks occur, at an elevation of quite 500 feet above the level of the same rocks a few miles to the south; a fact presumably due to the upheaval of the gneissic area. Two patches of coarse white sandstone, over 100 feet in thickness, occur near Dambu. The rock is felspathic and shews much false bedding. The true bedding is not visible. A third small patch is entirely composed of nummulitic limestone, a massive grey shelly band, about 60 feet thick, dipping a few degrees southwards. This rests directly on the gneiss, and its relation to the sandstone is doubtful.

Above the Jamuna Falls a few feet of nummulitic limestone are seen, dipping gently northwards, and overlying the white rock and mottled trap. Similar limestone is seen again in the Langhit gorge, about 100 feet thick, with a gentle dip south-west, and resting apparently on the gneiss. On the Borojan the limestone appears to be overlaid by white, coarse sandstone and quartzite, the whole dipping 3° south. A spring of tepid water, with a slight smell of sulphuretted hydrogen, rises on the Borojan limestone. In the hills round Miji the nummulitic limestone seems to be interbedded with white and iron-stained sandstone, with a dip of 20° S. in the Jamuna river. The beds reach a development of several hundred feet here.

In the Jirilangso nala nummulitic limestone is overlaid by fine-grained, iron-stained sandstone, which again is conformably overlaid by grey clay-shales.

Haria Jan.

On the Haria Jan the lower tertiary rocks are well exposed. A continuous section of fine, grey clay-shales is seen, and their junction with the limestone below is plainly visible. Massively bedded, nummulitic limestone is seen to be overlaid with perfect conformity by the grey clay-shales, the whole having a dip of 20° S.E. Below this limestone comes a band of massive, unfossiliferous, soft, brown sandstone, which again overlies a lower band of nummulitic limestone. The upper limestone is 150 to 200 feet thick, the sandstone 50 feet and the lower limestone about 100 feet thick. The whole series dips from 5° to 20° S. E. Below the lower limestone comes the mottled trap band, which rests on the gneiss.

Sandy nummulitic limestone, with a low easterly dip, rests on the mottled trap of the Deopani, but it is only seen in one or two places. The last exposure of the nummulitics occurs in the Boro Neoria at Pangso, where a few feet of sandy and light-blue limestones are seen, lying horizontally in the stream bed.

Summary.

The total absence of sections, continuous from top of base, of the nummulitic rocks, makes it impossible to do more than estimate their composition and thickness. The series seems to vary rapidly, sandstone and limestone replacing one another frequently. Northwards, as on the Haria Jan, the nummulitic band reaches some 300 feet in thickness, and is composed of limestone with an intermediate band of sandstone. Near Miji the thickness must be rather greater, probably 200 feet of sandstone overlying about an equal thickness of limestone, with some sandstone partings. Southwards the thickness decreases again to about 200 feet, of nodular limestone overlaid by coarse sandstone.

No actual junction of the nummulitics with the lower rocks is seen, but they always rest, either horizontally or with gentle dips, on the gneiss, or upon the overlying mottled trap and white chalk-like rock.

No trace of fossils is met with in any of the sandstone bands; and the limestones, though frequently made up of nummulites and bivalve shells, do not yield any well-preserved fossils.

North of the Boro Neoria the nummulitic band is apparently overlapped by the grey clay-shales of the younger tertiary.

Younger Tertiary—Siwalik.

At the two places where contact-sections between the older and younger tertiary beds are seen—on the Haria Jan and Jamuna—

there is perfect parallelism of stratification and apparent conformity, but at the same time a complete change of facies comes in. Massive limestones, full of foraminifera, are overlaid immediately by finely laminated, grey clay-shales, with usually no trace of fossils. Besides this, the shales rest on nummulitic sandstone beds to the south and limestone to the north; and the nummulitic band decreases in size and thickness from south to north, being eventually overlapped by the shale series. This all points to the fact that there is some unconformity between the two, but the intervening disturbance has been so slight that the parallelism of their strata remains perfect.

The younger tertiary beds remain very constant throughout the Mikir hills. They consist of a lower series of grey clay-shales, with frequent calcareous, lenticular concretions and bands, occasional thin bands of lignitic coal, and rare shell beds, passing upwards, through local bands of conglomerate near the junction, into an upper sandstone series, with rare calcareous bands, and much silicified wood at the base. The two series can be traced southwards, across the Lumding plain, to the corresponding beds of the North Cachar hills.

Lower Siwaliks—Shale-series.

The grey clay-shales are probably the reported coal-bearing rock of the Mikir hills. Thin veins of brownish coal do occur in them, but none that I have seen exceed 18 inches in thickness, and the coal is generally intercalated with shale.

Exposures of the shale-series are only met with in the deeper nala beds. They present exactly the same appearance throughout the whole of the Mikir hills, a few subordinate bands alone causing any alteration in them.

Meyongdisa river.

In the Meyongdisa valley some fair exposures occur. Near the junction of the Megik nala with the Meyongdisa the nummulitic beds are overlaid horizontally by finely-bedded, grey clay-shales, with sandy bands, and one or two strings of lignitic coal an inch or two in thickness. Further up the Meyongdisa, half a mile south-east of Gudu, a curious 'Pung' or 'salt-lick' is seen in the shales. Several springs of soft blue mud, probably slightly sulphurous, ooze out at the surface. This is a general rendezvous for wild elephants and deer, which eat the saline mud with avidity.

On the Dilangso nala, 3 miles from the Meyongdisa, the grey clay-shales are seen to contain several dark layers of carbonaceous shale, in one of which a band of coal occurs. The coal is 18 inches thick, but it seems to thin and die out rapidly, both up and down the stream bed.

To the north of the Langisso nala, there is another small stream, called the Langator, and not marked on the map. A small coal exposure occurs on the Langator, about one mile west of the Meyong. Soft grey to yellow shaly sandstones overlie 5 feet of interbanded coal and soft grey clay. About six bands of coal, from 1 to 8 inches thick, occur, alternating with the clay. The thickness of the bands varies rapidly. Below the coal band come grey-blue to lavender carbonaceous shales. The whole series is seen to be horizontal for some distance, and then suddenly to dip 60° W. in a few yards; but this is probably due to some small landslip.

In several of the bands of coal large rounded bits of fossil resin or amber, up to 3 and 4 inches in length, are found, suggesting a similar age to the Burman amber-bearing beds, which are believed to be upper tertiary.

Diphu river.

At the mouth of the Diphu nala, and in the Jamuna river, horizontal grey clay-shales are seen. Two miles up the Diphu the shales contain one or two thin coal-seams, but the thickest bed of coal is exposed half a mile up the Diphu, and in a small tributary. In the Diphu, below the sandy alluvium, finely banded sandy and micaceous clay-shales occur, which are generally reduced to stiff blue clay in the stream bed. A band of coal 14 inches thick, with 3 inches of brown carbonaceous clay overlying it, occurs in the stiff blue clay, with a dip of 15° S.S.E.

The coal can be traced for 50 yards to the south-west, where it appears again, in a small nala, giving the same section, but quite horizontal, which seems to be the normal condition of the beds around.

Other localities.

Grey shales are seen lying horizontally over most of the Lumding plain. Thin bands of conglomerate occur in it on the Dyung river, and concretionary slabs of blue sandy limestone, 1 to 2 feet thick, are seen in it east of Lumding.

In the Katabaiong nala, on the northern flanks of Inlong Giri, similar hard calcareous bands are frequently seen in the shales, which are somewhat disturbed but usually horizontal. A shell bed is associated with one of these bands, giving the following section in descending order :—

	Ft.	In.
Fine grey clay-shales	...	...
Shelly clay-limestone	0	8
Grey clay-shales, without shells	0	6
Shelly-clay-limestone	0	6
Grey clay-shales, without shells	0	8
Hard blue limestone, without shells	0	2
Hard blue limestone, full of shells	1	6
Soft blue clay shales, full of shells	2	0
Fine grey clay-shales	...	...

The broken bivalve shells seen in these bands give no further evidence than that of a probable tertiary age.

Round Lokpo and Dawk hard calcareous and arenaceous bands are common in the fine grey shale, which is sometimes micaceous or sandy. The hard bands vary from 6 inches to 2 and 3 feet in thickness, and from grey limestone to very hard, yellow, micaceous, calcareous sandstone in composition. The rocks are horizontal.

Dhansiri valley.

The low hills covering most of the Dhansiri valley are composed of alluvial sands, gravels and clays; but in nearly all the larger nalas and in the Dhansiri itself the horizontal grey clay-shale appears. Up the Haria Jan, a good continuous section of the shale-series is seen. The upper beds are hard laminated grey shales, interbedded with grey micaceous sandstone. These pass down into similar shales with occasional sandy bands. The dip is always low but undulating. Below this the sandstone dies out and frequent layers of lenticular, calcareous concretions occur. These concretions are generally traversed by thin veins of hard calcite, which stand out and give them the exact appearance of a tortoise-shell. The lenticular nodules increase in size, from about 1 foot in diameter and 2 or 3 inches in thickness, to several yards in diameter and feet in thickness, and in fact, until the neighbouring ones join together and form the hard, calcareous bands, up to 2 and 3 feet thick, interbedded in the shales. This form of rock lasts down to the junction with the nummulitic limestone.

Nambor Falls.

A good section is seen from the Nambor bridge on the Golaghar road, for about 2 miles up the river to the falls. At the bridge a small patch of fine grey-shales is seen, and it is from this rock that the Nambor hot-spring rises. Similar shales with hard calcareous bands are seen along the river up to the falls, and one or two more small warm-springs are seen on them. The dip is gentle and undulating. One or two of the calcareous bands have been quarried for limestone.

A hundred yards below the Falls limestone is being extracted now from beds which have always been regarded as cretaceous. In the quarry 8 feet of fine, grey clay-shales overlie, with perfect conformity, a hard band of clay-limestone, full of oyster shells, and dipping 10° S.E. This band is 2 feet 6 inches thick, and passes down into a soft bed of clay-shale, full of oyster shells above, but unfossiliferous below, where it rests on the trap band overlying the gneiss. Frequent small nodules of yellow pyrites occur in the soft shaley beds.

There does not seem to me to be any doubt that the Nambor shales and limestone belong to the lower Siwalik shale-series, which can be traced continuously up to them throughout the whole length of the Dhansiri valley.

Upper Siwaliks—Sandstone-series.

Overlying the horizontal shales, which have a total thickness of some 800 feet, come about 1,000 feet of sandstones, which are usually horizontal also, and probably quite conformable with the shales. The sandstone beds only occur capping the low south Mikir hills, to the south of which they are connected with the sandstones of the north Cachar hills. Two forms of rock occur representing the sandstone series. Firstly, a dull-red or purple to light-pink, soft, earthy sandstone, more or less ferruginous. When any depth of section of this rock is exposed, the surface rock is much more ferruginous than the underlying beds. The sandstone often becomes an earthy, sandy hæmatite superficially, and the soft rock is frequently penetrated in all directions by veins of compact hæmatite, up to an inch in thickness, enclosing rounded lumps of soft sandy rock.

Secondly, a coarser grained rock, usually an earthy, hæmatitic conglomerate, sometimes vesicular and resembling laterite, with small quartz pebbles included in it. It generally occurs capping the lower hills, representing probably the basal beds of the sandstone-series.

The sandstone, like the greater part of the grey-shales, is unfossiliferous, except in the matter of silicified wood. Lumps of fossil wood, entirely silicified, but never carbonaceous, up to 4 and 5 feet in length, occur abundantly at the base of the sandstones, and probably at the top of the shales also, but no trace of coal is met with in the sandstone-series.

Nambor Coal Beds.

About 8 miles above the falls on the Nambor river a curious small patch of coal-bearing rocks occurs, mentioned previously by Messrs. Mallett[1] and LaTouche. I think it is an isolated patch, as gneissic hills certainly surround it to the west, south and east; but

[1] Mem. Geol. Sur., Ind., Vol. XII, Pt. 2, p. 17, footnote.

the outcrop may continue to the north, where no definite exposures are seen, and may connect it with the coal-bearing rocks of the Doigrung river, described by LaTouche,[1] though the lithological diversity of the strata in the two streams does not seem in favour of their close connection.

The exposures on the Nambor are entirely under water, even in the dry season, so the coal would be useless, unless traced on to higher ground. Three sheets of coal are seen in the river, but the section is so broken, that it is difficult to say how they are connected with each other.

For 8 miles above the falls, the Nambor traverses massive gneiss. Above this a gap of a quarter of a mile occurs, with no exposures. Then a seam of 2 feet of coal occurs, resting horizontally on coarse white sandstone, and visible for about 30 yards. Above this is another gap of 200 yards; and then a sheet of coal, a few yards in length, and 2 to 3 feet thick, is seen overlying whitish clay-shale with leaf traces, with a gentle dip to north-east. A hundred yards above this a bed of fine, white, felspathic sandstone, with frequent small concretions of vesicular pyrites, occurs dipping gently north-east apparently under the shales and coal.

A broken section of this sandstone is visible on the river bank, and the dip changes from north-east down stream to north-west up-stream. Another 100 yards of blank section follows, and then the main coal sheet appears, overlying similar light-grey clay-shale, with a dip of 8° W.N.W., and so apparently overlying the white sandstone. Above this exposure nothing is seen except the massive gneiss.

The last coal-seam forms a considerable sheet over the whole stream bed, about 10 yards in breadth and 20 in length. The dip of 8° is seen over an outcrop of 55 feet, giving the seam a minimum thickness of 7 feet.

LaTouche describes the coal seen on the Doigrung—about 3 miles north-west of the Nambor coal—as a seam 3 feet in thickness

[1] Rec. Geol. Sur., Ind., XVIII, Pt. 1, p. 31.

"overlaid by calcareous shales containing large nodular masses of limestone." This description suggests a similarity to the shale-series below the Nambor falls, rather than to the white shales and sandstone associated with the Nambor coal. But throughout the whole section of the shale-series, as seen on the Haria Jan or the lower Nambor, there is no trace of coal. The age of the Nambor beds must, therefore, remain, for the present, in doubt.

I have never met with similar white pyritous sandstone in the Mikir Hills, nor have I seen any nummulitic coal. If the Nambor coal be cretaceous, it is strange that no trace of cretaceous beds should occur in the lower Nambor or the Haria Jan.

Correlation of the Mikir Rocks.

The oldest rocks of definite sedimentary origin in the Mikir hills appear to be the Longloi coal-bearing shales, which underlie the nummulitic band, and are presumably of cretaceous age. They have no very close resemblance to the Shillong cretaceous beds, which Medlicott describes[1] as sandy throughout, but showing at Maobelarkar a small section of carbonaceous shales and coal. The nearest cretaceous rocks are those of the Kopili river, described by LaTouche.[2] They apparently consist chiefly of some hundreds of feet of fine grained sandstone, but contain some coal and carbonaceous shale. The cretaceous beds in any case die out northwards in the Mikir Hills, and the Longloi shales and coal apparently represent their last occurrence in this direction.

There can be no doubt as to the eocene age of the nummulitic band, and it is possible that the overlying shales may be eocene also, corresponding to the coal-bearing 'Ghazij shales' of middle eocene age in Baluchistan. But the total disappearance of nummulites immediately above the limestone, and their absence in the shales, even though marine shell-beds are present in the latter, are strong evidence that the shales are of post-eocene age.

[1] Mem. Geol. Sur., Ind., Vol. VII, Art. 3, pp. 18—33.
[2] Rec. Geol. Sur. Ind., Vol. XVI, Pt. 4, pp. 199—201.

It is interesting to see how the younger tertiaries of the Mikir hills correspond with the rocks of the Naga hills across the Dhansiri valley. The fullest report, up to date, on these rocks will be found in Mallett's Memoir[1] on the "Coal Fields of the Naga Hills."

I am inclined to think that Mallett, following the example of Medlicott, assigns too great an age to beds of doubtful position in these hills. Doubtful beds, especially coal-bearing ones, were frequently classed as cretaceous. Now the nummulitic band is seen to be continuously developed from far west of Cherra Poonjee, in an easterly and northerly direction, for 250 miles, as far as the Haria Jan in the Mikir hills. In the North Cachar hills, it underlies some thousands of feet of shales and sandstones. It is highly probable, then, that it occupies a similar position in the Naga hills, which seem to be a direct continuation, stratigraphically as well as orographically, of the North Cachar hills. If this be so, the great thickness of shales and sandstones of the Naga hills, overlying a presumable nummulitic band, would be entirely post-eocene.

These Naga hill rocks, described by Mallett under the names of Disang, Coal-measures, Tipam and Dihing groups, correspond very fairly closely with the post-eocene rocks of the Mikir hills.

The shale-series of the Mikir hills, probably oligocene and miocene, seems to represent Mallett's 'Disang' and 'Coal-measure' groups.

The Disang grey-shales, with some sandstone, and nodules of calcareous sandstone towards the base, corresponds with the Haria Jan section. The 'Coal-measures' of alternating shales, sandstone and coal represent the upper beds of the Mikir shale series, passing into the sandstone series, and containing a few bands of coal. The massive 'Tipam' false-bedded sandstone seems

[1] Mem. Geol. Sur., Ind., Vol. XII, Pt. 2, pp. 17—35.

to be a continuation of the great sandstone band of Haflong and the Burrail range, in the North Cachar hills, which is again continuous with the sandstone series of the Mikir hills, of pliocene age. Much silicified wood occurs in the Tipam, as in the Mikir sandstone; and the 'arenaceous cellular limonite' in the Tipam beds must closely resemble the 'vesicular sandy hæmatite' common all over the south Mikir hills.

No beds corresponding to Mallett's Dihing coal-conglomerate group are met with in the Mikir or North Cachar hills, where probably the uppermost pliocene is wanting.

The shale and sandstone series are seen to thicken considerably southwards from the Mikir hills. A similar increase evidently takes place eastwards also, resulting in greatly developed groups in the Naga hills.

The nummulitic coal-beds of the Cherra Poonjee district have completely died out in the Mikir nummulitic rocks, and the great seams in the coal measures of Upper Assam and the Naga hills have almost died out before reaching the Mikir hills from the opposite side. The latter fact may be partly accounted for by the presence of local marine shell-beds in the coal-bearing shale-series of the Mikir hills, showing that it was to some extent a salt-water deposit.

Economic Geology.

Limestone.

The chief mineral of value in the Mikir hills appears to be limestone, and this unfortunately always occurs at some distance from the road and railway-line. The stone quarried on the Nambor is used for many miles up and down the road, and it seems improbable that the far greater quantities of much purer limestone available on the Deopani, Haria Jan, and Jamuna rivers, will be made accessible for many years to come.

Iron.

As in many other parts of India, iron-ore is of widespread occurrence throughout the south Mikir hills. There are great quantities of ferruginous sandstone passing locally into sandy hæmatite and hæmatitic conglomerate. But it is probably seldom that the hæmatite becomes sufficiently concentrated to make a workable ore. When the railway is finished and coal easily obtainable, the Mikir iron-ore may be of use. The local blacksmiths invariably make their spear-heads and daos from bars of English iron, bought in the larger towns.

Coal Analyses.

Of the eight coal-exposures seen in the Mikir hills, only two—those on the Longloi hill and the Nambor river — are of sufficient thickness to be taken into account from an economic point of view.

Six thin bands, or series of bands, occur as already mentioned in the shale-series, varying in thickness from ½ to 18 inches. The coal is similar throughout, of black colour, with dark-brown streak, splintery fracture, a slightly woody sound when struck, and generally frequent specks of red fossil resin scattered through it. The general character of this coal, of younger tertiary age, is very similar to that of the cretaceous coal of the Shillong plateau, as described by Medlicott, a fact which deprives the coal of any value as general evidence of the age of the beds in which it occurs.

The 15 inch seam near the mouth of the Diphu gives the following analysis:—

Moisture	7·10
Volatile matter	37·48
Fixed carbon	40·38
Ash	15·04
	100·00

This coal is, by its composition, the best found in the Mikir Hills, but its insignificant thickness, coupled with the fact that it is under water half the year, deprives it of any value as a workable coal seam.

Longloi Coal.

The Longloi seam consists of 12 feet of visible coal, with one parting of a few inches of shale, dipping 10° to 20° N.N.W. The coal is exactly similar in character to that mentioned above. Analyses of two specimens of this seam, one near the top and one near the base, give the following results :—

	Coal near top of seam.	Coal. near base of seam.
Moisture	5·36	3·88
Volatile matter	49·96	57·52
Fixed carbon	25·32	25·40
Ash—sinters slightly	19·36	13·20
	100·00	100·00

It will be seen that the coal is of very poor quality, with a low percentage of fixed carbon and a high one of ash. Longloi hill is in the centre of the south Mikir hills, and though not far from Lumding —12 miles as the crow flies—it is somewhat inaccessible, as the country between them is covered with dense jungle and cut up by steep nalas. Longloi is some miles nearer to the Jamuna river, but there is no track leading to it, and the Jamuna is only a small stream, on which nothing larger than a 'dug-out' canoe can be navigated. These considerations are probably sufficient to make the coal valueless, at present, to the Assam-Bengal railway.

Nambor Coal.

The Nambor coal, six miles west-north-west of Borpathar, is the most accessible, but its quality seems the poorest of any in the Mikir hills. The large percentage of ash stamps it at once as useless.

The following three analyses are of the 7-foot seam on the Nambor. The first one was made years ago and published in Mallett's Memoir already referred to ; the second and third are from the bottom and middle of the seam, respectively :—

	Mallet.	Base of seam.	Middle of seam.
Moisture	10·0	3·14	9·40
Volatile matter	29·2	29·00	34·42
Fixed carbon	28·6	15·24	26·32
Ash—does not cake . . .	32·2	52·62	29·86
	100·0	100·00	100·00

The following is from the middle of the three seams seen on the Nambor, 2 to 3 feet thick :—

Moisture	10·74
Volatile matter	31·12
Fixed carbon	25·90
Ash—does not cake	32·24
	100·00

The first, third and fourth of these analyses are very similar to each other, and suggest the idea that the western and middle seams on the Nambor are the same. The second analysis is from a specimen brought in by a native, and said to come from the position indicated. It is probably from a layer of shaley coal, at the junction of the coal and shale. It is remarkably like LaTouche's analysis of the Doigrung coal, which is as follows :—

Moisture	5·08
Volatile matter	31·06
Fixed carbon	15·10
Ash	48·76
	100·00

The Nambor seams, where visible, are under water all the year round, a fact which would probably prove fatal to coal of far better quality. But there is a possibility that the Nambor and Doigrung seams may be connected. In this case, and if, as LaTouche remarks, 'the quality should improve to the deep', in a remarkable degree, a workable seam might be found across the intermediate country.

Reports.

Coal in considerable quantities is reported as occurring on the Jahenri and Koliani rivers, in the hills west of Golaghat. Ten maunds of the Jahenri coal are said to have been brought into Borpathar and to have given good results. Both localities were out of my working ground however, and the wet season prevented my exploring the hills in this district.

On the Geology *of* Tirah *and the* Bazár Valley, *by* H. H. Hayden, B.A., B.E., *Assistant Superintendent, Geological Survey of India.* (With plates V and VI).

INTRODUCTION.

The following paper is compiled from notes made by me while attached to the Tirah Expeditionary Force, during the months of October to December, 1897.

Area examined.

The area examined consists of parts of the country lying between the Samána range and the southern slopes of the Saféd Koh, with portions of the Khaibar, Chúra and the Bazár Valley. Of this area, the geology was in part known from the survey made by Mr. Griesbach[1] in 1891, yet there still remained a considerable portion the geology of which could only be conjectured, and although the nature of the late expedition was such as to preclude the possibility of an exhaustive examination of the still unmapped country, yet—the route followed by the troops crossing the strike of the strata at right angles—opportunity was afforded for an examination of almost the entire sequence of beds between the Samána range and the southern slopes of the Saféd Koh.

Previous observers.

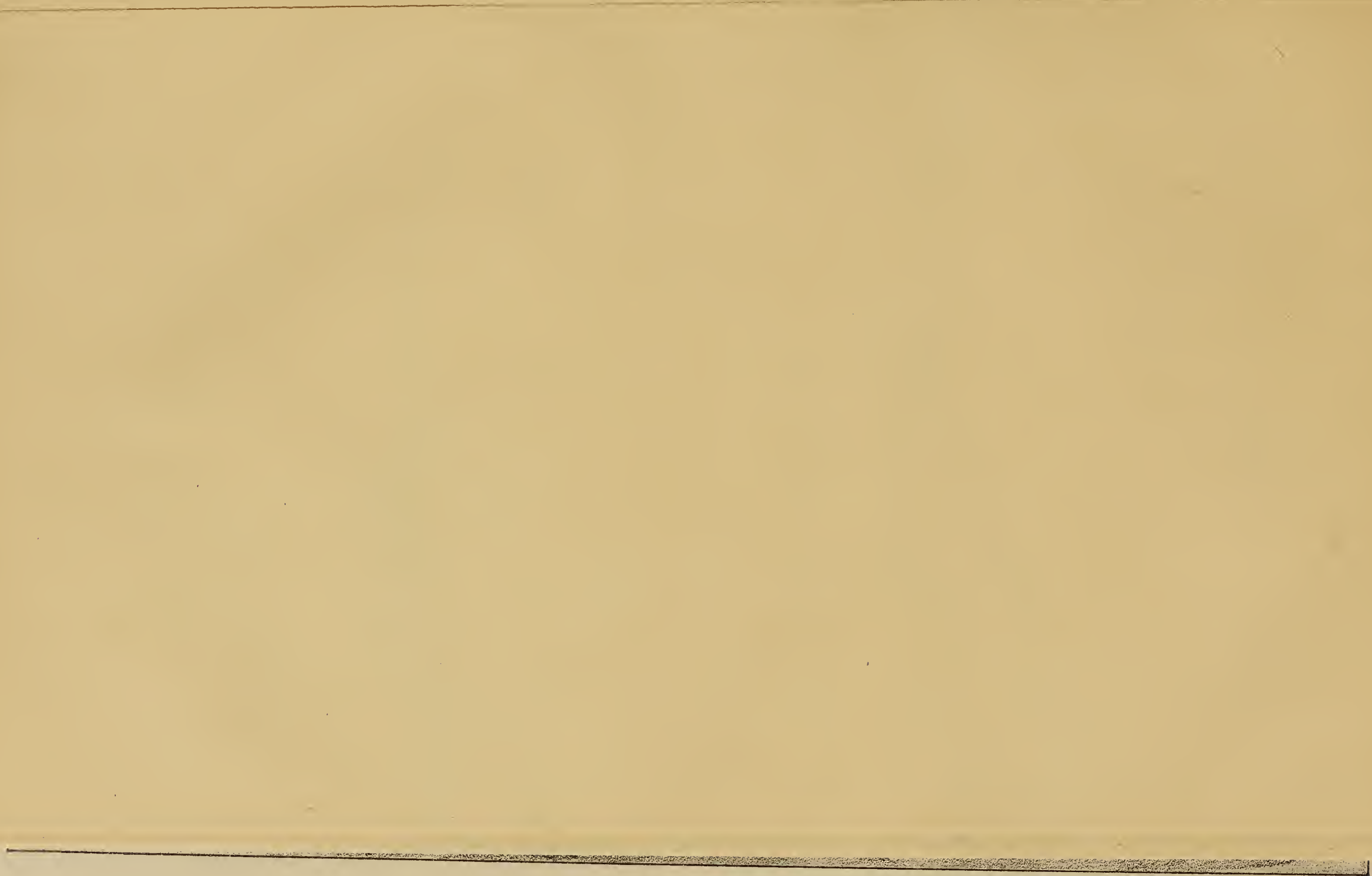
I propose to divide this paper into two sections: the first dealing with the country south of the Saféd Koh and its eastern extension, the Surghar range, and the second dealing with the area lying north of those ranges.

I.—THE AREA SOUTH OF THE SAFÉD KOH.

Orography.

Orographically this area consists of four main mountain ranges parallel to one another and running almost due E. W. These ranges are separated by longitudinal troughs, but locally connected with one another by spurs trend-

[1] *Vide* his paper on "The Geology of the Saféd Koh." Rec. G. S. I., Vol. XXV, p. 59. In the same paper will be found a list of the most important literature bearing on the subject. Since the above list was made by Mr. Griesbach, no fresh addition has been made to our knowledge of the geology of the area.



FOLDED CRETACEOUS STRATA, WARÁN VALLEY.

FIG. I. SECTION FROM SHINÁWARI (LAT: 33° 31′ N: LONG, 70° 50′ E.) TO SARAN SAR IN TIRAH.

c *cretaceous and jurassic.* *f* *eocene.* F F *Fault.*

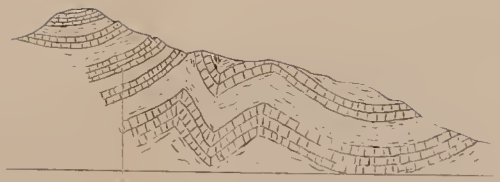


FIG. 2. SECTION ON S. SIDE OF THE ARHANGA PASS.

FIG. 3. SECTION FROM SÁGH IN TIRAH TO DWATOWI IN THE BÁRA VALLEY.

a_2	*Older palæozoic.*	*d*	*Rhætic.*
c	*Triassic.*	*e*	*Cretaceous and jurassic.*
		F F	*Fault.*

FIG. 4. PROBABLE SECTION FROM ALI MASJID TO THE BÁRA RIVER.

a_1	*Carboniferous.*	*c*	*Trias.*
a	*Permo-carboniferous.*	*d*	*Rhætic.*
b	*Permian.*	F F	*Fault.*

H. H. Hayden.

FOLDED CRETACEOUS STRATA, WARÁN VALLEY.

ing north and south. Between the Samána range on the south and the Saféd Koh on the north there are three main ridges and four troughs, the order being from south to north :—

Samána Range—
- Valley of the Khanki river.

Tsappar Range—
- Valley of the Mastúra river.

Western portion of the Targhar Range[1]—
- Maidán and Warán valleys.

Eastern portion of the Torghar range[1]—
- Bára valley.

Saféd Koh and Surghar ranges.

The above ranges all present steep scarps to the south, but slope away more or less gently to the north.

Structural Geology.

Beds everywhere much folded.

As already noticed by Mr. Griesbach,[2] the rocks of this area appear at first sight to dip steadily at low angles to the north, but on closer inspection are found to be thrown into a series of folds, frequently reversed. Not only is this true of the area immediately to the north of the Samána range, but from that range up to Ali Masjid in the Khaibar, this feature is constant. The rocks have undergone much folding, and, if examined in detail, their structural geology is highly complicated (see Pl. VI). The key to the structure of the whole area is, however, the inverted fold, and

Inverted folds.

when examined in this light, the whole section from the Khaibar to the Samána resolves itself broadly into a series of reversed flexures, often much complicated by crumpling and faulting, the faults frequently taking the form of overthrusts.

Lithological characters of the rocks not distinctive.

The recognition of the various beds, being dependent either on fossils or on the lithological character of the rocks, is, therefore, a matter of no small diffi-

[1] As shown on map of "Tirah and surrounding country." (1″=2 miles. Jan. 1893.)
[2] *Op. cit.*, p. 80.

culty, for the appearances of limestones of what are probably widely different ages are frequently so similar, that any separation on lithological grounds is unreliable, if not impossible, while, on the other hand, the paucity of fossils renders any separation of the rocks on palæontological grounds equally doubtful. The classification adopted in this paper must therefore be regarded as merely tentative, and liable to considerable modification, when the area involved has been studied in greater detail. For although, owing to the nature of the late expedition, I found only a small number of fossils, yet many beds showed indications of their presence, and I have no doubt that a more extended search, should such ever become possible, would result in the discovery of a number quite sufficient for the identification of most of the rocks found in this area.

Age of the rocks.

By far the greater part of the area consists of rocks of mesozoic age, with tertiary beds in two places. Towards the northern limit the mesozoic strata are brought into abrupt contact with beds of an older type, which probably belong to the older palæozoic systems.

Chiefly mesozoic.

Junction between mesozoic and palæozoic beds: a fault.

The line of contact of the two series is undoubtedly the great fault, the existence of which had already been predicted by Mr. Griesbach in his paper before quoted.[1]

Geological sequence.

South of the Saféd Koh the strata fall under the following sub-divisions :—

8. Nummulitic limestones overlying	Eocene.
7. A great thickness of greenish and red shales, with buff sandstones and subordinate limestone bands; all underlain by grey limestone	
6 and 5. Limestone, chiefly grey, with sandstones, shaley limestones and calcareous shales	Cretaceous and Jurassic.
4. Great thickness of dark grey massive limestones, with occasional carbonaceous bands, and, at the base, red shales .	Rhætic.
3. Red gritty shales, passing down into finer beds, then grits and conglomerates, overlying reddish-brown needle shales	Trias.
2. Schistose slates and altered limestone	Carboniferous.
1. Much altered rocks, chiefly indurated and banded slate and white quartzite	Prob. older palæozoic.

[1] Rec., XXV, p. 88.

Eocene. Between Kohát and Hangu.

The eocene rocks are well seen on the road from Kohát to Kai, and have already been described by Mr. Wynne.[1] To his description I have nothing to add except that, in the alluvial plain about ¾ mile west of Hangu dák bungalow, part of a large mammalian femur was found by Major O'Sullivan, R.E., A.Q.M.G., T.E.F. It was not perceptibly waterworn, and could not, therefore, have travelled any great distance; this would point to the existence, not far from Hangu, of a bed containing mammalian fossils.

Eocene of Kai. Sandstone.

Between Kai and Shinâwari (Lat. 33° 31′ N., Long. 70° 50′ E.) the eocene beds are composed of sandstones inter-bedded with light-coloured and greenish shales. The sandstone, which is well seen on the small hill on which the village of Kai stands, varies in colour from a pale buff to a dark, highly ferruginous rock, but in almost every case its weathered surface is black: a characteristic also noticed by Mr. Smith in the eocene sandstone of the Tochi Valley.[2] At about 1½ mile south-east of Shinâwari it is underlain by olive-coloured and reddish-brown shales containing, locally, thin bands of highly altered limestone, which, on the southern flanks of the Samâna range, are in turn under-lain by a hard, compact, grey limestone, of either lowest tertiary or uppermost cretaceous age. The above rocks form the southern flank of the Samâna range and dip at high angles to the south.

Shale. Limestone.

Eocene of Tirah.

Tertiary rocks are not seen again north of the Samâna range till the Maidán Valley of Tirah is reached: here they occur in a narrow band not more than 700 feet wide. They are best seen on the saddle between Maidân and Warân, where they form the low "Kotal" (Tseri Kandáo) separating the two valleys. Their strike is almost due E.-W., and they dip at high angles (60° to vertical) to the north. They extend for some miles along the

Extension.

[1] Rec., XII, pp. 100—299.
[2] Rec., XXVIII, p. 106.

banks of the stream flowing eastward from the Kotal, through the Warán Valley, but to the west, in Maidán, they soon become covered up by the mass of alluvial deposits, which spread over the greater part of this valley, extending often for several hundred feet up the hill-sides. Between Guldast and Bágh, however, they are found again on a small hill on the right bank of the river, while on another spur about 2½ miles S. W. of Bágh they are again seen. On the Tseri Kandáo these beds form a sharply folded synclinal, their base being seen on the southern side of the Kotal, but on the north the lower beds are cut off by a reversed fault, which has pushed the older cretaceous limestone over the younger eocene beds. This fault, which has a strike of E. 10° N. to W. 10° S., persists for several miles, and as it runs slightly obliquely to the strike of the tertiary beds their outcrop gradually thins out towards the west.[1] On the Kotal it is 650 feet in width, while at the small hill S. W. of Bágh only some 250 feet are seen; it is, therefore, probable that still further to the west these beds are cut out altogether: unfortunately I had not an opportunity of verifying this.

Faulted junction with the cretaceous.

At its base this series consists of a grey calcareous sandstone, flaggy and thin-bedded, the lower portion of which is in places conglomeratic, containing small rounded fragments of the underlying pale grey cretaceous (?) limestone. This conglomeratic character, though often well-marked, appears to extend vertically for only a few inches, and there are no signs of unconformity between the two beds.

Basal sandstone.

The calcareous sandstone passes upwards into a bed of brownish-red shale about 150 feet thick—in which I found no fossils; this bed is in turn overlain by a shaley limestone containing many fossils, chiefly *lamellibranchiata*, with spines of *echinoidea*, while the upper portion is composed

Overlying shales.

[1] This cannot be shown correctly on the map, which is very inaccurate. In mapping faults and junctions I have followed as faithfully as possible the physical features as shown on the topographical map.

This map has not been published.—Dir., G. S. I.

almost entirely of the remains of *ostrea*; none of these fossils, however, are sufficiently well preserved for identification.

Above the oyster bed is another narrow band of red shale, only a few feet in thickness; its upper portion is highly calcareous and contains *nummulites*. Upon this lies a bed, some 200 feet thick, composed of nummulitic limestone. The whole sequence is then exactly repeated in reverse order down to the middle of the shale (*b*), which is brought into abrupt contact with the dark cretaceous limestone already mentioned.

Nummulitic limestone.

The nummulitic limestone is a dark grey, very compact variety, exactly resembling the nummulitic limestone of Tsinghe là in Zanskar, and composed of large numbers of small nummulites; below it is a band of crushed shaley limestone, containing larger nummulites, some specimens being over an inch in diameter. The upper portion of the shale underlying this bed contains numerous cylindrical rods of the limestone, evidently resulting from the great pressure to which the beds have been subjected.

Sequence of eocene beds.

The following is the sequence of eocene rocks as seen in Tirah:—

e. Nummulitic limestone, passing through shaley limestone with *nummulites*, into

d. Reddish shale. About 10 feet.

c. Shaley limestone, with remains of *ostrea*. About 2 feet.

b. Reddish-brown, finely-laminated needle-shales. About 150 feet.

a. Calcareous sandstone (conglomeratic at base). About 100 feet.

I found no tertiary rocks younger than eocene.

Cretaceous.—By far the greater part of Tirah is composed of rocks of cretaceous age. They are first seen on the southern slopes of the Samána range, where they underlie, with perfect conformity, the lower tertiary

Samána.

shales and limestones. Unfortunately circumstances did not allow of my working out these beds in any detail. This would in any case be a matter of considerable time, for although most of the rocks show signs of fossils, chiefly represented by section of bivalve shells, with some gastropods, it was impossible to extract the shells from the hard limestone matrix in which they occur. On the Samána range, the rocks consist of hard grey limestones underlain by sandstones, which in turn are underlain by shaley calcareous beds, the whole series forming an anticlinal, the beds on the south side dipping at high angles, while those on the north have a gentle dip of usually about 20° N.

Fossils.

The route followed by the troops crossed the Samána range at the Chagru Kotal, a saddle lying between Gulistan on the east and Dargai[1] on the west. A little to the south of the Kotal are seen the oldest beds exposed in this locality: they consist of reddish sandstones, with bands of shale and shaley limestone, containing sections of *brachiopod* shells, and in places remains of *ostrea*. These beds probably correspond to Mr. Griesbach's horizon 7 of (Rec., XXV, p. 81), but owing to the impossibility of recognising any of the fossils, I was compelled to unite the whole series under the term "cretaceous and jurassic". On crossing the Kotal, the lower beds are overlain by a series of limestones, very hard and containing the remains of many fossils, chiefly *gastropoda* and *lamellibranchiata*.

Chagru Kotal.

Fossils.

About two miles further north, in the Chagru Valley, the limestones are succeeded by a bed of hard white quartz-sandstone, almost a quartzite, pebbles of

Chagru Valley.

[1] The heights of Dargai—now so famous as the scene of the engagement of Oct. 20th—furnish a good example of the feature so characteristic of all the mountain ranges between Shinâwari and the Saféd Koh, the beds presenting a steep scarp to the south but to the north falling away in a comparatively gentle slope,—a feature which during the late campaign was of great strategic advantage to the enemy, while equally disadvantageous to the British force attacking the position from the south.

which are very common in the stream-bed at Ustarzai.[1] Above this sandstone is a thick bed of light-coloured limestone. Both these beds appear to be devoid of fossils.

White quartzitic sandstone.

As the Chagru stream approaches the Khanki river, the rocks on either side of the valley show signs of much folding, and are thrown into a series of small anticlinals and synclinals, frequently faulted. At the junction of the Khanki and Kandi rivers, the lower beds of the cretaceous series are again seen, but a little further to the north a fault has brought them into contact with the higher white quartzitic sandstone, which here dips at 60° to the south. The dip of the rocks then continues steep for some three miles, but on the Sanpagha Pass the beds are almost horizontal, dipping at low angles to the north. On the north side of the Sanpagha, in the Mastúra valley, the beds, which are still cretaceous, are thrown into a series of sharp folds. These rocks are hard limestones, in which I could find no fossils. They continue northwards, with a slight undulating dip, to the Arhanga Pass, where again they have been thrown into the folds characteristic of all the mountain ranges of this area. This folding is very well seen on a spur running south from the summit of the pass (Pl. V, fig. 2).

Khanki Valley.

Rocks much folded.

Sanpagha Pass.

Mastúra Valley.

Arhanga Pass.

At about 2½ miles north of the pass, limestones are found containing numerous fossils, chiefly *belemnites* and *brachiopods*, which, however, are not sufficiently well preserved for identification. This limestone is overlain by a narrow band (18 ins.) of bright red ferruginous sandstone, quite soft and rotten, containing casts of *belemnites* and fragments of other *cephalopods*. Although these fossils were too

Maidán.
Sandstone and limestone with *belemnites*, etc.

[1] *Cf.* Wynne, Rec., XII, p. 105.

badly preserved for identification, the age of the beds can still be proved to be cenomanian, for they occur again further north in the Warán Valley, where the included fossils are in a better state of preservation; there they include chiefly *brechiopods*, with *belemnites* and locally numerous shells of *ostrea*. The brachiopods, which Dr. Noetling has kindly examined for me, are forms typical of the cenomanian beds of Europe, and we are thus enabled to fix definitely at least one horizon of these cretaceous beds, which are so extensively developed throughout Tirah. From the Maidán Valley, the cretaceous rocks extend northwards and are well seen in the narrow defile, which extends for some 8 miles, from Bágh to Dwatowi in the Bára Valley (see fig. 3, Pl. V.). Almost throughout the whole length of this gorge the beds are vertical or nearly so, but it is highly probable that the same section is several times repeated owing to the intense folding to which the area has been subjected. The rocks strongly resemble those seen on the Samána range; the same shaley limestones with indistinct brachiopod remains are overlain by similar sandstones which here contain worm-tracks. But the whole series is much faulted, and at about 3½ miles north of Bágh, just below Mir Khán of the map, it is brought into abrupt contact with an equally crushed series of red shales overlain by grey limestones. This latter is a dark grey, massive rock, with occasional narrow bands of carbonaceous shale, and extends from Mir Khán to within three quarters of a mile of Dwatowi. Like the cretaceous and jurassic rocks to the south, it is bent into a series of steep anticlines and synclines, with local faulting. In its upper portions, it is a pure limestone, containing many traces of corals, which, however, cannot be identified. Towards its base it becomes rather arenaceous, and interstratified with it are bands of red shale, which gradually

Warán.

Cenomanian beds.

Defile between Bágh and Dwatowi.

Intense folding.

Similarity to the Samána beds.

Rhætic.

Coral limestone.

increase, till the series becomes one of shale. It is very difficult to estimate the thickness of this limestone, but it cannot be less than 2,000 feet. Nor can its age be determined in the complete absence of recognisable fossils, but it immediately overlies a series of red grits and shales, which cannot be older than triassic, and it will, therefore, represent the rhætic and possibly, in part, jurassic.

Thickness.

Age.

Immediately under this limestone series is a great thickness of bright red and brown shales, with grits and conglomerates. They are well seen on the bank of the river flowing from Bágh, at about ½ mile south of the point at which it joins the Bára river. The uppermost member is a red gritty shale identical with that already mentioned as underlying the rhætic limestone at Mir Khán. This shale is underlain by a coarse sandstone in thin bands, interstratified with brownish-red needle shales, the whole succeeded by about 200 feet of fine red needle shale, on which bed the village of Dwatowi stands. The shales, which here dip at high angles (almost vertical) to the south, are underlain by a thin band of limestone which in turn is succeeded by a series of sandstones and grits, gradually becoming coarser till they pass into a conglomerate composed of large rounded blocks and pebbles of limestone and sandstone, with some gneiss, all embedded in a coarse sandy matrix. Next follow beds of coarse grit and sandstone in rapid alternation, and underlying the whole series a bed of brown needle-shale, several hundred feet in thickness. I found no fossils in these rocks, but plant markings can be seen in the lowest shales. By far the most extensive member of the series is this needle-shale, which at the head of the Bára Valley forms rolling downs extending from the Bára river to the Saféd Koh. Owing to the softness of the beds, the river has cut out its course along their outcrop, which can be traced

Trias.

General characters.

Shales at Dwatowi.

Sandstone, grits and conglomerates.

Needle-shale.

for many miles along the river-bed, being, however, covered up by recent gravels and alluvium terraces on either side of the stream. Both from the position of the above series of beds in the Bára Valley and also from the fact that they occur also in the Bazár Valley, where they overlie beds of permian age, there can be little doubt that they represent the triassic system.

Age of the beds.

In the Bára Valley unfortunately their junction with the older beds is not clearly seen, but between Sandána and Sher Khel, about 2½ miles west of the latter village, the river takes a slight bend and runs up to the foot of the Surghar hills, which rise steeply from its northern bank.

Junction between trias and older beds.

These hills consist of a hard, dark blue slate, with bands and patches of white quartzite, all greatly indurated and dipping at high angles to the north. These are, no doubt, a continuation of the older palæozoic beds which form the main axis of the Saféd Koh, and their junction with the trias is certainly a faulted one; for although the valley is here completely covered with recent gravels and alluvium, and the triassic shales are hidden, yet at a short distance further east, near Sher Khel, the trias beds are again seen on the right bank of the river, while on the left (northern) bank the valley again widens out and the ground rises gradually to the foot of the hills. This rising ground is composed of triassic rocks, still dipping steeply to the south.

Older rocks.

Junction a faulted one.

At the eastern end of the Bára Valley, the junction between the trias and the older beds is seen. Here the valley ends, being closed by a broad kotal or low ridge, the river escaping through a narrow gorge carved out of the rhætic limestone. On the kotal near Spin Kamar, the trias shales and grits dip at high angles (70°—85°) to the south, but near the foot of the northern hills they are faulted against a series of blue schistose slates and highly altered limestone. These beds

Junction seen near Spin Kamar.

are very similar to the carboniferous rocks seen in the Khaibar and probably represent a part of that system. Between the two series of beds is a confused mass of broken slates, schists, and trias shales and grits. There can be little doubt that this fault continues for the whole length of the Bára Valley, following more or less closely the line of the southern foot of the Surghar Range, and, passing on further west, it probably forms an important feature in the geology of the Saféd Koh Range, eventually emerging in Kharwar and the Shutargardan, where Mr. Griesbach found it forming the boundary between the mesozoic and the palæozoic beds.[1]

The fault.

From the kotal the Surghar Range trends north-east, and with it, the palæozoic rocks, and on passing eastward from the kotal the ground once more slopes down to the Bára River where only triassic beds are seen. On nearing Swai Kot, these are overlain by recent and sub-recent conglomerates, clays and gravels. Along the road from Swai Kot to Bára Fort the triassic beds are again well seen and form the small range of hills running south-east from the Surghar Range to the Bára River. These rocks extend to within about 7 miles of Bára Fort, after which the road passes down on to the gravels and alluvium of the Pesháwar plain.

Trias at Swai Kot.

It will, therefore, be seen that, broadly speaking, the Bára Valley is a narrow trough eroded out of the soft triassic shales and grits, bounded on the south by a high range of (probably) rhætic limestone, and on the north by another high range composed of palæozoic rocks. The beds to the south appear to dip to the south, but except in the gorge between Bágh and Dwatowi, I was unable to examine the hills between the Bára Valley and the Maidán-Warán trough ; nor could their structure be seen, for throughout the march down the Bára Valley they were completely covered with snow.

The Bára Valley.

[1] *Op. cit.*, p. 76.

II.—Chúra and the Bazár Valley.

In the foregoing pages I have given a brief sketch of the area lying between the Samána Range and the southern slopes of the Safed Koh, and imperfect as is our knowledge of that area, it is unhappily less incomplete than that of the country lying immediately to the north of the Bára Valley. Owing to a heavy fall of snow, the passes between the Bára and Bazár Valleys were blocked, and it was considered expedient to enter the latter valley by way of the Khaibar. From the Bára Valley, therefore, the route lay across the plains *viâ* Bára Fort to Jamrúd. As already stated, the trias shales are the last rocks seen before descending into the plains, but between Bára Fort and Jamrúd, a small spur, shown on the map as the eastern prolongation of the Surghar Range, runs out to within a short distance of the road, and I was, therefore, enabled to examine it to some extent. It is composed of hard, banded and flaggy limestones, to a great extent crystalline, dipping at high angles to the north. The limestone is greatly altered, and I could find no fossils. It is, however, identical with the rock seen on Ghund Ghar, the hill overhanging the eastern mouth of the Khaibar, and also with much of the limestone of the Rohtas hill. This latter rock has already been described as carboniferous by Mr. Griesbach, who found that it "dips (in reversed order) below a series of shales, which are in great force from 1½ mile south-east of Ali Masjid to the eastern mouth of the Khaibar." This was apparently the southern limit of the area examined by Mr. Griesbach, and the expedition into the Bazár Valley has fortunately enabled me to carry the section some miles further to the south. There still remains, however, a considerable gap between that valley and the Surghar Range, of which we can only conjecture the geology.

Rocks between Bára Fort and Jamrúd.

Carboniferous limestone.

Broadly speaking it would seem that the area between the Rohtas hill and the Bára Valley is bounded on either side by carboniferous rocks—those of Rohtas on the north and the altered beds of the Surghar Range on the south. They form in the main a synclinal, and folded between them are beds ranging in age from upper carboniferous to trias, and possibly younger.

Area between Rohtas hill and the Bára Valley.

The carboniferous limestones have already been described by Mr. Griesbach, and I will, therefore, restrict myself to the exposures not specially mentioned by him, *viz.*, that near Bára Fort and that of the high hill (Ghund Ghar), which stands on the southern side of the entrance to the Khaibar. The former I have already described, and the latter is very similar, with the exception that near the summit of Ghund Ghar, the limestones are locally altered to a finely crystalline marble of great beauty, and are overlain by a band of highly ferruginous quartzite with beds of alum shale, the whole capped by grey limestones. The intense alteration of the limestones is found to be due to intrusions of a green igneous rock, which occurs in several small patches on, and at the foot of, this hill.

Carboniferous.

Ghund Ghar.

Limestones altered by igneous intrusion.

The overlying shale series—(*e*) of Mr. Griesbach's list—is first met with at about 1 mile west of Jamrúd Fort, and extends thence into the Khaibar, where it forms low hills cut up in all directions by ravines, and continues for many miles to the south of the Khaibar road. This series was classed by Mr. Griesbach as "upper carboniferous or even younger" and "possibly triassic." From Lála Chína, about two miles south-east of Ali Masjid, the road to the Bazár Valley lay over these shales. For several miles it ran almost parallel to the strike, but after crossing the Chúra Pass (about 5 miles from Lála Chína) it turned southward and ran almost at right angles to the strike of the beds. On the western side of the

Upper carboniferous to permo-carboniferous.

Shales between Lála Chína and Chúra.

pass, about 1 mile from the summit, the dip of the beds is almost vertical, and bands of dark grey limestone are found interbedded with the shales. The chief band is about 20 feet thick and consists of a much crushed crinoidal limestone overlain by a dense coral limestone, on the surface of which stand out the silicified remains of many corals and echinodermata. Below this limestone is more shale, with bands of flaggy quartzite and slate, dipping to the south.

Crinoidal and coral limestone.

To the south of the Chúra river, the ground rises steeply, and the area between this point and the Surghar Range consists of a series of parallel ridges, rising higher and higher till they culminate in the latter range. The beds, as seen from Chúra, appear to dip steadily to the south, but it is probable that the dip soon changes and the beds form a synclinal, in which will be found the youngest rocks exposed in this area.[1]

Hills south of Chúra.

In the river bed at Ucha Tangi, between Chúra and the Bazár Valley, the crinoidal limestones are again seen dipping to the south and overlying a bed of shale. Near Walai, the river suddenly changes its course, which had hitherto been W. E., and passes in a southerly direction through a gap in the hills. The northern flank of these hills consists of much contorted shales, but over these are beds of massive dark grey limestone, with beds of a peculiar yellowish sandstone, highly calcareous, and containing remains of numerous *brachiopods* now replaced to a great extent by bright red oxide of iron. The limestones also contain many remains of *brachiopods*, with *corals*, but the rock was so hard that I failed to extract any recognisable fossils. Further west, however, in the middle of the Bazár Valley, stands a small range of

Permo-carboniferous to permian.

Fossiliferous limestones and sandstone near Walai.

Fossiliferous limestones of China.

[1] I have endeavoured to depict this in section 4, which shows broadly the structure as observed between Ali Masjid and the Chúra Valley, but south of that, up to the Surghar Range, the section is purely conjectural, while the remaining portion is based on observations made in the Bára Valley.

hills, overlooking the village of Chína. These hills are composed of limestone, and are the continuation, along the strike, of the limestones just described. From these beds I succeeded in collecting a fair number of specimens, including *Eumetria grandicosta*, Waag., *Rhynchonella morahensis*, Waag., and *Camerophoria purdoni*, Davids.

The calcareous sandstone.

The sandstone seen in the river-bed was unfortunately as unproductive as the limestone, for although I found numerous remains of fossils, I had already spent so much time over the limestone that I was unable to devote more than a very short time in endeavouring to extract recognisable fossils: I was, however, able to examine it sufficiently closely to ascertain that it was identical with certain travelled blocks, which are found in great profusion in the neighbourhood of Jamrúd Fort. These blocks are usually of considerable dimensions, weighing on an average from ¼ to ½ ton. I found them only in the neighbourhood of the stream flowing from the direction of Chúra—in fact, the continuation of the Chúra river—none being found to the north of this nor yet in the Khaibar river. They are, no doubt, derived from the eastern extension of this sandstone bed. Some of these blocks were crowded with fossils, which could be extracted in very fair condition from the matrix. They include the following species:

Fossils found in the sandstone.

†**Productus abichi*, Waag.
* „ *serialis*, Waag.
†*Camerophoria pinguis*, Waag.
† „ *purdoni*, Davids.
†*Rhynchonella morahensis*, Waag.
†*Terebratuloidea minor*, Waag.
†**Eumetria grandicosta*, Waag.
†**Spiriferina* sp (*cf. multiplicata* Sow.).
**Allorisma* sp.

* indicates that the species is found in the Upper Productus limestone of the Salt Range.
† indicates that the species is found in the Middle Productus limestone of the Salt Range.

No doubt a more detailed examination of the material will increase the above list. The general character of the fauna, however, at once proves that we are dealing with beds closely related to the Productus limestone of the Salt Range, and to it we must look for assistance in determining the age of the rocks in which these fossils occur.

Productus limestone forms.

Forms found in the middle division in the Salt Range.

Of the nine species in the above list, four *viz.*:—

Camerophoria pinguis, Waag,
„ *purdoni*, Davids.,
Rhynchonella morahensis, Waag., and
Terebratuloidea minor, Waag.,

are, in the Salt Range, restricted to the middle division of the Productus limestone; two, *viz.*:—

Productus serialis, Waag.,
and the genus *Allorisma*

Forms peculiar to the upper division.

are found only in the upper division, while the remaining three forms, *viz.*:—

Productus abichi, Waag.,
Eumetria grandicosta, Waag.,
and *Spiriferina multiplicata*,[1] Sow,

occur in both the middle and upper divisions. *Eumetria grandicosta*, however, is found also in the lowest division, and is therefore of little value in determining the age of the beds in which it occurs.

Age of the sandstone.

On the whole, therefore, the species are indicative of an age between Middle and Upper Productus limestone, rather nearer middle, however. Where the sandstone is found in the river between Chúra and the Bazár Valley, it is both underlain and overlain by limestones, the lower beds being those already mentioned as

Higher and lower beds also represented.

[1] The identification of the species quoted as *Spiriferina* cf. *multiplicata* is doubtful, for it differs from the type specimen in the greater fineness and larger number of its radial ribs, while some of the smaller specimens bear a strong resemblance to *S. verrucosa*.

forming the hill above the village of Chína, and having a thickness of perhaps 400 feet. These limestones, as already stated, yielded at Chína specimens of—

Specimens found in limestones at Chína.

Eumetria grandicosta, Waag.,
Rhynchonella morahensis, Waag., and
Camerophoria purdoni, Davids.,

of which the first is found throughout the Productus limestone, while the two last are found only in the middle division. It is, therefore, probable that a more detailed examination of the locality would prove that the whole series of the Productus limestone beds is here fully represented.

Whole *Productus limestone* probably represented.

The above beds, where seen in the river near Walai, form a broken anticlinal leaning over to the south. After passing through the gap in the hills, the river-bed turns again to the west, passing under the southern side of this overturned anticlinal, and higher beds are found dipping to the north under the permian limestones. The beds consist of the red gritty shales, so well developed at Dwatowi in the Bára Valley, and already described as triassic. From this point the Bazár Valley proper begins. To the south of the river are low undulating downs formed by the red trias rocks, rising gradually to the northern slopes of the Surghar Range, while to the west extends an open plain, in the midst of which rises the ridge, already mentioned, on the south-eastern flank of which stood the village of Chína. Further to the west and north-west the valley is closed in by a range of hills running from the Saféd Koh towards Lundi Kotal and forming the barrier between this country and Afghanistan.

Trias.

Trias of the Bazár Valley similar to that of Dwatowi.

So far, therefore, as our knowledge at present extends, the beds exposed between Ali Masjid and the Surghar Range may be sub-divided as follows :—

Sequence of beds between Ali Masjid and Surghar Range.

4. Red and brown shales and grits of the southern side of the Bazár Valley. } Trias.

3. Fossiliferous limestones and sandstone . . .	Permian to permo-carboniferous.
2. Brownish-green and reddish shales with flaggy quartzites and subordinate bands of limestone and dolomite.	Permo-carboniferous to upper carboniferous.
1. Altered limestones of Rohtas hill, Ghund Ghar and Surghar Range.	Carboniferous.

III.—Post-Tertiary Beds.

In the foregoing pages, I have, in order to avoid confusion, omitted all reference to the recent and sub-recent deposits, which, however, cover considerable areas in Tirah and the Bazár Valley.

In Maidán.

They are well seen in the Maidán Valley, where horizontal beds of clay, grit and conglomerate extend for many hundred feet up the hillsides.

In the Bára Valley.

In the Bára Valley, as already mentioned, the triassic shales are covered up by these deposits, which, near the head of the valley, consist chiefly of coarse conglomerates, containing rounded and sub-angular pebbles, not only of the rocks locally exposed, but also of quartzite, gneiss and dolerite. The three last-named rocks, which occur in large quantities, are evidently derived from the Saféd Koh range.

Probable erratics.

The gneiss, which is a coarse variety, composed chiefly of blue quartz and white orthoclase, is found also in large blocks, having all the appearances of erratics, lying on the hillsides as much as three or four hundred feet above the present level of the river-bed. Although I could discover no unequivocal traces of glaciation, yet the size of these blocks and the manner in which they are stranded on the hillsides strongly suggest a glacial origin.

Cave-dwellings of the Bazár Valley.

In the Bazár Valley there occur very extensive beds of conglomerate and gravel, covering the plain to a depth of quite 50 feet in places, and deposited upon the upturned edges of the triassic beds. It is in these conglomerates that the numerous cave-dwellings of the Afridis have been excavated.

IV.—Igneous Rocks.

The almost entire absence of igneous rocks *in situ* is very striking. No trace, even of pebbles, was to be seen either in the Khanki or Mastúra Valleys or in the stream beds of Maidán and Warán. At Bágh however, I found, in a house, a polished pebble of *olivine dolerite*, which had evidently been used for crushing salt. This pebble had no doubt been brought from the Bára Valley, for on reaching Dwatowi I found numerous blocks and pebbles of the same rock lying in the bed of the Bára river. Pebbles of it also occur on the hillsides among the sub-recent conglomerates and gravel beds. I could not, however, find the rock *in situ*, but it probably occurs at the head of the valley, possibly along the fault separating the palæozoic and mesozoic rocks: yet in the lower reaches of the valley, where the fault is seen, I found no signs of igneous intrusion.

Absence of igneous rocks south of the Bára Valley.

Olivine dolerite from the Bára Valley.

Not *in situ*.

In the neighbourhood of Jamrúd Fort and throughout the Khaibar, pebbles and blocks of *gabbro* and *dolerite* are very common, but the only locality, in which I found any of these rocks *in situ*, was on Ghund Ghar, the hill already mentioned as overlooking, on the south, the entrance to the Khaibar. On the north-east flank of this hill a small intrusive sheet of *dolerite* is found among the shales, while higher up the hillside are other intrusions, one about half-way up and another about 200 feet below the summit. All these intrusions are quite small: that nearest the summit occurs among the carboniferous limestones which it has locally altered into a fine saccharoid marble.

Dolerite of Ghund Ghar.

Intruded among the carboniferous limestones.

The rock is a green enstatite-dolerite, and under the microscope shows a confused mass of crystals of plagioclase, augite and enstatite with numerous secondary minerals, including chiefly green hornblende, bastite,

Microscopic characters.

chlorite and some zoisite. Ilmenite is very common, in every stage of alteration.

Gabbro. Not found *in situ.*

The *gabbro*, which I did not succeed in finding *in situ*, occurs in great quantity in the form of pebbles and blocks in the stream-beds. The freshest specimen available contains much the same minerals as the Ghund Ghar dolerite, but in larger crystals. The plagioclase is labradorite, while the augite is a pale green variety frequently twinned. It is partially altered to bright green hornblende, while the enstatite, which is either colourless or pale green in this section, is frequently converted into bastite.

Microscopic characters.

V.—Summary.

With the exception of the area lying between Chúra and the Surghar Range, a complete traverse has now been made of the country between Ali Masjid and the British frontier at Shináwari. In this area are found members of every system from the tertiary down to the carboniferous, and probably silurian or older.

The beds fall under the following sub-divisions :—

Limestone, with *nummulites*, underlain by green and red shales and sandstones	Eocene.
Grey limestones, with sandstones, shaley limestones and shales	Cretaceous and jurassic.
Massive coral limestone, — of the gorge between Bágh and Dwatowi	Rhætic.
Red gritty shales, grits and conglomerates, underlain by reddish-brown needle shales	Trias.
Limestones and calcareous sandstone, with *Productus Limestone* fossils	Permian to permo-carboniferous.
Greenish-brown shales, with flaggy quartzites and subordinate bands of limestone and dolomite	Permo-carboniferous to upper carboniferous.
Altered limestones of Rohtas hill, Ghund Ghar and Surghar Range	Carboniferous.
Hard banded slates and quartzites—near Sher Khel, Bára Valley	(Probably) older palæozoic.

Owing to paucity of fossils, much of the above classification is merely tentative, but eocene fossils were found in Tirah, and cenomanian *brachiopods* in the Warán Valley, while in Chúra and the Bazár Valley are beds containing species found in the *Productus Limestone* of the Salt Range.

Structurally this area consists of a series of reversed folds, with much crushing and many faults. To the south of the Bára river, no rocks older than mesozoic are found, but along the southern flanks of the Saféd Koh, these beds are faulted against rocks of palæozoic age.

No igneous rocks were found *in situ* south of the Surghar Range, but they probably occur on the southern flanks of the Saféd Koh. In the Khaibar an altered dolerite is found among the carboniferous rocks on Ghund Ghar, and in the stream-beds many boulders of an altered enstatite gabbro.

MEMOIRS

OF THE

GEOLOGICAL SURVEY OF INDIA.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

THE CHARNOCKITE SERIES, A GROUP OF ARCHÆAN HYPERSTHENIC ROCKS IN PENINSULAR INDIA. *By* THOMAS H. HOLLAND, A.R.C.S., F.G.S., *Officiating Superintendent, Geological Survey of India.*

INTRODUCTION.

The older workers on the Geological Survey in South India followed the prevalent theories of the day in considering the Archæan gneisses and schists to be merely sediments in a highly advanced stage of metamorphism; but Mr. R. Bruce Foote[1] has recently expressed an opinion that such a conclusion needs revision, and the task now left us is to determine which of these old gneisses are of igneous origin, and which show evidences of being merely metamorphosed sediments.

The first duty, evidently, is to define and separate from their associates the groups which show, throughout their constituent members, a sufficient similarity of family characters to indicate identity of origin and a genetic relationship one to another. The

[1] "The Geology of the Bellary District." *Mem. Geol. Surv. Ind.*, Vol. XXIV (1895), p. 27.

next duty is to apply to each group or family so defined the tests which are recognised as safe criteria for distinguishing rocks of igneous from rocks of sedimentary origin. The first section of this memoir is therefore devoted to explaining the general features which serve to connect and show the consanguinity of the types grouped together under the name *charnockite series*, whilst the succeeding chapters discuss the question of their origin.

The most abundant and not the least interesting of the old crystalline formations in South India are the great masses of rock whose two leading characteristics are a granulitic structure and the invariable presence of a rhombic pyroxene amongst the constituents. That such rocks as these existed in the Madras Presidency was, so far as I can find, first recognised by Professor Judd, who employed material collected in the Nilgiris to describe the properties of the highly pleochroic, rhombic pyroxene which approaches Vom Rath's amblystegite in composition.[1]

Later, Prof. A. Lacroix,[2] in his memoir "Contributions à l'étude des gneiss à pyroxène et des roches à wernérite" described as *pyroxene-gneisses* a number of specimens which had been collected as long ago as 1819 by Leschenault de la Tour.[3] Some of these rocks resemble the types herein grouped together under the name *charnockite series*.

At the end of 1891, and during the first three months of 1892, I made a tour through the southern districts of the Madras Presidency and then found that these rocks had a very wide distribution in the South of India. They were first found in full variety at St. Thomas' Mount and Pallavaram, 10 miles south of Madras city; from quarries in these localities large quantities of rock have been obtained for building and ornamental purposes in Madras. Subsequently the same rocks were found to make up the mountain masses of the

[1] *Quart. Journ., Geol. Soc.*, Vol. XLI (1885), pp. 371 and 372.

[2] *Bull. de la Soc. Fr. de Min.*, Vol. XII (1889), p. 83, and *Rec. Geol. Surv. Ind.*, Vol. XXIV (1891), p. 157 (translation by Mallet).

[3] In a separate paper I have given an account of M. Leschenault's geological observations in South India, together with the results of an attempt to identify the localities of the specimens described by Lacroix.

Shevaroys, the Nilgiris, the Palnis and the great ridge of high ground forming part of the Western Ghâts, stretching southwards as far as Cape Comorin and reappearing above the sea-level in Ceylon.

In the following year Mr. F. G. Brook-Fox, F.G.S., called my attention to the occurrence of the same rocks in the South Arcot district, and during the succeeding field season Dr. H. Warth made a representative collection of the principal types exposed in that area.

At about the same time Mr. C. S. Middlemiss commenced survey work in the districts of Salem and Coimbatore, and with the assistance of Mr. F. H. Smith has since added several new localities to those previously known.

In the summer of 1897 I was able to devote a month towards the examination of some of the interesting features presented by this group in the immediate neighbourhood of Salem, whilst the following field season was devoted to a systematic survey of the little province of Coorg on the Western Ghâts, where, with the help of Dr. T. L. Walker, some very interesting facts, bearing especially on the geological relations of these rocks to the older gneisses, were discovered.

All the observations above referred to were made after the real nature of the rocks had been discovered by microscopic examination, and although the petrological features of the same areas have frequently been referred to in papers on related subjects published since 1892, no systematic description of the group has hitherto been put on record.

Messrs. F. H. Smith and T. L. Walker have recently found the charnockite series developed over large areas in the districts of Ganjam and Vizagapatam.

PART I.

PETROGRAPHY OF THE SERIES.

CHAPTER I.

PREVIOUS DESCRIPTIONS OF THE SERIES.

Before the establishment of an organised Geological Survey of India various disconnected descriptions of the rocks now included in this group were published by several independent observers in the South of India, such as those by Dr. P. M. Benza,[1] Captain J. Allardyce [2] and Captain J. Ouchterlony.[3]

Benza referred to St. Thomas' Mount and the hills at Pallavaram as composed of "hornblende rock overlying the fundamental rock." Captain Allardyce evidently recognised the similarity between what he called the "primitive trap allied to sienitic granite" of Pallavaram and the rocks forming the principal mass of the Nilgiris (Neilgherrys) and Shevaroys, as well as those forming the Western Ghâts and Ceylon. He speaks of the great abundance of this rock, and asserts that it "cuts off and terminates all other granites". Benza referred to the rocks of the Nilgiris in somewhat similar terms. "The lowest visible rock of the Nilgiris is," he says, "of the primitive unstratified class, including true granite, pegmatite, sienitic granite and hornblende rock; sienitic gneiss and hornblende slate are occasionally seen, but they belong more to the outskirts of the hills" (*loc. cit.*, p. 256). The same author also noticed the smoky and bluish quartz which is so common in the charnockite series

[1] "Notes on the Geology of the Country between Madras and the Neilgherry Hills viâ Bangalore and viâ Salem". *Madras Journ. of Lit. and Sci.*, Vol. IV, pp. 1—27 (1836). "Memoir on the Geology of the Neilgherry and Koondah Mountains". *Ibid.*, Vol. IV, pp. 241—299 (1836).

[2] "On the Granitic Formation and direction of the Primary Mountain chains of South India". *Ibid.*, Vol. IV, pp. 327—335 (1836).

[3] "Geographical and Statistical Memoir of the Neilgherry Mountains. *Ibid.*, Vol. XV, pp. 1—1?8 (1848).

(p. 257). Captain Ouchterlony in 1848 referred to the mass or nucleus of the mountains as "granite frequently passing into sienite" (*op. cit.*, p. 2). He draws a distinction between the "granite", "sienite" and "hornblende rock" of the Nilgiris on the one hand, and the "beds of gneiss" met with in the plains on the other.

With the systematic mapping which was commenced by the officers of the Geological Survey of India in 1857, a large mass of information was accumulated concerning the distribution of the charnockite series, as well as other formations in South India. The macroscopic and field characters of the rocks have been clearly described in the reports of the work done by H. F. Blanford, C. Æ. Oldham, W. King, R. B. Foote and P. Lake, most of which have been published in the *Memoirs* and *Records* of the department.[1]

As at the time of the issue of these publications provision had not been made in the department for microscopic examination of the rocks, the wide prevalence of the pyroxenes, and especially of the rhombic forms, was not noticed, the dark mineral in the rocks being generally referred to hornblende, which is also an abundant constituent. Following also the theories then prevalent as to the nature of the Archæan crystalline rocks, most of the authors who described the geological features of Madras regarded the gneissose and the banded structures as evidence in favour of considering the crystalline rocks to be the results of the metamorphism of sediments. But we now know that neither the gneissose structure, nor the banding due to differences in mineral composition of the "beds," differs essentially from the phenomena presented by some rocks whose eruptive origin is established beyond dispute. In the light of this modification of old views concerning the gneisses it becomes necessary to separately re-examine each group and record the evidences bearing on its origin.

[1] See Manual, Geol. of India, 2nd Ed., pp. 36—39.

CHAPTER II.

Distinguishing Features of the Series.

Consanguinity of the members.

The unaltered varieties of this series present such a remarkable and unmistakeable individuality in macroscopic characters that they are easily distinguished in the field from the other crystalline rocks with which they are associated. On account of the striking nature of the characters which give the different varieties of the group such an unmistakeable family likeness—"consanguinity," to use Iddings' expressive term—the peculiar characters distinguishing one variety from another are so well masked, that the forms containing sufficient free quartz and siliceous minerals to raise the silica percentage to that of the granites might very easily be confused with the varieties whose mineral composition agrees with that of typical norites.

Macroscopic characters.

The leading features in hand specimen of the common, that is the unaltered and medium-grained types, are the blue-grey to dark-green colour, the subconchoidal fracture, and the absolutely fresh condition of the rock. Examination of the coarse-grained types with the naked eye, or of the fine-grained ones with the lens, shows that quartz when present is almost invariably blue in colour, like that of the well-known Rumburg granite (granitite); the felspars present a similar blue or blue-grey colour, and, but for their cleavage faces, might easily be mistaken for quartz. These minerals, therefore, which generally give the lighter colours to our ordinary acid rocks, are almost as dark in the Madras "pyroxene-granulites" as the associated ferromagnesian silicates; and this circumstance, together with the fact that opaque iron-ores are equally abundant in all types, are the principal causes which give the acid and basic members of the series such a similarity of appearance in hand-specimen.

17. Microscopic examination shows that the similarities in macroscopic characters are only the outward and visible signs of a constancy in structure and mineral composition. The one constant feature in *structure* is the *even-grained, granulitic* (panidiomorphic) character of the constituents. The constant feature in *composition* is the presence of *rhombic pyroxene*, which is generally highly pleochroic, approaching hypersthene, or in some cases amblystegite, in composition.

Microscopic characters.

The above two characters are constant in what I regard as the unaltered forms of the rocks. But in those which show a clearly defined gneissose structure by linear arrangement of the minerals signs of dynamo-metamorphism are sometimes displayed, and *pink garnets* almost invariably appear. I have said signs of dynamo-metamorphism are *sometimes* displayed, because, although nearly all varieties show a linear arrangement of the constituent minerals, the frequent absence of all signs of crushing shows that in some instances the crystals were arranged with their long axes at right angles to the direction of maximum pressure before consolidation. Whether this unequally distributed pressure was due to actual lateral compression, or to fluidal movements analogous to that which has frequently been recorded in dykes, it is impossible to determine, and, as far as concerns our conclusions as to the origin of these rocks, is of little consequence.

Characteristic constituents.

Besides *hypersthene*, which is an invariable constituent, and *garnet*, which is extremely common, the following minerals are frequently found in members of this series:—

Quartz.—Blue, grey, or greenish, often with innumerable acicular inclusions. Also intergrown with felspar to produce the so-called "quartz de corrosion" of the French petrographers.

Potash felspar.—Often as microcline and frequently microperthitic.

Plagioclase.—In the basic types generally approaches labradorite or labradorite-andesine in composition.

Augite.—A pale green, feebly pleochroic variety, frequently exhibiting lamellar twinning.[1]

Hornblende.—A brown-green, highly pleochroic variety with an extinction angle of about 11°.

Biotite.—Very variable in quantity, appears in most exposures.

Graphite.—Evenly distributed like the other constituents, though smaller in quantity, and found in two exposures only.

Zircon and *apatite* are nearly always present in small quantities.

Iron-ores, *magnetite* and *titanoferrite* are invariably present and generally in large quantities; *pyrite* and *pyrrhotite* are often developed near the junctions of two distinct varieties.

Except in one aberrant form presenting several peculiar and unusual features *sphene is absent*. The occurrence of the titanic acid in the form of ilmenite instead of as sphene is a feature which distinguishes these rocks from some associated gneisses, and also separates the normal from the altered forms.

[1] Lacroix (Rec. Geol. Surv., India, XXIV, 173) mentions the occurrence, in the "pyroxene gneisses" of Salem, of a monoclinic pyroxene with a pleochroism similar to that of hypersthene, namely, $\mathfrak{c}$=sea green, $\mathfrak{b}$= bright pink and $\mathfrak{a}$= yellowish green, with an extinction angle of 45° on the clinopinacoid (010). It may be stated at once that, although I have examined hundreds of cases from the Salem district and from all parts of the Madras Presidency, I have never yet found a pyroxene in these rocks giving the pleochroism of hypersthene without at the same time, when definite cleavage lines are exhibited, showing a straight extinction. At the same time the commonest of all the types of these rocks is one in which both pyroxenes occur together; the one strikingly pleochroic and unmistakeably rhombic in its crystallization, whilst the other is very feebly pleochroic in greens only, giving wide extinction angles.

The green colour of the hypersthene, however, so nearly resembles that of the monoclinic pyroxene, that without moving the polariser the similarity of refractive index and crystal habit might, in a hasty examination, result in a confusion of the two forms. As the rocks described by Lacroix so remarkably resemble in other respects those which I include in the series now under description, I have very carefully searched every specimen in the extensive collection made by my colleagues and myself, and have to confess my inability to discover a single instance of such a pleochroic monoclinic pyroxene.

Corundum, sillimanite, green spinel (hercynite or pleonaste) and rutile characterise the contact products in inclusions which are regarded as xenoliths and not true members of the series. Scapolite, sphene and lime-garnet occur where these rocks are associated with crystalline limestones and are considered to be either primary or secondary endogenous products of contact metamorphism.

CHAPTER III.

NOMENCLATURE.

So far as we know, the rocks described in this paper are of Archæan age and have as their nearest foreign equivalents the rocks known to the German petrographers as "pyroxene granulites" and to the French as "pyroxene gneisses". Although their predominating features are those which characterise the "pyroxene granulites," they also show points of resemblance to certain varieties of the "norites" of Scandinavia and sometimes to the "anorthosites" of Canada, besides possessing peculiarities of their own. But whether the rocks now under consideration ultimately prove to be the equivalents of anyone or all of the above-mentioned foreign groups is at present difficult to determine: the important point for us is that within the limits of Peninsular India they form a distinct and very large subdivision of our old crystalline rocks, possess a very well defined series of characters and present a constant relation to the older gneisses; in fact, *they constitute a distinct petrographical province*, which we propose to distinguish by a special name in our literature, and, when possible, by a special colour on our maps.

The name *charnockite series*, which we now commonly employ for these rocks in India, expresses the fact that we group together in one petrographical province a number of lithical types genetically related to charnockite (*vide infra*, p. 134) and to one another. Within this petrographical province there are petrical and lithical forms which vary from the acid charnockite to the ultra-basic pyroxenite; but any one who has studied the group in the field would readily recognise the consanguinity of the different members, and indeed would often find it difficult, without the aid of the specific gravity balance or the microscope, to distinguish an acid from a basic variety.

Our name charnockite series thus enables us to bring together a set of genetic relatives, which, by the ordinary systems of petrographical classification would be separated from one another; and at the same time we avoid the vexed questions which the terms "pyroxene granulite" and "pyroxene gneiss" would naturally provoke. We are far more certain that the different members of the charnockite series are related to one another than we are that they are related to the European "pyroxene granulites," and for the purpose of mapping it is safer, at least as a temporary measure, to adopt a local term, such as a stratigraphist, for instance, would do under like difficulties.

Besides the advantages which a new and local term offers from a purely survey point of view, there are certain theoretical objections to the use of the alternative foreign terms for rocks which are probably, though not certainly, the equivalents of our charnockite series. Against the use of the term "pyroxene granulite" for instance, there is (1) the fact that the rocks herein referred to are not all granulitic in structure, and (2) the specific meaning attached to the word "granulite" by the French petrographers, who apply it to an eruptive muscovite-granite poor in mica and approaching the so-called aplites in composition.[1] Against the use of the term "pyroxene-gneiss" there is (1) the fact that the rocks under consideration are not always "gneissose", (2) the circumstance that to many this term would imply a definite geological age and origin which are not proved, and (3) there are many gneisses in India containing pyroxene which are not genetic relatives of the charnockite series, and should not therefore be grouped with them.

Classification by petrographical provinces.

Unfortunately our modern systems of nomenclature make no provision for indicating petrographical provinces, because no system of rock-classification makes any pretence towards an expression of genetic relationship between the so-called families. From the purely petrological and hand-specimen point of view, it may be convenient to adopt Rosenbusch's system of dividing rocks into three classes according to the purely accidental circumstances attending their

[1] Michel-Lévy. *Bull. de la soc. geol.*, 3rd series, Vol. II (1874), p. 180.

consolidation; but as such a system must always separate rocks that are magma relatives, and bring together others that have no genetic relationship, it falls short of the requirements of the geological surveyor. For the wider problems of geology it is necessary that we should know how to subordinate the accidental differences to the general family likenesses between rocks, to group together, in fact, those which have been produced by the same geological effort, and which form a geological unit. In other words, the geological surveyor is more concerned with the delimitations of the petrographical provinces represented within his country than with the mere cataloguing of lithical varieties.[1]

Whilst, therefore, we group together, and map as one formation, a number of diverse varieties of rocks (which are true compatriots within this petrographical province) under the name *charnockite series*, the various constituents of this formation may be distinguished from one another by the ordinary names used for equivalent mineralogical aggregates. As we believe the charnockite series to be igneous in origin and to present intrusive relations to their older neighbours, the terms used for the rock varieties within the group are those commonly used for mineralogically similar igneous rocks. Thus the types which are composed essentially of hypersthene and plagioclase are *norites*, and, according to the ferromagnesian silicate associated with the rhombic pyroxene, we may have augite-norites, hornblende-norites, or mica-norites. The acid form, composed of quartz, microcline, hypersthene and accessory iron-ores, is strictly a *hypersthene-granite or charnockite*, and the non-felspathic forms, composed almost wholly of pyroxenes, are *pyroxenites*.[2]

[1] Prof. Judd was perhaps the first to show by a ground-work of accurately determined petrological and geological data that there is a recognisable set of family characteristics (*consanguinity*, Iddings; *Blutverwandschaft*, Brogger) presented by igneous rocks which, within a limited geographical area, have been formed at a definite geological period, and he expressed these facts by considering such rocks to be members of a *petrographical province*. *Quart. Journ. Geol. Soc.*, Vol. XLII (1886), p. 54.

[2] The term pyroxenite has been used in several totally distinct and unrelated senses, but is now more generally used for eruptive pyroxene rocks.

So too with the structures: the charnockite series occur in dykes and in bosses; they show basic schlieren, acid contemporaneous veins, primary breccia and other structures peculiar to igneous rock masses, and include foreign bodies (xenoliths).

The name charnockite limited to this province.

But unless a similar formation found in another country, can be proved to be a genetic relation of the typical exposures described in this paper, it is hoped that the name charnockite will never be used outside India. The name is applied to a definite member of a very definite petrographical province now exposed in India, and unless outsiders give it a wider application than that now proposed the terms charnockite and charnockite series need never become a burden to petrographical nomenclature. Charnockite is a convenient name for a quartz-felspar-hypersthene-iron-ore rock in the charnockite series, and not a name for *any* hypersthene-granite occurring in other petrographical provinces. The much-complained-of burdens of petrographical nomenclature are not due to the creation of specific names for local types, but to irresponsible and unwarranted extension of such names to include unrelated members of different and widely separated petrographical provinces, in which the accidents of differentiation and segregative consolidation may have produced by chance similar mineral aggregates.

The charnockite series belong to a very old petrographical province, so old that we have no present reason for separating them from the Archæan "group;" but still young enough to show their intrusive relations to older Archæan formations. During the great lapse of time since the production of the very old geological formations—whether sedimentary or eruptive—secondary changes have tended to remove many of the primary peculiarities of rocks, and have induced the development of a resemblance between genetically distinct types; so that there is always a danger of including unrelated formations when delineating the boundaries and distinctive characters of a very ancient petrographical province. It is possible, therefore, that we may be including under the name "charnockite series" hypersthene-bearing rocks derived from more than one magma, though all of very great antiquity. That, however, is a difficulty which the stratigraphist has to face also in attempting to compare the chronological values of different "epochs." Still, as long as we keep in view several points of similarity between isolated exposures of the charnockite series, the danger of including too much is partially insured against. As a set-off against this danger, there is a strong probability that the magmas tapped in earlier geological periods were larger than those which gave rise to eruptions after the earth's crust had advanced in physical differentiation.

CHAPTER IV.

Description of the chief types.

As already stated, the members of the charnockite series vary from acid types, having the mineralogical and chemical composition of granites, to ultra-basic forms or pyroxenites. For convenience of description, however, they may be divided into four groups which are not sharply marked off from one another :—

(1) *Acid division*, represented by *charnockite*, a hypersthene-granite having a constant specific gravity of 2·67 and silica percentage of about 75. The type-mass forms the central portion of the hill near St. Thomas' Mount (fig. 1). The type-mass is cut through by contemporaneous veins of coarse *quartz-felspar* rock. The garnetiferous forms resemble *leptynites* in composition.

(2) *Intermediate* varieties are by far the most abundant and are characterised by an apparently composite structure, *all* the minerals of the series being frequently found in one hand-specimen with a tendency for the coloured minerals to gather into groups. The average specific gravity is 2·77, with a silica percentage of about 64. Acid contemporaneous veins and basic fine-grained *schlieren* are common. The Shevaroy mass is a typical exposure.

(3) *Basic* forms, mineralogically equivalent to the *norites* and composed of pyroxene (hypersthene and augite), plagioclase and iron-ores, often with hornblende. The type-mass forms the flanks of the hill near St. Thomas' Mount (fig. 1). Specific gravity, 3·03 and silica percentage, 50 to 52. Garnetiferous forms are common near the outskirts of mountain masses, and form large, lenticular bodies in the older gneisses and schists. Garnetiferous as well as non-garnetiferous varieties in Coorg form dykes having chilled selvages.

(4) *Ultra-basic* forms, or pyroxenites, composed of hypersthene, augite, hornblende, sometimes with olivine, green spinel and magnetite. The hypersthenes are sometimes porphyritic, but more generally are perfectly granulitic. Specific gravity, 3·37; silica percentage, 47 to 50. Amphibolization of the pyroxene sometimes results in an almost complete change to hornblende.

These four divisions are described in order below:—

(1) Acid Division.

Charnockite.

Discovery of charnockite.

In October 1892, the Director of the Geological Survey of India announced in his tri-monthly notes, the occurrence in South India of a rock composed of hypersthene, microcline, quartz and accessory iron-ores, referring to it as a hypersthene-granite.[1] As at that time little more was known than the mere occurrence at Pallavaram of a mass of this rock, no further details were published until after my second visit to Madras in September 1893. It was then found that the hypersthene-granite formed large masses associated with granulitic rocks, having the mineral composition of norite (*infra*, p. 153). At about the same time the tombstone of Job Charnock, the founder of Calcutta, was discovered by the Rev. H. B. Hyde in St. John's Churchyard, Calcutta, and when it was found that the tombstone was made of the same hypersthene-granite (which was at the time thought to be a new type of rock), the name *charnockite* was suggested for it in honour of the man who was the unconscious means of bringing the first specimen of this interesting rock to the city which ultimately became the capital of India.[2]

In the same year (1893) Prof. J. H. L. Vogt published the first instalment of a series of papers on the "Bildung von Erzlagers-

[1] *Rec. Geol. Surv. Ind.*, Vol. XXV (1892), p. 190.

[2] *Journ. As. Soc. Beng.*, Vol. LXII (1893), p. 162. Job Charnock died in 1693, and the tombstone was erected two years later.

tätten durch Differentiation-processe in basischen Eruptivmagmata," and referred to the occurrence of a series of rocks at Ekersund in south-west Norway, which appear to strongly resemble those of Pallavaram. The three principal types represented at Ekersund are, according to Vogt, (1) labradorite rocks, resembling apparently the anorthosites of Canada, (2) norites rich in hypersthene and biotite; and (3) a granite composed largely of potash-felspar and quartz with a rhombic pyroxene approaching bronzite in composition, iron-ores in considerable quantities, and a small proportion of an acid plagioclase.[1] Such a description applies exactly to the rock which is known to us in South India as charnockite. But the resemblance of this special type of rock to our charnockite becomes doubly interesting on account of the similarity between the associates in both localities. Although the norites and labradorite rocks differ from the granite so widely in silica percentage, the whole group, according to Vogt, belongs to one petrographical province in which all the members are characterised by the presence of a rhombic pyroxene, and the rocks show an unmistakeable consanguinity (*Blutverwandschaft*) which leaves little doubt as to their derivation from an originally common magma basin. Almost the same words were used in referring to the relatives of charnockite as they are displayed in the neighbourhood of Pallavaram. As remarked in a previous paragraph, the macroscopic characters of the various types so strikingly display the common family characters of the group, that the differences which serve to distinguish the varieties are often remarkably masked.

Norwegian granite with rhombic pyroxene.

At about the same time, therefore, and independently, Vogt discovered in south-west Norway a granite resembling charnockite both in its own composition and in the characters of its associates. Vogt apparently (as well as myself) was under the impression that rhombic pyroxene had not previously been recognised in a granite. I am indebted to Professor Zirkel, however, for calling my attention to the fact that Törnebohm found a rhombic pyroxene to be a constituent of a granite in the neighbourhood of Roxen-See and

[1] Zeitschr. für prakt. Geol., 1893, p. 4.

Ingelsbye in Sweden, whilst Rosenbuch referred to the occurrence of bronzite as a constituent of granite in the Julian Alps.

The type-mass of charnockite.

The mass of rock from which Job Charnock's tombstone was quarried is probably that which forms part of the hill south-west of the powder magazine at St. Thomas' Mount.[1] The north-east and south-west ends of the hill are composed of norite (Nos. 9·657 and 9·660),

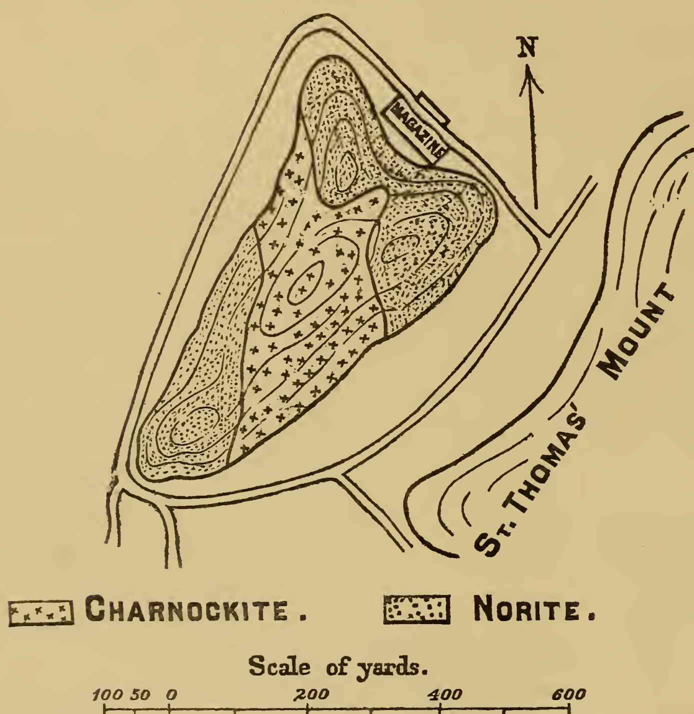

Fig. 1.—*Plan of hill showing the type-masses of charnockite and norite near St. Thomas' Mount, Madras.*

[1] I am indebted to His Grace Dr. P. Goethals, S. J., Catholic Archbishop of Calcutta, for calling my attention to the following passage in the East Indian Chronologist for the year 1801. "Charnock's ponderous tombstone appears to have been cut from the quarries of St. Thomé, as well as most of the tablets in the pristine cemetery of Calcutta" (page 85). This confirms the conclusion based on the petrological resemblance of Charnock's tombstone to the rocks of Pallavaram and the adjoining mass known as St. Thomas' Mount. The rock is still quarried and used for ornamental purposes in Madras; but, as a result of an attempt to get polished samples from a firm in the city, I find the basic norite, with a specific gravity of 3·03, is as often used as the charnockite.

whilst the central mass is composed of charnockite, which is uniform in character up to its junctions on either side with the norite. It is from this mass that the type specimens of the rock, now preserved in the Geological Museum, Calcutta, were obtained (No. 9·658). Through it, and the associated norite as well, run coarse-grained veins—like the contemporaneous veins of ordinary granites—in which the ferro-magnesian silicate and the iron-ores are reduced to mere traces, whilst the rock is made up almost wholly of microcline and quartz (9·659).

Whilst the norite shows practically no signs of a parallel arrangement of its constituents, the charnockite, forming the central mass of the hill, shows by the linear disposition of the dark minerals a rough foliation of north-north-east—south-south-west, being thus parallel to the protaxis which has determined the Coromandel coast-line. If the charnockite, the most acid member, represents the residual portions of the magma whose segregative consolidation resulted in the hypersthene-bearing complex at Pallavaram, it is only natural to expect that one result of its probably late consolidation would be a disposition of its constituents parallel to the fissure it occupied and at right-angles to the direction of maximum lateral pressure. That this rude foliation occurred before and not after consolidation is shown by the fact that the most delicate interlocking structures have been preserved in the rock: the common signs of dynamo-metamorphism, such as peripheral granulation of the constituents and the production of mylonite, are entirely wanting.

Specific gravity.

The determination of a large number of specimens, taken from the type mass near St. Thomas' Mount, gave, as an average of numerous closely agreeing results, a specific gravity of 2·67.

Mineral composition.

Under the microscope, the rock is seen to be an even-grained, crystalline aggregate of quartz and potash felspar as the two most abundant of the constituents, with smaller quantities of oligoclase, rhombic pyroxene, approaching hypersthene in optical characters, opaque iron-ores and an occasional granule of zircon.

Acicular inclusions in the Quartz.

The shapeless crystals of *quartz* are often crowded with minute hair-like inclusions, which are arranged with crystallographic regularity. The crystallographic disposition of two sets of these acicular inclusions are easily studied in sections cut at right angles to the vertical axis (isotropic sections). In such sections (No. 1604, for instance) long acicular inclusions lying in the plane of section (that is, parallel to the basal plane) cross one another at angles of 60° and show straight extinction. The angles formed by the crossing of these long needles are bisected by a set of shorter needles lying oblique to the plane of section. Taking the first set of inclusions to be arranged parallel to the lateral axes, that is, to the lines joining the opposite solid angles of the prism of the 1st order, the second set must lie in the secondary set of symmetral planes, and, being oblique to the basal section, probably lie parallel to some pyramidal face. The numerous black dots seen in the basal sections represent the cut ends of those which in vertical sections are found to lie parallel to the axis of minimum optical elasticity, and, therefore, also parallel to the vertical axis. The three sets of inclusions exhibited by basal sections of blue quartz are shown in the diagram (fig 2).

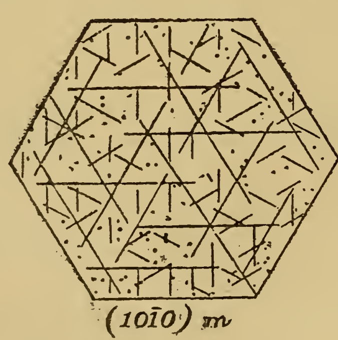

Fig. 2.—*Diagrammatic representation of the needles in basal sections of Quartz.*

On comparing the phenomena presented by the basal sections with those exhibited by longitudinal ones, the assumed positions for two of the sets of needles are easily verified at once. Long needles lying in the plane of the vertical sections are found on application of the quartz wedge to be parallel to the axis of minimum optical elasticity, which is the vertical crystallographic axis also. These are the needles whose cut ends appear as mere dots in the basal sections. Others are found lying at right angles to the vertical axis, some in the plane of section and some oblique to it; these clearly represent the needles lying parallel to the basal plane and assumed to be also parallel to the lateral crystallographic axes. Besides these there are others lying oblique to the directions of extinction and oblique also to the plane of section. To verify the position of these needles, which are assumed to lie parallel to the rhombohedron, it has been necessary to find a section cut parallel to the prism. Such a section would be one in which the polarisation colours attain a maximum order, and in which long needles should lie in the plane of section, both parallel and perpendicular to the vertical crystallographic axis, whose direction is determined by means of the quartz wedge. Such a case occurs in section No. 1781. In this section it was found that besides numerous needles lying oblique to the plane of the section there were other sets lying in the plane of the section—(1) one set parallel to the vertical axis, (2) another set parallel to the basal plane, and (3) a set meeting the vertical axis at an angle of 52° and meeting the trace of the basal plane at angle of 38°, agreeing thus with the inclinations of the unit rhombohedron in quartz. With the rough means supplied by the cross-wires of a microscope, and in the presence of many other possible planes approximating to the rhombohedron it is dangerous of course to put too much reliance on this determination ; but it is worth recording that the determinations made give results which would be expected if it were known that the needles were lying parallel to the face of the unit rhombohedron.

I conclude, therefore, that the hair-like inclusions, to which probably the blue colour of the quartz is due, are arranged with crystallographic regularity as follows :—

(*a*) Parallel to the lateral axes, and thus lying in the principal planes of symmetry.

(*b*) Parallel to the vertical axis.

(*c*) Parallel to the face of the unit rhombohedron and lying in the secondary planes of symmetry.

There may be other sets of needles in some cases, but it is impossible to determine their crystallographic disposition in crystals which are devoid of idiomorphic outlines. The needles lying in isotropic (basal) sections show straight extinction; but, being thinner than the doubly refracting medium in which they are imbedded, further details concerning their optical characters could not be determined.

The hair-like inclusions which occur in the garnets so frequently found to be constituents of the charnockite series I have shown before to be biaxial in their double refraction, exhibiting very wide extinction angles.[1]

Potash-felspar.

The *potash-felspar* is mostly in the form of microcline and often presents the *streifige* appearance due to regularly-arranged intergrowths with a plagioclase to form the microperthitic structure which has been so commonly recognised in the felspars of pyroxenic rocks similar to those of the charnockite series. "Quartz of corrosion" is frequently found in the angular spaces between crystals of felspar. In some of the coarse-grained "contemporaneous veins" traversing charnockite the large crystals of potash-felspar resemble the well-known "moon-stone" in presenting an opalescent appearance.

Plagioclase.

The *plagioclase* present appears, from its narrow extinction angles, to approach oligoclase in composition. The fusiform bodies so frequently found in this mineral, and resembling at first sight those which produce the microperthitic structure in orthoclase, possess a higher refractive index and stronger double refraction than their host. Lacroix has referred similar bodies to quartz, regarding their occurrence in the oligoclase as a peculiar form of "quartz of corrosion."[2]

[1] *Rec. Geol. Surv. Ind.*, Vol. XXIX (1896), p. 16.
[2] *Rec. Geol. Surv. Ind.*, Vol. XXIV, p. 168.

Hypersthene.

The *rhombic pyroxene* seldom presents any noticeable approach to idiomorphic outlines. Whenever definite cleavage cracks are exhibited, the extinction is always straight. I have never found a monoclinic pleochroic pyroxene in the mass of charnockite near St. Thomas' Mount (*vide supra*, p. 126, foot-note). The pleochroism is very distinct, similar to that of hypersthene.

a, reddish brown or bright pink.

b, reddish yellow.

c, green with a bluish tinge.

A greenish-yellow, fibrous, pleochroic mineral resembling *delessite* is often developed along irregular fissures in the hypersthene and is evidently the same as that noticed by Lacroix in the pyroxene of a rock described by him as a " pyroxenic leptynite " from Ceylon. The maximum absorption is parallel to the fibres which is also the axis of minimum optical elasticity.

Accessory minerals.

The opaque iron-ores appear to be referable chiefly to magnetite ; titaniferous varieties, however, occur very commonly in the basic associates of charnockite. I have never found a garnet in the unaltered type mass at St. Thomas' Mount, but, as shown below, this mineral is an invariable constituent of the varieties which have suffered from marked dynamo-metamorphism.

Chemical composition.

Chemical analysis shows that the type-mass of charnockite agrees with normal granite in the predominance of potash amongst the alkalies and in the general proportions of the other constituents. The following results (I and II), obtained from specimens collected near St. Thomas' Mount, Madras, are compared with the hypersthene granite of the Ekersund area,

S. W. Norway (III) and an acid variety of "pyroxene granulite" from near Penig (IV).

	I	II	III	IV
SiO_2	75·54	75·30	73·47	72·97
TiO_2	undetermined	trace	0·12	—
Al_2O_3	13·75	11·40	15·42	12·69
Fe_2O_3	4·99	5·40	0·26	4·55
FeO			0·67	
MgO	0·69	0·60	0·20	0·63
CaO	0·94	0·75	1·35	2·33
K_2O	3·34	6·13	3·64	3·46
Na_2O	1·55	1·45	5·57	3·16
H_2O	0·28	...	...	0·13
	101·08	101·03	100·70	99·92

I. By Dr. T. L. Walker, Geological Survey of India.

II. By Dr. P. C. Roy, Presidency College, Calcutta.

Both specimens of charnockite from St. Thomas' Mount.

III. Hypersthene granite, Birkrem, Ekersund, S. W. Norway. C. F. Kolderup, Bergens Museums Aarbog., 1896, No. V (Abstract, *Neues Jahrb.*, 1899, I, p. 445).

IV. Orthoclase-bearing "pyroxene-granulite", near Penig. Anal. quoted by Zirkel, Lehrbuch, III, 252, and Rosenbusch, Gesteinslehre, p. 486.

Garnetiferous leptynite.

Near its margins, especially where it comes into contact with masses of norite as seen near the railway station at Pallavaram, the charnockite loses its compact texture and dark colour, and passes into a friable, cream-coloured rock, which is sprinkled with pink garnets. The signs of dynamo-metamorphism, so evident in the field, are confirmed by an examination of this rock under the microscope. The weaker minerals have been crushed and are surrounded with granulated selvages, whilst the fragments of quartz show very strongly marked undulose extinctions. The proportion of quartz to microcline and opaque iron-ores is the same in this rock as in the unaltered charnockite, but instead of hypersthene we have about an equal quantity of irregularly-shaped pink garnets (see Nos. 9·665 and 9·668). The rocks now referred to present the characters of those known to German petrographers as "normal granulite," but the minerals rutile, kyanite, sillimanite, etc., so frequently found in the Saxon granulites do not occur in these rocks at Pallavaram. I have previously detailed the evidence which shows that garnets are developed in rocks of this group at the expense of the pyroxene.[1]

A comparison of this leptynite with the fresh and unaltered charnockite affords interesting examples of the difference between the results of the pressure which brings about a parallel disposition of the rock-constituents before complete consolidation, and that by which the stable minerals, after the solidification of the rock, are smashed into a mylonised mosaic, whilst the pyroxenes are converted into the commonest of all the products of metamorphism, garnets.

The different circumstances under which garnets appear in the charnockite series enable us to indicate the conditions which are favourable to their manufacture. In acid exposures near Pallavaram we have seen that the garnets appear in a rock which only differs from the charnockite in being crushed; but in the basic members of this series garnets are abundant in rocks which do not show the slightest signs of crushing. Clearly then simple dynamo-metamorphism is not essential for their production. This at once suggests an enquiry into the influences of special temperature conditions. We know that by the fusion of garnet we obtain pyroxene amongst the products of the devitrification of the melt. It is also known, from the experiments of Fouqué and Michel-Lévy, that whilst pyroxene is stable at high temperatures, hornblende is the stable form of the same compound at low temperatures. If then our pyroxenic rocks were subjected to dynamo-metamorphism at low temperatures, the pyroxene would be amphibolized and hornblendic rocks would result. Probably, therefore,

Conditions essential for the production of garnets.

[1] "On the origin and growth of garnets and of their micropegmatitic intergrowths in pyroxenic rocks." *Rec. Geol. Surv. Ind.*, Vol. XXIX (1896), p. 20.

some intermediate temperature favours the production of garnet, some temperature short of actual fusion but sufficiently high to prevent amphibolization. If this be so, then we may have garnets produced without dynamo-metamorphism, as in some cases they certainly are. At the same time they may also be produced if the rocks are crushed at high temperatures, which may be high because of the heat produced by the crushing or on account of the depth to which the rock is accidentally buried at the time. In the instance exposed near Pallavaram and illustrated in figs. 4 and 5, the charnockite has been altered probably by the intrusion of the norite, which alone would be sufficient to account for the high temperature accompanying the crushing of the neighbouring charnockite.

Quartz-felspar rocks associated with charnockite.

Contemporaneous veins.

Although, on account of the absence of hypersthene, these rocks would not, if found isolated, be recognised as members of the charnockite series, yet on account of the facts that they occur as veins in normal charnockite and are composed of the same blue quartz crowded with minute hair-like inclusions, together with a beautifully microperthitic microcline (fig 3), they must be considered to be as

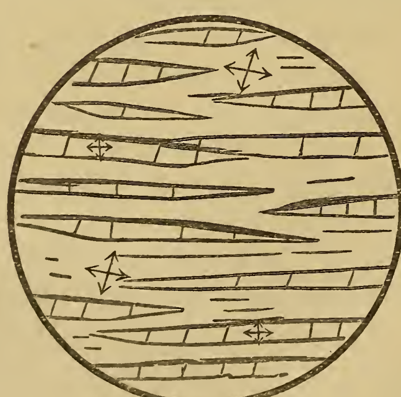

Fig. 3.—*Microperthitic inclusions in the felspar of No. 9· 677. Positions of extinction indicated by crosses.*

much genetic relatives of the charnockites as the common acid "contemporaneous veins" which in granites have always been regarded as the results of the final consolidation of the magma which gave rise to the main masses of the rock they run through. No. 9·659 is an example of such a rock occurring as veins in the typical charnockite near St. Thomas' Mount. These veins run in various directions, but more generally coincide with the linear arrangement of the constituents of the charnockite. Their constituents are arranged parallel to the sides of the veins; but they show no sign of crushing, and this linear arrangement of the constituents must, as in the case of the charnockite of the same mass, be referred to the results of pressure during consolidation.

Whilst on the weathered surfaces it is perfectly easy to distinguish these coarse-grained veins from the fine-grained charnockite through which they cut, it is almost impossible on a freshly fractured surface to indicate the junction between the two, the crystals interlocking to form one rock. The blue-grey colour of the fresh charnockite is precisely that of the quartz-felspar veins which run through it. Sections across the junction examined under the microscope show no abrupt line between the veins and the main mass of charnockite. They differ from the normal charnockite merely in the complete suppression of the hypersthene and concomitant increase in the size of the two remaining constituents, quartz and felspar, which present precisely the same microscopic peculiarities as the constituents of the normal charnockite.

The veins cannot thus be regarded as subsequent and distinct intrusions with a separate origin; they are evidently related to the charnockite, and present all the features which characterise the so-called "contemporaneous" veins of ordinary granites; they would be classed by Reyer as *hysterogenetic schlieren* forming the last phase in the consolidation of the magma from which the associated hypersthene-bearing rocks had previously separated. Larger masses of rock having a similar mineral composition are exposed within the immediate neighbourhood, and in the absence of evidence to the contrary should be regarded also as members of this series.

Similar large masses.

The mass of rock out of which the remarkable Seven Pagodas have been hewn *in situ* is also almost wholly made up of quartz (which is crowded with the peculiar acicular inclusions already described) and microperthitic felspar; but the evidence for connecting this rock with the charnockite series is confined purely to the similarity in the microscopic characters of the two principal minerals (No. 9·677). The rock is coarse in grain, and shows slight signs of kaolinization which gives it a dirty-white colour instead of the blue-green of the normal charnockite. This decomposition which extends to great depths in the rock of the Seven Pagodas, and which enables one at once to distinguish hand specimens of it from the charnockites of the hill masses further inland, is probably due only to the fact that, being near the coast, it has been submerged below the sea during the limited oscillations of level which are shown to have taken place by the deposition of cretaceous and younger marine beds on the Coromandel coast.

The rock of the Seven Pagodas shows on weathered surfaces a very imperfect gneissose structure parallel to the direction of the exposed ridges, and, as Mr. Foote[1] has remarked, parallel to the coast line; that is, N. 5° E. and S. 5° W. But that this foliation was induced before the complete consolidation of the rock seems almost certain, for the crystals are seen under the microscope to be interlocked in a complicated way, and the only definite signs of pressure subsequent to consolidation are indicated by the undulose extinctions of the quartz crystals with an occasional granulation of the more delicate intergrowths.

(2) Intermediate Division.

At St. Thomas' Mount and Pallavaram, the norite and the charnockite form large masses, which whilst being uniform in composition throughout, are very distinctly marked off from one another. Specimens taken from any part of the mass of charnockite will be found to have a specific gravity which never differs greatly from 2·67

[1] *Mem. Geol. Surv. Ind.*, Vol. X (1871), p. 127.

whilst those taken from the mass of norite will be found to be equally constant in their characters and seldom much above or below 3·09 in their specific gravity. These two rocks, therefore, form definite and distinct individuals, the one an acid rock with 75 per cent. of silica, and the other a basic rock with only 53 per cent. of silica.

Apparently composite character of the intermediate group.

But whilst these rock individuals are so well-defined in our type locality, the members of the charnockite series found in other parts of the Presidency generally present no such constancy of characters. Even in a hand-specimen the composite nature of these "intermediate" rocks is generally very noticeable, the basic and the acid portions being either distributed in irregular patches or arranged in parallel bands. This fact makes it very difficult to place any one specimen in the commonly employed system of rock classification.

Whilst the microscope shows an equally marked irregularity in the relative distribution of white and dark elements through the sections of these intermediate members of the charnockite series, one interesting fact presents itself at once, namely, the large number of mineral species represented in each specimen. In fact in nearly all sections of these intermediate rocks *all* the minerals characteristic of charnockite are found mixed irregularly with *all* the minerals of the norites. The commonest variety would thus be described as composed of quartz, orthoclase, plagioclase, augite, hypersthene, hornblende, iron ores, apatite and zircon (No. 9·807; section 1534). Such a mineral list would apply to by far the larger number of specimens of the charnockite series picked up in the Madras Presidency.[1]

In view of the composite nature of these intermediate varieties, one would naturally expect that every gradation between pure norite and pure charnockite ought to occur. This may be true if we take only small specimens into consideration. But by determining

1 The garnetiferous varieties are not taken into this consideration, as they nearly always show signs of having suffered from dynamometamorphism, and I regard the garnet as a secondary constituent.

the specific gravity of a large number of large specimens, we find that these intermediate members of the charnockite series are comparatively limited in the extent of their variation, and present an average specific gravity of 2·775, seldom being under 2·72 or over 2·84. It is just possible that if we employed larger specimens the range of variation would be still more restricted.

Specific gravity of the Intermediate group.

As an example in illustration of this statement we may take the specimens collected by Dr. H. Warth in South Arcot during his survey of that district in 1893-94. Neglecting the garnetiferous varieties, which are generally greatly crushed and probably have a specific gravity slightly differing from that of the original unaltered rock,[1] we have the following list of specimens from the South Arcot district.

Registered No.	Locality.	Sp. Gr.
9,805	Top of Perumakal hill	2·72
9,813	Tindivanum	2·73
9,786	Kunam village	2·74
9,792	South of Perumbakam hill	2·75
9,785	South-west of Karasanur	2·77
9,791	North-east of Perumbakam hill	2·77
9,800	South-west of Molasur	2·78
9,780	Tirvukarai	2·78
9,783	South-east of Nemeli	2·79
9,779	Tirvukarai	2·80
9,787	Near Kunam village	2·82
9,807	East-south-east of Eraiyanur	2·84
	Average specific gravity .	2·774

[1] F. Becke has recently drawn attention to the fact that the minerals formed as the result of dynamometamorphism have generally lower molecular volumes than those of the original constituents from which they have been formed by such secondary processes. The dynamometamorphosed rocks thus contain the elements in minerals which occupy the smallest possible space. ("Ueber Beziehungen zwischen Dynamometamorphose und Molecularvolumen", *Neues Jahrb. f. Min.*, 1896, II, p. 182).

A very closely agreeing result was obtained by me in the Shevaroy hills: 48 specimens taken from different parts of the mass gave an average specific gravity of 2·777.

From analyses made by my colleague, Dr. T. L. Walker, of Nos. 11·915, 9·785 and 9·791, it seems evident that these intermediate forms are composed of about half norite and half charnockite.[1] A fragment having a specific gravity of 2·787 was found to contain 61·40 per cent. silica; one having a specific gravity of 2·818 contained 58·30 per cent. of silica, whilst a third specimen, having a specific gravity of 2·772, contained 63·77 per cent. of silica. A mixture of equal parts of norite and charnockite would have a silica percentage of 64.

It does not necessarily follow, however, that these intermediate varieties of the charnockite series are actually the result of the mixing together of previously differentiated charnockite and norite magmas. On the contrary, the limited amount of variation which they present would be regarded by some as an argument in favour of regarding the intermediate forms as the result of the consolidation of a magma from which, under special conditions developed locally, charnockite on the one hand and norite on the other have been differentiated. That is to say, the large, well-defined masses of charnockite and norite at St. Thomas' Mount would be regarded by some as the more complete separation of the acid and basic rocks, whose intermixture on a smaller scale gives rise to the apparently composite nature of the members of the charnockite series included in this intermediate group.

If the intermediate varieties are really the result of the admixture of charnockite and norite; if, that is, they are only contact products, we ought to expect every gradation between the acid and the basic extremes, which, as has already been pointed out, is not the case. Until, therefore, further observations show that the apparent constancy in the composition of these intermediate varieties is only the result of the limited number of determinations which I have been

[1] On account of the specific gravity of the felspars and quartz being in close agreement the density of the rock fragment does not form a safe index of silica percentage.

able to make, I prefer to claim this point as evidence in favour of regarding the intermediate varieties as the result of the direct consolidation of the original magma, whilst the acid and basic masses are the result of more perfect differentiation favoured by purely local conditions.

Two other facts appear also to favour this view of the case :—

(1) The remarkable resemblance of the charnockite to the norite masses points to the consanguinity of these two extremes. Although one rock is distinctly acid and the other is very basic — one, in fact approaches Bunsen's normal trachytic magma and the other his normal pyroxenic magma in chemical composition — the differences between the two are so well obscured by their remarkable agreement in outward appearances that they are often confused with one another in the field.

(2) The intermediate varieties are the most abundant representatives of the charnockite series in South India, whilst large masses of pure charnockite and pure norite are comparatively rare and restricted in their distribution, thus indicating that their separation has been favoured by local and unusual circumustances.

Although, therefore, the acid and basic extremes so closely resemble Bunsen's *t* and *p* magmas in composition, and although the intermediate varieties at first sight appear to be composite in their characters, I think the facts favour the view that the apparent composite character of the intermediate forms is due only to imperfect differentiation, whilst the occurrences of locally large and distinct masses of charnockite and norite are due to more complete differentiation of the original magma. The phenomena presented by these rocks may be regarded therefore as analogous to those of the augite-diorites (diabases) in which the magma may give rise to a microscopic admixture of augite-diorite and micropegmatite, or may become under other conditions separated into distinct masses of basic gabbro and acid granophyric rocks.[1]

[1] *Cf. Rec. Geol. Surv. Ind.*, Vol. XXX. (1897), pp. 39 and 40; *Quart. Journ. Geol. Soc.*, Vol. LIII (1897), p. 416.

Chemical composition.

A specimen from the typical exposures of the intermediate series in the Shevaroy Hills has been analysed by Dr. T. L. Walker. The specimen had a specific gravity of 2·772, being thus near the average for the group, and the *whole* of the piece used for specific gravity determination was crushed up for analysis and gave the following results :—

No. 11·915 from Arthur's Seat, Yercaud, Shevaroy Hills.

SiO_2	63·77
Al_2O_3	16·30
Fe_2O_3	7·49
CaO	6·33
MgO	2·49
Na_2O	3·68
$K\ O$	1·21
Ignition	*Nil*
	101·27
Sp. Gr. =	2·772

Microscopical characters.

The minerals which enter into the composition of the intermediate varieties are similar in character to the same species represented in the pure charnockite and pure norite. The quartz is generally the blue or grey variety which is characterised by its hair-like inclusions (*supra*, p. 138). The augite is the pale, blue-green variety (*infra*, p. 156), the hypersthene, highly pleochroic (*supra*, p. 141), and the hornblende is the strongly pleochroic, brown-green, basaltic form described below (p. 158). Opaque iron-ores, zircon, apatite and biotite occur as accessories, as in all varieties of this series. The fact that the same species of minerals present similar microscopic peculiarities in all members of the charnockite series is of course the cause of the striking resemblance which specimens of these rocks bear to one another in macroscopic characters, and which shows their undoubted consanguinity.

Probably the most characteristic features of the intermediate varieties are the *microperthitic felspars* and the *quartz of corrosion*. The quartz of corrosion generally occurs in small patches in which the quartz presents a pseudo-dendritic arrangement with the felspar; but isolated spindle-shaped blebs also occur in the plagioclase and from their refractive index and double refraction appear to be quartz. These small blebs are in crystallographic continuity with one another over large areas. The fusiform inclusions which give the microperthitic structure to some of the non-striated felspars are generally crossed by cleavage cracks, by which means they are readily distinguished from the small blebs referred to above as doubtfully composed of quartz.

The irregular distribution of the *ferro-magnesian silicates* amongst the other constituents has already been referred to as a noticeable characteristic of the intermediate group (Nos. 9·779 and 9·787). Sometimes only hypersthene is present, in which case this irregularity of distribution is not so marked; but generally both augite and hornblende accompany the hypersthene, whilst biotite, in most cases probably of secondary origin, occurs in nearly all varieties of this group. This tendency of the ferromagnesian silicates to congregate in groups—microscopic patches—was noticed by Hatch in the case of very similar pyroxene granulites from Madagascar (*Quart. Journ. Geol. Soc.*, Vol. XLV (1889), p. 344).

One of the specimens of this group is interesting on account of the large quantities of *graphite* it contains (No. 10·670). Besides graphite, the rock is composed of hypersthene, quartz, an unstriped felspar with microperthitic inclusions, oligoclase, pyrite, titaniferous iron-ore, and a small quantity of garnet.

The large crystals of hypersthene in this rock are extremely well schillerized and the quartz contains the hair-like inclusions noticed before (p. 138). The graphite is scattered in small flakes through the rock and is regularly distributed like a normal constituent. A considerable quantity was easily isolated by means of a heavy liquid from the other constituents of the crushed rock. It floated in the liquid after the precipitation of all the other minerals, and began to sink itself on reducing the specific gravity of the liquid to 2·1. Graphite has recently been found as minute scales scattered through an elæolite-syenite in the Coimbatore District, its presence therefore in these rocks may be quite consistent with the evidences which indicate their igneous origin. It will be interesting to see if the veins of graphite which occur in Ceylon and Travancore pass through members of the charnockite series.

[Since the above was written an interesting memoir ("Beitrag zur Kenntniss der Gesteine und Graphitvorkommnisse Ceylons") has been published by Max Diersche, giving an account of granulites and pyroxene-granulites collected in Ceylon. The author failed to find graphite as microscopic constituents of these rocks, although the graphite veins occur near the granulites and include fragments of both the ordinary and the pyroxene-granulite (*Jahrb. der k.-k. geol. Reichs.* XLVIII (1898), 241, 257, 279, 284 and 286).]

(3) Basic Division.

Use of the term norite.

Associated with the charnockite masses at St. Thomas' Mount and Pallavaram, and forming distinct masses uniform in composition over large areas, are rocks which in mineral composition agree very closely with the rocks known generally as *norites*. Norite is one of the many names which, on account of the changes introduced into petrographical nomenclature as a result of the use of the microscope, has undergone a variation in meaning since its first use in 1838 by Esmark. In describing these rocks the word norite is used for rocks composed essentially of plagioclase and rhombic pyroxene, the meaning which has generally been given to it in petrographical literature since the limitations proposed by Rosenbusch in 1877. Under the names augite-norite and olivine-norite I have previously described many of the dyke rocks which cut through the charnockite series in South India.[1] Although there is not the slightest difficulty in distinguishing between these and the members of the charnockite series which have a corresponding mineralogical composition it seems inadvisable to complicate the already confusing petrographical nomenclature by proposing modifications in name to indicate the other differences which are evident in hand specimen as well as under the microscope. The

[1] *Rec. Geol. Surv. Ind.*, Vol. XXX (1897), p. 16.

weakness of our system of rock classification, however, is strongly emphasised by a study of these rocks. In the charnockite series we have large masses of rock composed essentially of rhombic pyroxene, augite and plagioclase, a composition precisely similar to that of some of our black dyke-rocks, and yet no one who has studied these rocks could fail to notice that the norites now under description differ far more from the norite dykes than they do from the acid rock charnockite. To group together a basic rock and an acid one as we do here is contrary to the usual practice of petrographical classification, and yet there can be no more doubt about the close genetic relationship of these two types in South India than there is about the consanguinity of those described by Vogt in the Ekersund area.

Granulitic structure.

The norites are almost always granulitic (panidiomorphic) in structure, neither the ferromagnesian silicates nor the plagioclase showing any noticeable approach to idiomorphic outlines; but when quartz occurs, as it sometimes does in small quantities, it is generally irregularly developed around the other minerals as if it were the last of the constituents to crystallize. Consequently the granulitic structure is more perfectly developed in the varieties free of quartz. The fact that many rocks, which, like marble, have taken on a granulitic structure as the result of metamorphism naturally favours the idea that the pyroxene granulites are metamorphic rocks. But we now know, however, that a granulitic structure may result from disturbance of the magma during the process of consolidation, so the phenomena displayed by these norites belong as much to igneous rocks as to those formed by metamorphism (see p. 239). The dykes of pyroxenite which are associated with, and cut, these norites at Pallavaram are as perfectly granulitic in structure as the norites are and there is no reason to doubt their igneous origin.

Specific gravity.

The norites of the Pallavaram area are very uniform in their specific gravity and by it are sharply marked off from the associated charnockite. The following table gives the average specific gravity of the leading types of hornblende and augite norites :—

No.	Variety.	Sp. Gr.
8·752	Hornblende-augite norite	3·10
8·754	Augite-norite	3·09
9·661	Hornblende-augite norite	3·08
9·395	" "	3·085
9·397	Augite-norite	3·185
9·657	"	3·03
9·656	"	3·11
9·660	"	3·02
	Average specific gravity =	3·09

Augite is almost always associated with hypersthene in these norites, and a peculiar greenish-brown variety of hornblende is found to be extremely common. The augite and the hornblende are remarkably uniform in character in all occurrences of the charnockite series, and are almost as characteristic as the hypersthene. The amount of opaque iron-ore in the norites always exceeds that in the pyroxenites associated with them. A large quantity of the opaque iron-ore is titaniferous. Sphene is typically absent ; it occurs, however, in a biotite-norite near Pallavaram (No. 9·671), but this rock presents many other exceptional characters, and is a distinct departure, for some reason not apparent, from the normal type.

Mineral composition.

The silica percentage, the specific gravity and the great predominance of labradorite amongst the felspars marks these rocks as distinctly basic, as basic in fact as the augite-norite dykes which cut through them.

A partial analysis of No. 9·660 by my colleague Dr. T. L. Walker gave the following results:—

SiO_2	53·38
Al_2O_3	19·38
Fe_2O_3 and FeO	15·39
CaO	7·68
MgO	2·79

Augite-Norite.

The nearest approach to normal norite is the rock which forms the only associate of the type-mass of charnockite near St. Thomas' Mount. Charnockite forms the central mass of the hill whilst augite-norite forms the north-eastern (No. 9·660) and south-western (No. 9·657) ends.

This norite is uniform in structure throughout the mass exposed and specimens have a specific gravity seldom varying by ·05 from 3·025. The foliation is scarcely noticeable except on weathered surfaces.

The principal constituents are hypersthene, augite, plagioclase and opaque iron-ores with accessory apatite, quartz and a felspar that shows no lamellar twinning.

The *hypersthene* crystals are devoid of idiomorphic outline although they generally show a well marked prismatic cleavage and the normal pleochroism, with straight extinction.

The bluish-green colour of the rays vibrating parallel to the axis of minimum optical elasticity $\mathfrak{c}$ in the *augite* is so precisely similar to that of the rays vibrating parallel to the corresponding axis in the hypersthene, that without moving the polariser the two minerals might very easily be confused. The feeble pleochroism and the wide angle of extinction of the augite, however, form a ready means of distinction in polarized light. The colours of the rays vibrating parallel to $\mathfrak{b}$ and $\mathfrak{c}$ only differ from those parallel to $\mathfrak{a}$ by a yellowish tinge in the former and a bluish tinge in the latter. The angle of extinction on the clinopinacoid is about 44°. The crystals very frequently show the characteristic lamellar twinning of augite, a feature which is never shown by the pleochroic pyroxene that I consider to be rhombic (*vide supra*, p. 126).

The crystals of *plagioclase* are always remarkably clear and fresh. They are twinned both after the albite and the pericline plan. Measurements of the angles between the positions of extinction of adjacent lamellæ in sections across the albite twins seldom vary much from 29°; so the felspar approaches labradorite (Ab, An) in composition.

The crystals of felspar which show no lamellar twinning appear sometimes as Carlsbad pairs, and thus probably indicate the presence of potash felspar; but I have never found a trace of microcline in the norites whose specific gravity exceeds 3. From the abundance of microcline in charnockite one would expect the same structure to appear also in the accessory potash-felspar of the norites, but extended search has so far been unsuccessful, and in view of the fact that plagioclase occasionally shows no twin lamellæ, the evidence in favour of orthoclase must be looked upon with suspicion.

The opaque *iron-ores* are always abundant in the norites, much more so than in the associated pyroxenites. Sometimes they are pyritous; but magnetite, often titaniferous, is the prevailing variety. I have found no green spinel in the norites near Pallavaram, although it is abundant in the non-felspathic associates.

Quartz often occurs intergrown with the other constituents. The quartz-bearing veins show no sharp junction lines with the norites amongst which they ramify, the crystals interlocking across the junction after the manner of segregation and contemporaneous veins.

Apatite, in short prisms, is always more abundant in the norites than in the associated charnockite.

An occasional granule of *zircon* is found in almost every slide. So far as my experience goes, *sphene* never occurs in the unaltered varieties of norite.

Hornblende-Augite Norite.

The most prevalent variety of the basic forms of the charnockite series is one in which hornblende, as well as augite and hypersthene, are the ferromagnesian constituents. Rocks of this kind are represented especially well in the hill-mass east of the railway station at Pallavaram (Nos. 8·752, 9·661, 9·667) and also in the Pammal hill, west of the railway (No. 9·395).

The hypersthene, augite, felspar and accessory minerals are apparently of the same kind as those already described as constituents of the augite-norite obtained in the neighbourhood of St. Thomas' Mount.

The hornblende is the peculiar deep green-brown, highly pleochroic variety which seems to be characteristic of these rocks and of their ultra-basic associates. Its crystals are often larger than those of the augite and hypersthene, sometimes giving the rock in consequence a feeble porphyritic aspect on weathered surfaces. The crystals are generally elongated parallel to the vertical axis and in cross-sections the characteristic cleavage is extremely well marked. The pleochroism is—

$\mathfrak{a}$=pale yellow to bright yellow.
$\mathfrak{b}$=brown.
$\mathfrak{c}$=brownish green.

The absorptions for $\mathfrak{b}$ and $\mathfrak{c}$ are about equal, both being much greater than for rays vibrating parallel to $\mathfrak{a}$. The extinction angle ($c : \mathfrak{c}$) is very narrow, and, on account of the great absorption, difficult to measure precisely.

Biotite-Augite Norite.

The basic rock described under this name forms an exceptional type amongst the charnockite series and appears to be very limited in its distribution. Biotite is extremely common as an accessory amongst the intermediate and basic members of the series, but it is generally small in quantity compared with the hypersthene, augite and hornblende, and from its intimate association with the hornblende appears to be, in part at least, of secondary origin. In this particular rock, however, it presents its crystal-outlines against both the augite and the

Aberrant form of norite.

hypersthene, and in crystallizing at such an early stage has apparently taken up most of the iron ; for both the rhombic and the monoclinic pyroxene are most unusually pale, almost colourless in fact, in section. Another point which marks off this rock as an abnormal form is the presence of a considerable quantity of sphene, the titanic acid being in normal members of the charnockite series characteristically confined to ilmenite. The quantity of opaque iron-ore in this rock is consequently much smaller than in the normal norites, and most of it is in the form of the sulphides, pyrite and pyrrhotite.

A distinct mass of this rock occurs about one mile east of the railway station near Pallavaram (No. 9·671). Specimens have an average specific gravity of 2·96, and are composed of a pale enstatite with very faint pleochroism, colourless augite, plagioclase, a little quartz, magnetite, pyrite, pyrrhotite, apatite in numerous short prisms, brown pleochroic sphene and a deep-brown biotite with strong pleochroism and very narrow optic axial angle. The pyroxenes show a marked tendency to ophitic development around the other minerals which is another feature quite exceptional in the charnockite series. Although the association of this rock with the normal members of the charnockite series, and the presence in it of considerable quantities of rhombic pyroxene, necessitate its inclusion in the series, I am unable at present to recognise any peculiar conditions in its occurrence which would account for the distinct departure from the normal characters which it shows under the microscope.

A rock on the western margin of Pammal hill, west of Pallavaram (No. 9·675), shows by the large quantity of biotite in it an approach to this strange variety ; but it agrees nevertheless more nearly with the normal type in the absence of sphene, and in the more marked pleochroism of its rhombic pyroxene. This rock also contains a large proportion of quartz and is situated, apparently forming a passage, between normal augite-norite, which forms the central mass of the hill, and a garnetiferous, more acid, form, also with biotite, forming the north-western margin of the same mass.

Types rich in Garnet.

In the immediate neighbourhood of Salem there are several occurrences of the garnetiferous basic members of this series forming small, bare, rocky hills with apparently a lenticular outline ; the hill immediately W.-S.-W. of Salem and Nagaramalai near the Chalk Hills to the north of the town are good examples—Nos. 9·683, 9·684, 11·895, 11·903. These are presumably amongst the rocks referred to by Lacroix [1] as members of his "pyroxenic and hornblendic gneiss, (*b*)", and which, quoting Leschenault's labels, he says forms the valley of Salem. It is a little difficult to say what is meant by the valley of Salem ; but these rocks are certainly not the most abundant in the neighbourhood of the town, although, on account of the abrupt little hills they form, and on account of the conspicuous garnets they contain, it is likely that they would figure largely in the "bag" of an amateur collector.[2] This particular type very commonly occurs in such lenticular masses in the schists and old biotite-gneisses of the plains in the immediate vicinity of large mountain masses like the Nilgiris and the Shevaroys. Those referred to here, for instance, as occurring in the vicinity of Salem entirely resemble the little hillocks which fringe the foot of the Nilgiris in the Bhavani valley.

These rocks are generally but not always coarser in grain than the average basic varieties of the series. Sometimes they are very hornblendic and at other times are comparatively free of hornblende. In general the optical characters of this mineral and its fellow ferro-magnesian silicates are in agreement with the data already recorded for the other members of the series described above.

Garnets.

One interesting peculiarity is the frequent correspondence in the intensity of colour shown by the hypersthenes and the garnets. Without turning the

[1] *Rec. Geol. Surv. Ind.*, Vol. XXIV, p. 175.

[2] Leschenault de la Tour's only published reference to the exposures of these rocks south-west of Salem is as follows :—"Une montagne dans le sud-ouest (of Salem) est presque entiérement formée de roches oú l'amphibole domine, et sur la surface desquelles des grenats grossiers et opaques sont disposes par plaques." (*Mem. du Mus. d'hist. nat.*, Vol. VI (1820), p. 343).

polariser one might very well confuse the pink of the hypersthene with that of the garnet. The garnets are often very irregular in their shape and spongy in structure on account of the inclusion of numerous vermiform or otherwise-shaped pieces of white mineral (quartz or el spar) which I regard as the acid bye-product separated during the break-up of the pyroxene to produce garnet. Sometimes the garnets form a sort of corona to the hypersthenes, and all stages are found from a narrow ring around the pyroxene to a complete broad ring of garnet surrounding a core of granular quartz (Plate VIII, fig. 6).

Schiller phenomena and acicular inclusions.

In common with all the rocks in the neighbourhood of the Chalk Hills the rocks of Nagaramalai are schillerized. The most interesting form of schillerization is displayed by the garnets, which contain numerous needles possessing a high double refraction with a wide extinction angle up to as much as 39°. These needles are arranged with a remarkable regularity of crystallographic disposition within the garnets, as described in a previous paper.[1] Needles apparently similar in crystallographic disposition and somewhat similar in optical characters were noticed by Harker in the garnets of an eclogite from Port Tana, N. Norway, and were referred to as kyanite on account of the wide extinction angles which they exhibited.[2] In the garnets of a pyroxene-granulite found near the peridotite of Elliott County, Kentucky, Diller found what appears to be similar inclusions, which he says are arranged at angles of 45° to one another, and are distinctly monoclinic with a maximum extinction angle of 30°.[3]

Lacroix, on the other hand, has referred to rutile regularly arranged needles in the garnet of rocks which he has described as basic pyroxenic and hornblendic gneiss from Salem and Ceylon.[4]

[1] *Rec. Geol. Surv. Ind.*, Vol. XXIX (1896), p. 16.

[2] *Geol. Mag.*, 3rd decade, Vol. VIII (1891), pp. 170, 171. In his "Petrology for Students" (p. 300), Harker refers to these needles as rutile, although in his original paper he says they exhibit extinction angles up to about 31°, whilst rod-like, reddish-brown crystals of rutile were found in the same rock, which I find to be the case also with the rocks of Nagaramalai.

[3] *Bull. U. S. Geol. Surv.*, No. 38 (1887), p. 27.

[4] *Rec. Geol. Surv. Ind.*, Vol. XXIV (1891), p. 176; translation from *Bull. de la Soc. Min. de Fr.*, Vol. XII (1889), p. 311.

These needles, he says, exhibit a positive double refraction and give straight extinctions. It is now practically certain, however, that the particular rocks referred to in this connection came from the immediate neighbourhood of Salem town and are very similar in composition to those occurring at Nagaramalai, which, as already stated, contain inclusions with quite different physical properties. I have found very similar acicular inclusions in the garnets of the charnockite series in other parts of the Madras Presidency, particularly on the southern flanks of the Nilgiri Hills, but in all cases the needles show a wide extinction angle.

It is impossible to determine with certainty the mineralogical nature of needles so exceedingly minute. Harker referred those in the Port Tana eclogite to kyanite, a mineral which has frequently been found in eclogites, and the narrow extinction angles which kyanite displays in brachypinacoidal sections would make it a difficult matter to distinguish small needles of the mineral from monoclinic crystals, as they have been considered to be by Diller and by myself. Having obtained extinction angles up to as much as 39,° I favoured the idea that the needles might be sphene. The fact that they are often black and opaque for a portion of their whole length might then be due to replacement by ilmenite.

It is certain, however, that they are not rutile, although the hair-like inclusions in the blue quartz of the charnockite series may be so nevertheless, as they invariably show straight extinctions in horizontal sections of the quartz (*vide supra*, p. 138). Titanic acid introduced into quartz might remain pure and might crystallize as rutile needles; but the same substance introduced into a garnet might be changed to a titanate of some protoxide. It is not without interest that the plates and rods which give the schiller appearance to hypersthene, and which are very abundant in the hypersthenes of the Nagaramalai rock, have also been referred to titanic acid by Kosmann, Törnebohm, Brögger and others, although the different authors are not agreed as to the precise origin of the inclusions. Whatever they are in composition—and there is little doubt about the fact that they are not precisely the same mineralogically in all the rocks—there must be some agreement in the conditions under which they have originated; for when these needles appear in the garnets the accompanying quartz crystals are always crowded with acicular inclusions and the hypersthenes beautifully schillerized. When, on the other hand, garnets are free of such acicular inclusions, the quartz is also clear and the rhombic pyroxenes belong to the variety which Professor Judd has referred to as proto-hypersthene. It seems to me that the simultaneous appearance of these similar phenomena in all the constituents of the rocks must be regarded as the result of secondary causes, and the theory which is most in agreement with all the facts of the case is that for which Judd has proposed the term "schillerization."[1]

Although from the evidence obtained from hypersthene alone, it may be difficult to show any great objection to the theory that the schiller plates are the result of infiltration along cleavage planes; such a theory could not account for the regularity of crystallographic disposition of the needles in the accompanying garnets and quartz, nor could it account for the fact that the inclusions in the hornblende of these rocks are arranged, not parallel to the cleavage planes, but parallel to an axis of optical elasticity. It seems much more likely that the action of secondary chemical agents displays itself by phenomena developed in directions definitely related to the axes which determine the crystal-form as well as the other physical properties of the mineral. If, also, negative crystals are produced by solvents acting more effectually along planes of chemical weakness, then the composition of the mineral acted on will naturally influence the nature of the product and of the substance forming the schiller plate or rod. From this it follows that when the constituents of a rock are schillerized, the rods, plates or needles will vary in composition according to the chemical nature of the mineral which is acted on.

[1] *Quart. Journ. Geol. Soc.*, Vol. XLI (1885), p. 408; *Min. Mag.*, Vol. VII (1886), p. 81.

(4) Ultra-basic Division.

Pyroxenites.

Besides the instances of *Schlieren* described (p. 215) as due to a partial or complete local failure of the plagioclase, pyroxene-rocks occur also as narrow dykes cutting through the norites at Pallavaram. In the Pammal hill, two miles west of the railway station, these dykes are found to be from 3 to 5 feet wide, and are seen distinctly to bifurcate with branches proceeding in different directions through the norite (Nos. 9·394, 9·672). Near the summit of one of the hills on the eastern side of the railway line at Pallavaram there is an exposure of what appears to be a vein 9 inches wide of the non-felspathic rock in a hornblende-norite (No. 9·667). The absence of all signs of chilled edges, such as are distinctly shown for instance by the trap dykes when they cut through the charnockite series shows that the norites were probably still hot when the pyroxene-rocks were intruded, and in the last-mentioned instance, where it is easy to obtain microscopic sections across the junction, the sharpness which the line presents to the naked eye is not so apparent when the crystals are magnified. Under the microscope the two rocks are seen to differ only by suppression of felspar in that forming the vein; there is no change in either the size or relative proportion of the ferro-magnesian silicates, and the crystals interlock across the junction line. What, therefore, might be looked upon on account of its limited exposure, as an intrusive vein in the field is really more of the nature of an ultra-basic segregation. As this rock only differs from the norite (No. 9·667) in which it occurs, and which has already been described (p. 157), in the absence of felspar, no further details as to its characters need be given.

The non-felspathic types, however, of Pammal hill to the west of the railway station at Pallavaram form undoubted dykes, and on account of their ramifications must be regarded as intrusive in the norites. In these cases, also, the intrusions must have taken place whilst the norites were still hot, as no signs of chilled edges are noticeable, and this fact, together with the similarity in mineralogical characters between the ferro-magnesian minerals composing the dyke-rocks and those entering into the composition of the associated norites, point to the genetic relationship of the two rocks notwithstanding the undoubted differences between their periods of consolidation.

These pyroxenite dykes often show a slight banding as if successive injection had occurred. A case is illustrated by No. 9·672 in which bands of pure pyroxene-rock alternate with hornblendic bands without, however, a sharp junction line between them (Slide No. 1438).

In describing the basic dykes which cut through the charnockites and other massive rocks in South India I have referred to the occurrence of enstatite-bearing rocks which also approach pyroxenites in composition,[1] but there is no doubt about the differences between those (which are relatives of the supposed Cuddapah traps) and the pyroxenites now under consideration, which are relatives of the older charnockite series. Although the constituent minerals belong to the same species in both cases the crystal-habits are sufficiently marked to enable a distinction to be readily made even in a microscopic section. If this conclusion be correct we ought to find instances of trap dykes of the kind described in the paper just referred to cutting across pyroxenite dykes of the kind occurring in the Pammal hill and now under description. The absence up to the present of evidence of this kind I prefer to attribute to the limited number of observations hitherto made.[2]

[1] *Rec. Geol. Surv. Ind.*, Vol. XXX (1897), p. 30.

[2] Mr. Middlemiss has called my attention to two dykes exposed at a point 6 miles south of Royakotta in the Salem District, which in my opinion ought to be regarded as evidence in support of this conclusion. One of the dykes is a pyroxenite similar in character to those described in this paper as ultra-basic members of the charnockite series. It has a specific gravity of 3·31 and is composed of a medium to fine-grained mixture of hypersthene, often schillerized, and pale augite with brownish-green hornblende, without white minerals and practically devoid also of opaque iron ores. These characters it will be seen agree with those of the pyroxenites of Pammal hill near Pallavaram. This rock is cut through by a later dyke which is undoubtedly similar to the rocks generally regarded as the dyke-representatives of the Cuddapah lavas, and in mineral composition and structure is related to those which I have described under the name augite-norite (*Rec. Geol. Surv. Ind.*, Vol. XXX, p. 27).

The non-felspathic forms of the pyroxenic rocks may be divided into the following leading types:—

(*a*) Types rich in hypersthene.

(*b*) Types rich in hornblende passing into amphibolites.

(*a*) *Types rich in hypersthene.*

The purer forms of pyroxenite forming dykes in the norites west of Pallavaram are perfectly granulitic in structure and are composed of hypersthene, brown hornblende and augite, with small quantities of olivine, green and black spinelloids and occasionally apatite. In rocks where the microscopic structure is so perfectly granulitic as in these pyroxenites it is impossible to determine the relative ages of the constituent minerals with certainty. It is an interesting circumstance to find that the granulitic structure of the norites described above is so perfectly displayed also by their ultra-basic relatives whose intrusive characters can hardly be doubted.

A chemical analysis of No. 9,394, by Dr. T. L. Walker, gave the following results:—

SiO_2	46·86
Al_2O_3	9·80
Fe_2O_3 and FeO	16·35
CaO	9·57
MgO	18·08
Alkalies	traces
Ignition	0·67
	101·33

Sp. Gr. = 3·333

Hypersthene is by far the most abundant constituent of the Pallavaram pyroxenites (Nos. 8·756, 9·394, 9·672). It is a highly pleochroic variety, probably approaching in composition the varieties of rhombic enstatite for which Judd has proposed to revive Vom Rath's term *amblystegite*. The crystals are very frequently schillerized, with the development of brown-red plates similar to those of the well-known hypersthene of St. Paul.

The *augite* is almost colourless and is far less abundant than the *brown hornblende*, which is somewhat similar in its optical characters to the hornblende occurring so commonly in the associated norites. Crystals of the latter mineral give a maximum extinction angle on (010) of 16° and are strongly pleochroic—

𝔞 = pale yellow.
𝔟 = deep brown.
𝔠 = deep greenish brown.
𝔟 = 𝔠 > 𝔞.

They are often schillerized by black needles and plates, the needles being generally arranged parallel to a direction of extinction and therefore inclined to the cleavage cracks.

Olivine appears to be irregular in its distribution in these rocks. In some slides (No. 1438) it appears in considerable abundance as small, irregular crystals, which are cracked in characteristic fashion, with formation of a yellowish-green serpentine. The high index of refraction, strong double refraction, absence of colour and the characteristic fracture and secondary alteration leave no doubt as to the identity of this mineral, although its appearance as an accessory mineral in pyroxenite is so exceptional. In a rock, however, in which the large predominance of hypersthene shows that the percentage of alumina is low, whilst the protoxides of iron and magnesia are in large quantity, the appearance of olivine in the least siliceous types would naturally be less surprising than in those in which the predominating pyroxene is of the aluminous, monoclinic varieties. The present instance, therefore, forms an interesting example of a link between the pyroxenites and the peridotites.

Green spinel similar to pleonaste and hercynite in appearance is very commonly found in these rocks, and appears to be a common constituent or associate of such pyroxenic rocks all the world over. As a constituent it appears in the pyroxene rocks and sometimes in the basic norites. As an associate it occurs amongst the products (apparently) of contact metamorphism; under the latter circumstances it is a very constant associate of corundum. The late G. H.

Williams found these two minerals, together with sillimanite, in the Cortlandt series of New York,[1] and compared the occurrence with the previously better-known similar association of these minerals with the pyroxene-granulites near Ronsberg on the eastern edge of the Bohemian forest, whilst very numerous similar instances have recently been found in South India[2] The occurrence of the green spinel as a simple constituent of the series as well as a contact product of the pyroxenic rocks adds another instance to the already numerous examples which show that the distinction between simple igneous rocks and highly metamorphosed products cannot be marked by a sharp line.

The green spinel in these pyroxenites occurs in irregularly shaped granules and sometimes vermiform blebs, associated invariably with lumps of magnetite and generally crowded with minute granules and dust of presumably the same substance. Where the crystallization has been very coarsely developed we frequently find cubic crystals of magnetite lying in the green spinel, which, except in the immediate neighbourhood of the magnetite crystals, is crowded with magnetite dust. From the immediate precincts of each magnetite crystal the dust has been completely removed and a clear green zone indicates the extent of its "crystal court."

In one case of a hypersthene pyroxenite from the Salem District (sections 1030 and 1031) the green spinel is generally seen to be surrounded by a zone of a pale-pink, isotropic and highly refracting mineral, which is presumably the ordinary magnesia-alumina spinel.[3] In this case, therefore, the spinelloids are represented by three different types formed apparently in an order which indicates a gradual decrease in the protoxide and sesquioxide of iron and a

[1] *Amer. Journ. Sci.*, Vol. XXXIII (1887), p. 194.

[2] See Manual of Economic Geology of India, 2nd Edition, 1898, pp. 12, 13, 14, 18, 41 and 45.

[3] The specimen from which these sections were cut I found in the Madras Museum labelled "Salem district," but without any further details as to its origin. Judging from the slides the rock must be a most remarkably interesting one, and it is extremely unfortunate that in consequence of the absence of details as to its precise locality we are unable to examine its geological relationships.

corresponding increase of magnesia and alumina amongst the consolidating oxides. The order of crystallization is thus :—

(1) Magnetite . . . . $FeO.Fe_2O_3$.
(2) Pleonaste (Ceylonite) $(Mg.Fe)O.(Al.Fe)_2O_3$.
(3) Spinel . . . . $MgO.Al_2O_3$.

(*b*) *Types rich in hornblende.*

In many places it is found that the non-felspathic types of the charnockite series are characterised by the predominance of hornblende over the other ferro-magnesian silicates, so that the rocks would be more accurately described as pyroxene-amphibolites. But as it seems certain from the evidence obtainable in places like Tirrupur in the Coimbatore District, that the amphibole has in part been formed by alteration of the pyroxene, it is better to recognise the genetic relationships which these highly hornblendic types bear to the purer pyroxenites than to separate them under the name amphibolite, which would more correctly express their present mineralogical composition.

In one of the specimens (No. 9·317) obtained near the Travellers' bungalow at Tirrupur, there are very pretty instances illustrating the change from augite to hornblende; patches of the latter mineral are scattered through the large augites, showing, by their simultaneous extinction, a crystallographic parallelism to one another, and by the cleavage cracks, an axial parallelism also to the augite from which they have been derived. Although this specimen contains considerable quantities of felspar, the ferro-magnesian silicates, augite, hypersthene and hornblende, which it contains, are precisely similar in character to the representatives of the same species forming the associated ultra-basic masses. Near the Travellers' bungalow at Tirrupur, narrow dykes or veins of a sparkling black amphibolite (No. 9·309) are found ramifying amongst the granulitic rocks which are composed, as already stated, of augite, hypersthene, hornblende and felspar. These dykes of amphibolite bear to the felspathic rocks

Amphibolization of the Pyroxenes.

which they cut a relation precisely similar to that existing between the pyroxenites and norites of Pallavaram (see plate IX).

The hornblende in these rocks is of two kinds, a blue-green actinolitic variety occurring as patches in the pyroxenes and evidently secondary, and a dark, brownish-green, basaltic variety occurring both in large crystals and as patches in the pyroxenes. This also in part, at least, appears to be of secondary origin. It has a very deep pleochroism and exhibits a very narrow extinction angle (c : c), which on account of the great absorption, it is impossible to measure with precision. The crystals are often twinned parallel to the orthopinacoid (100), cross-sections showing both the trace of the twinning plane and the prismatic cleavage very distinctly.

So far as my experience goes, whenever hornblende becomes a prominent constituent of these ultra-basic representatives of the charnockite series, the associated felspar-bearing types—the norites, that is—have also a conspicuous amount of hornblende amongst their constituents. Besides the instances at Tirrupur in the Coimbatore District, there are good examples illustrating this fact in the South Arcot District. At the south-west base of Vitlapuram hill, for instance, we have a good example of a rock composed of pale pyroxene and dark-green hornblende (No. 9·809), whilst a hornblende-augite norite forms the summit of the same mass (No. 9·810).[1] This fact also supports the conclusion that the ultra-basic rocks are true relatives of those which contain felspar, and that they only differ from the latter merely in the local suppression of the white minerals. Sometimes they appear as basic *schlieren*; at other times they form distinct and ramifying veins, which must be regarded as intrusive. But the absence of chilled edges, and the similarity of peculiarities amongst the ferro-magnesian silicates, show that the pyroxenites and amphibolites were intruded whilst the norites were still hot, and also that they have been derived from the same magma as that which gave rise to the norites.

[1] A somewhat similar arrangement of ultra-basic forms with regard to the felspathic and quartz-bearing types is seen in the Shevaroys, the rocks composed of pure ferro-magnesian silicates occur near the foot of the ghât leading to Yercaud, whilst the upper parts of the hill are often as acid as pure charnockite.

CHAPTER V.

Description of the Principal Exposures.

It has already been pointed out that notwithstanding the great variations in silica percentage which the members of the charnockite series present, they exhibit distinct characters, both microscopic and macroscopic, which readily serve to group them together, and which point to the unmistakable consanguinity of the different varieties. Partly because their true mineralogical characters were not recognised before the microscope was used in South Indian petrology, and partly because the earlier surveyors were compelled for economic reasons to confine their attention to isolated areas, this very important fact was not recognised before 1892. Some members of the charnockite series have been referred to as "quartzo-felspathic gneiss," others have been spoken of as "hornblendic gneiss," whilst in other localities they have been mapped as "syenitoid gneiss." This system of nomenclature has resulted firstly, in the separation from one another of the different members of one series of related rocks, and secondly, in the grouping together of rocks, which, though composed of the same mineral species, are not genetic relatives of one another. In consequence of these unfortunate circumstances, for which only the great petrological progress of recent years is to blame, only a small portion of the voluminous literature of South Indian geology can be made use of in summarising the facts concerning the geological relations and geographical distribution of the rocks now grouped together under the name "charnockite series."[1]

The type-exposures near Madras.

On account of their proximity to the city of Madras, the

[1] Mr. R. B Foote has, by referring to the rock at Cape Comorin as a type, given a convenient means for identifying the members of the charnockite series in the districts of Madura and Tinnevelly. ("On the Geology of the Madura and Tinnevelly Districts," *Mem. Geol. Surv. Ind.*, Vol. XX, p. 28.) It is unfortunate that this practice of supplementing the mineralogical description of a rock series by reference to a local type has not been universally followed in our publications.

exposures of the charnockite series at St. Thomas' Mount and the adjoining hills of Pallavaram may be conveniently placed first in the list of occurrences of this series in South India. It is from this locality that large quantities of the rocks have been quarried for structural and ornamental use in Madras, and it is from the neighbourhood of St. Thomas' Mount that the rock of Job Charnock's tombstone was obtained (*vide supra*, p. 134).

Charnockite and Norite.

The low hill on the west side of St. Thomas' Mount is composed of a mass of charnockite in the centre, with masses of augite-norite on the north-east and south-west sides. The central mass has been selected as the type mass of charnockite (No. 9·658), whilst the sides may be regarded as type examples of augite-norite (No. 9·657 on the south-west side, and No. 9·660 on the north-east). Both rocks are penetrated by veins (contemporaneous veins) of a rock composed mainly of blue quartz and microperthitic microcline which on account of its coarse grain may be called charnockite-pegmatite (No. 9·659).

Charnockite-pegmatite.

The main mass of St. Thomas' Mount itself is augite-norite which, however, is so cut through by acid veins, that in places the rock becomes an irregular mixture of charnockite and norite such as characterises the varieties described as "intermediate."[1]

St. Thomas' Mount, or "The Mount" as it is often called in Madras, is only eight miles south of the city, on the South Indian Railway; so the locality is easily visited during the time that most of the steamers are delayed in the harbour. The type-exposures are thus easily examined by visitors who may not be able to make a tour through the Presidency. The hill rises to about 250 feet above the sea-level and is crowned by a curious old church built by the Portuguese in 1547.

The railway station of Pallavaram, 3 miles further south on the South Indian Railway, is situated between the Christian village (Isa-Pallavaram) and a

Garnetiferous leptynite.

[1] The common occurrence of what Lossen called *Primärtrümer* in this series is referred to in another section of this paper (p. 218).

number of low rounded hills which lie on the east side of the line, forming an irregular range not exceeding 500 feet in height. The rocks immediately east of the line are garnetiferous leptynite, which are here regarded as the result of the metamorphism of the charnockite. Whilst the normal charnockite is a compact, dark-grey rock which breaks with a semi-conchoidal fracture, the garnetiferous leptynite is dirty-white in colour, is more distinctly foliated and crushes easily under the hammer. The blue quartz, however, which is so characteristic of the charnockite series, retains its colour in this leptynite, but instead of hypersthene the rock is sprinkled with garnets. Microscopic examination shows that this rock, like charnockite, is composed largely of quartz, microcline and opaque iron-ores, whilst pink garnets appear to replace the original pyroxene. The crushed character of the rock bears evidence to the dynamic action to which it has been subjected (No. 9·665).

The leptynite is limited on the north and south sides by two rocky ridges, which mark its junction with the normal charnockite. These ridges are generally rust-coloured through the decomposition of pyrite, which occurs in large quantities near the margins of the leptynite. A depression between the exposures of leptynite shows masses of norite cropping out in a gully.

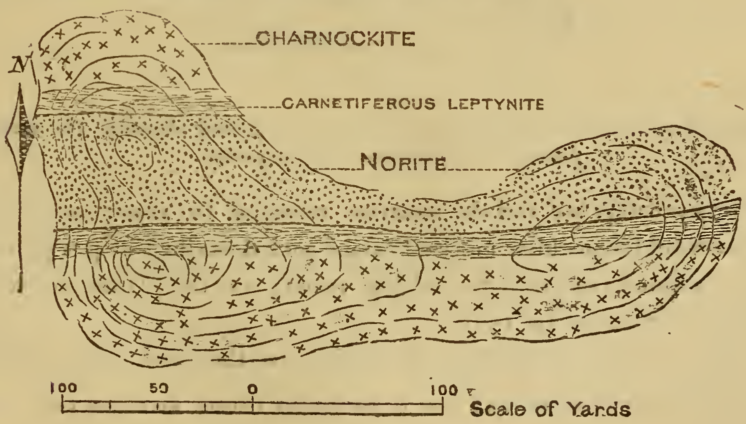

Fig. 4. *Plan of hill near Pallavaram, showing the zones of leptynite between the norite and unaltered charnockite.*

The hill on which this garnetiferous leptynite occurs is separated from a number of quarries further east by a narrow tract of alluvium running N.-N.-E. and S.-S.-W.[1] At the southern end of the quarries the leptynite is again found associated with charnockite, the junction line being obscured in a rubbish-covered gully. About a mile E.-S.-E. of this point a further occurrence of leptynite associated with charnockite shows a gradual passage from the former (No. 9·668) to the latter (No. 9·669). This occurs on both sides of the central mass of norite, which is thus fringed by leptynite and charnockite. The facts revealed at this point leave little doubt as to the secondary origin of the characters which serve to distinguish the leptynite from normal charnockite.[2]

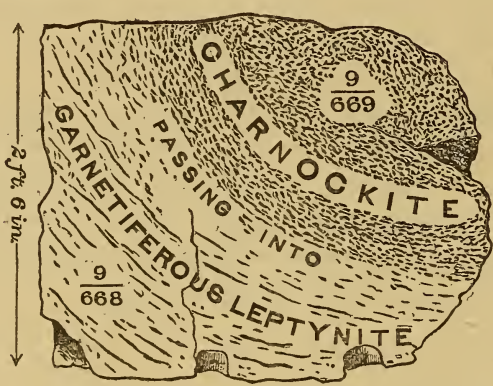

Fig. 5. *Sketch of block occurring at A in fig. 4, and showing the gradual passage of charnockite into leptynite.*

Between this hill and the quarries referred to above occur the exposures of the peculiar biotite-bearing rock described on p. 158, near which is found the graphite-bearing variety of the "intermediate" group of this series (p. 152).

The principal exposures of norite on the east side of the

[1] From these quarries the rock used in the Madras Harbour works has been largely obtained.

[2] See also p. 142. For further evidence as to the formation of garnets from pyroxenes, see *Rec. Geol. Surv. Ind.*, Vol. XXIX, p. 20.

railway occur to the north of the leptynite and charnockite. The most abundant variety is that in which both augite and basaltic hornblende accompany the hypersthene. In some cases the hornblende crystals are distinctly larger than the other constituents, and by their more rapid decomposition on weathered surfaces give the rock a spotted appearance (Nos. 8·752 and 9·661). Sometimes, however, the hornblende is practically absent, whilst augite and hypersthene are associated in about equal proportions with the plagioclase and opaque iron-ores (No. 9·397).

On the west side of the railway station the charnockite series is represented in the Christian village, Isa Pallavaram, by a garnetiferous and micaceous variety, resembling, apparently, the peculiar biotite-bearing rock referred to on p. 159.

The sections exposed in the wells near the village show the prevalence of a coarse-grained quartz-felspar rock resembling that which veins the charnockite at St. Thomas' Mount. Although the rock is generally much decomposed, the quartz crystals retain the characteristic blue colour of this series. Sometimes fragments of garnet and biotite occur in this rock. Further exposures appear rising like islands through the alluvium of the paddy-fields to the west. Rounded lumps of black rock mark the outcrop of a dyke of augite-diorite (diabase) with micropegmatite, whose microscopic characters have been described elsewhere.[1]

The hill which rises to about 200 feet above the alluvium near the village of Pammal, 2 miles west of Pallavaram, is composed principally of hornblende-augite norite (No. 9·673), with less hornblende in the central portions of the hill (9·676). On the western and north-western margin of the hill considerable quantities of biotite and quartz appear (9·675) sometimes with garnet (9·674). The rocks here include numerous veins of the acid forms, generally much coarser in grain than the average sample of norite.

The most interesting feature in this hill is the occurrence

[1] *Rec. Geol. Surv. Ind.*, Vol. XXX (1897), p. 31, *Quart. Journ. Geol. Soc.*, Vol. LIII (1897), p. 405.

of veins of pyroxenite, 3 to 5 feet wide, cutting through the norite.

Pyroxenite.

Although the pyroxenite dykes run in some cases parallel to the general direction of foliation, Dr. King and myself, whilst tracing one on the west side of the hill in September 1893, found it to distinctly ramify, one branch running westwards almost at right angles to the strike of foliation. The pyroxenites never show any chilled edges, so the fissures which they occupy must have been filled whilst the norites were still hot, and from the evidence of their occurring in distinct and ramifying dykes amongst this norite, they are probably part of the same series and derived from the same magma after the manner of some forms of Reyer's so-called *Schlierengänge*.

On a hill to the north-east of the Pallavaram railway station a 9-inch vein of hornblende pyroxenite (No. 9·667) in a hornblende-augite norite more completely displays the character of a *Schliere*. The vein is aligned parallel to the direction of foliation, that is, N.-N. E.—W.-S.-W.; and a section across its junction with the norite shows the ferro-magnesian silicates interlocking across the border (p. 164).

The rocks of St. Thomas' Mount and Pallavaram show a distinctly linear arrangement of their minerals in a N.-N.-E.—S.-S.-W or a N.-E.—S.-W. direction parallel, that is, to the adjoining

Foliation.

Coromandel coast-line. Although this linear arrangement of the constituent minerals has been referred to as "foliation", this term is generally used to imply the effects of dynamo-metamorphism developed to a much greater degree than has probably been the case with the charnockite series at Pallavaram. There is no evidence of the rocks having been folded since consolidation, and only local signs of their having been crushed. As pointed out in another section of this paper, it is probable that the linear arrangement of the minerals was probably induced during the process of consolidation, although of course it may have been accentuated in many, perhaps in most, exposures by continued exertion of the forces which determined the main physical conformation of South India in very early geological times.

Previous descriptions.

Many of the features presented by the rocks at Pallavaram and St. Thomas' Mount were noticed by Dr. P. M. Benza as long ago as 1836, who recorded an abundance of accurate information in his "Notes on the Geology of the Country between Madras and the Neilgherry Hills, *viâ* Bangalore and *viâ* Salem".[1] The garnetiferous rock, the trap-dykes, the decomposed, kaolinized form of the rock herein referred to as charnockite-pegmatite were noticed by Benza. The rocks forming the hills and here included in the charnockite series he speaks of as hornblende rock, and considered them to be overlying the fundamental granite.[2]

The rocks of St. Thomas' Mount and the Pallavaram Hills are referred to by Mr. R. B. Foote as "hornblendic gneiss of a very compact character," whilst the more acid forms of the charnockite series in this neighbourhood are spoken of as "quartzo-felspathic gneiss".[3]

THE SEVEN PAGODAS.

The Seven Pagodas.

Along the East Coast south of Madras, the crystalline rocks rise up like islands in the midst of the cultivated alluvium, the great prevalence of which reduces the value of the necessarily isolated geological observations. The only exposure of crystalline rock in the Chingelput District south of Pallavaram, which I have been able to examine carefully, occurs near the village of Mahavalipuram, or the Seven Pagodas (lat. 12° 36′ 55″; long. 80° 13′ 55″) which is 35 miles south of Madras and on the coast.

The Seven Pagodas are well known on account of the interesting rock-cut caves and temples, for the production of which nearly every exposure of rock for about two miles along the coast has been elaborately carved. The rock is referred to in Mr. Foote's memoir[4] as a "quartzo-felspathic gneiss" in which the

[1] *Madras Journ. Lit. Sci.*, Vol. IV (1836), pp. 1—27.

[2] For remarks by Capt. J. Allardyce, see section 12.

[3] *Mem. Geol. Surv. Ind.*, Vol. X, p. 127 (1871).

[4] *Op. cit.*, p. 127.

linear disposition of the constituents coincides with the direction of the exposed ridges as well as the coast line which runs a few degrees east of north to west of south. The petrological characters of the rock have been described on p. 146.

On the slight grounds of its resemblance in mineral composition to the coarse-grained quartz-felspar rocks associated with, and sometimes occurring as veins in, the charnockite of St. Thomas' Mount and Pallavaram, I have referred this rock to the charnockite series and have regarded the dirty white colours of its felspar as due to decomposition. In another section of this paper (p. 197), I have pointed out the differences between simple subaërial action (which in the compact charnockite series appears to be very limited in its effects) and the hydration, due possibly to submarine action, which extends to greater depths through the rocks. It is more likely that the low-lying rocks near the coast have been depressed more often and to greater depths than the higher portions of the hills and the rocks further inland, and if there really is the difference between the two kinds of decomposition—subaërial and submarine—such as I have imagined, it is not unnatural to expect that the low-lying crystalline rocks near the coast will be found to have lost the freshness which is so characteristic of the charnockite series in the Shevaroy and Nilgiri Hills for instance. Although the narrow fringes of marine beds lying near the east coast of Madras cover only a part of the land which has in past ages been depressed below the sea-level, the absence of all traces of marine deposits further inland justifies the conclusion that subaërial denudation has proceeded uninterruptedly for many geological ages on the high lands of the Madras Presidency.

South Arcot District.

The only detailed account of the distribution of the charnockite series in South Arcot District is due to Dr. H. Warth, who surveyed a portion of the district during the field-season 1894-95. Unfortunately no opportunity occurred for tracing out the relations between the charnockite series and the remarkable rock which has been referred to by the older members of the survey as "the granitoid gneiss of South Arcot".[1]

This latter rock is distinguished by the white colour of its quartz and the inclusion of grains of pink felspar, accompanied by only a feeble development of gneissose and banded structures. Inclusions of hornblendic and micaceous gneiss and schist are extremely numerous and are often arranged with their planes of foliation at various angles to that of the imperfect foliation which the "granitoid gneiss" displays. So far these rocks agree with the granitoid gneisses which are so largely developed in the Hosur and Krishnagiri taluks of the Salem District; but their geological and petrological characters have not been studied sufficiently to justify more than a mere suggestion as to their correlation. The large tors and piles of loose blocks of this rock are very conspicuous along the Madras Railway at several points between Arkonam and Ulli stations, a distance of about 57 miles.

The specimens of the charnockite series collected by Dr. Warth in the South Arcot District belong to the "intermediate group," and their microscopic characters have already been described. As in other localities they form low, rounded hills isolated by stretches of alluvium which frustrate all attempts to trace out any character over more than very limited areas.[2]

SALEM DISTRICT.

The most conspicuous exposure of this series of rocks in the Salem District forms the main mass of the Shevaroy hills, which cover an area of about 100 square miles, and form a mass 16 miles long from north-east to south-west and 10 miles wide from south-east to north-west. The highest portions exceed 5,000 feet above sea-level. The southern

Shevaroy Hills.

[1] See King and Foote, *Mem. G. S. I.*, Vol. IV, p. 298, and Foote, *Mem. G. S. I.*, Vol. X, p. 129. Dr. Warth's report on this area has not been published.

[2] My attention was first called in 1892 to the existence of the charnockite series in South Arcot District by Mr. F. G. Brock-Fox, F.G.S., Executive Engineer, P. W. D., who collected specimens near Mailam, and from slides prepared by himself, recognised their resemblance to the rocks of Pallavaram.

flanks are precipitous cliffs, which give the hills a peculiarly massive appearance, but the valley of the Vániár, opening out to the north bisects the mass into two main lobes.

Messrs. King and Foote agreed with Dr. Benza in classifying the rocks of the Shevaroys as hornblende-schist.[1] Hornblende is generally a constituent—often a prominent constituent—of the charnockite series represented in these hills, and in the ultra-basic forms well-exposed near the foot of the ghât leading to Yercaud from the Suramangalam side, hornblende is so abundantly in excess of the hypersthene that the rock might be classified from hand specimens as an amphibolite. Sometimes small quantities of felspar occur, and so link these rocks with the norites (No. 9·114).

The main mass of the Shevaroy hills, however, is composed of "intermediate" members of the charnockite series comparatively free from garnets. Determination of the specific gravity of 48 specimens taken from different parts of the mass gave an average of 2·77 with closely agreeing results. In the prevalent intermediate variety there occur frequent examples of coarse-grained, acid contemporaneous veins, as well as basic, fine-grained, hornblendic schlieren (11·910, 11·911, 11·917). The basic schlieren are sometimes broken into irregularly shaped fragments which are cemented by more acid material, thus producing a kind of primary eruptive breccia. The much more recent dislocation-breccia of the so-called "trap-shotten" kind forms bands in several parts of the hills (11·909).

Sections taken from the Shevaroy rocks form good illustrations as a rule of the tendency which the ferro-magnesian silicates show to gather themselves into groups. Number 9,111, for instance, shows patches as basic as norite mixed with portions as acid as charnockite (compare slides 1,807 and 1,398).

All the rocks of the Shevaroys appear to be well schillerized, the blue quartz and blue-grey felspars being crowded with the hair-like inclusions described on p. 138, whilst the hypersthenes show the usual brown rods and plates. Microperthitic felspars are found in all specimens (Nos. 9,111, 112, 113, 692, 693, 694, 695, 696).

[1] *Mem. Geol. Surv. Ind.*, Vol. IV, p. 242.

A linear arrangement of the constituents, often accompanied by banding of an imperfect kind, is well displayed on weathered surfaces, and has been in some cases accentuated by slight crushing. The direction of foliation is very constantly N. E.—S. W. with a general dip of 50°-60° to the S. E. The mass is crossed from edge to edge by a dyke 50 yards wide of augite-diorite (diabase) with micropegmatite.

The scenery and physical features of the Shevaroys have been described by Messrs. King and Foote, and in the Salem District Manual by Mr. H. LeFanu. Like on many of these plateau masses of the charnockite series the gentle slopes of the wide valleys facilitate the artificial production of lakes of considerable dimensions. That at Yercaud, and the hills in the neighbourhood, are shown in plate XII which is the reproduction of a photograph taken from Arthur's Seat.

The Nagaramalai type.

Near the S.W. foot of the Shevaroys, and again between Salem town and Kanjamalai, small, bare, rocky hills stand up abruptly above the general level of the plain. Some of these show clearly their lenticular structure, and consist of masses of basic garnetiferous members of the charnockite series. The rocks are comparatively coarse in grain and sometimes contain garnets as large as one's fist. As a rule the only signs of foliation they show is an imperfect linear disposition of the constituents parallel to the long axes of the lenses and to the foliation of the gneisses around. Occasionally one comes across small E.N.E. dislocations in which a certain amount of mylonite is produced (see fig. 6)

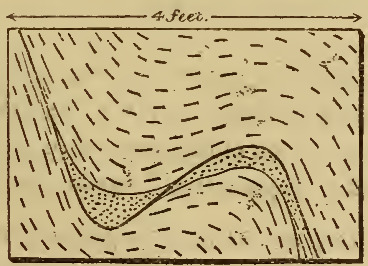

Fig 6. *Local twist with formation of mylonite in garnetiferous norite near Salem.*

and a local N.W. foliation. These garnetiferous types, of which Nagaramalai is a good example, are always accompanied by marginal lenses of pyroxenite (pyroxene-rocks) which often contain small quantities of olivine and hercynite. The minerals of these rocks in the immediate neighbourhood of the Chalk hills are always well schillerized and the garnets contain strongly bi-refringent needles whose characters and regular crystallographic disposition have been described in a separate paper.[1]

Other masses of the basic varieties (norites) without garnets occur as lenses of all sizes in the "leaf gneisses" of the Salem-Ahtúr valley. They resemble very closely in mineral composition and structure the basic schlieren in the Shevaroys (11·918, 11·923).

"Chalk Hills."

The members of the charnockite series cropping up between the two main magnesite-producing areas of the Chalk hills form interesting examples of alteration by the action of the peridotites intruded into them. The fresh appearance and the blue colour of the normal rock has been changed to a dirty white. This change of colour is seen under the microscope to be due to the development in the felspars of an innumerable number of minute black dots arranged in rows parallel to the twin planes (plate VIII, fig.5). The action has, however, been apparently confined to the felspars; for the quartz, hypersthene and iron ores appear to be unaltered (No. 9·689). The change in the felspars is not unlike that which in the neighbourhood of the Giridih coalfield of Bengal appears to be the preliminary form of static metamorphism which on dynamic action results in the production of scapolite.[2]

Tongues of charnockite corroding the older biotite gneiss are exposed $3\frac{1}{2}$ miles south of Salem on the Namakal road; these are described in another section of this memoir (p. 226). The dislocation breccias or so-called "trap shotten" bands are also described in a

[1] Holland, "On the acicular inclusions in Indian garnets." *Rec. Geol. Surv. Ind.*, Vol. XXIX, 1896, p. 16.

[2] *Cf.* Holland and Saise, "On the igneous rocks of the Giridih (Karharbari) coalfield and their contact effects." *Rec. Geol. Surv. Ind.*, Vol. XXVII (1895), p. 123.

special section and further details of the geology of the immediate neighbourhood of Salem will be published in a separate memoir.

The charnockite series are represented in other hill masses in the Salem District, for instance in the Javadis and in the Dharmapuri Hills. In the Dharmapuri taluk corundum occurs, with sillimanite, rutile, biotite and cryptoperthite, as constituents of large ellipsoidal inclusions near the junction of the charnockite series with a biotite granite which occurs in large quantities in this taluk and that of Hosur. As the Salem and Coimbatore Districts are now being carefully surveyed, it is advisable to postpone further discussion of the local geological relations of the charnockite series until they have been worked out in greater detail.

Coimbatore District.

Hornblendic forms near Tirrupur.

The charnockite series exposed in various parts of the Coimbatore District will be described by Mr. Middlemiss, who has been surveying this area for some four years. But one instance illustrating the amphibolization as well as one of the ways in which banding is produced, should be referred to at once. Near Tirrupur railway station there are considerable exposures of hornblendic gneisses along the banks of the Noyal river, which, on microscopic examination, are found to contain hypersthene, and in other ways to repeat the essential features of the charnockite series. As sections shew various stages in the amphibolization of the pyroxene with consequent production of green hornblende, the unusually large quantity of the latter mineral is satisfactorily accounted for. Garnets, more often than hornblende, are found amongst the products of the alteration of pyroxene in the South Indian charnockites, but it now seems likely that, whilst the unstable pyroxene may give rise to garnet at high temperatures, hornblende is the more usual result of change at lower temperatures. It is thus likely that one of these minerals may characterise one area or one mass which happens to be deeply buried, whilst the other may arise when the rock becomes deformed nearer the surface.

The other feature of interest displayed near Tirrupur is the production of banding by *lit-par-lit* injection of the non-felspathic forms along the foliation planes of the basic types. That this is the correct explanation of the well marked banding in this neighbourhood is shown by the fact that the non-felspathic "bands" sometimes break across the foliation planes, and sometimes actually bifurcate (see plate IX). The ultra-basic (non-felspathic) bands often weather with formation of onion-like shells and with deposition of calcareous kankar along the cracks. A good case is badly represented in the photograph forming plate X.

The charnockite series here, as they often are, are associated with quartz iron-ore beds, and in other parts of the same district also with crystalline limestones.

NILGIRIS.

The civil district of the Nilgiris, which is very nearly coincident with the hill ranges known as the Nilgiris and Kundas, is practically made up of members of the charnockite series. The plateau, which forms such a conspicuous feature in the south of India, measures 42 miles long and 15 miles broad, covering an area of about 750 square miles. In a large number of places it exceeds 8,000 feet in height, and attains its maximum altitude of 8,760 feet in Dodabetta, a rounded hill near Ootacamund (lat. 11° 24′ 5·40″; long. 76° 46′ 44·39″).

The characteristic scenery of a charnockite area is typically developed in the Nilgiri Hills. The rounded peaks and grass-covered undulating "downs" of the plateau are features characteristic of a country in which the inequalities developed by uninterrupted weathering have completely obliterated all the physical features originally formed by earth-movements. The scenery of the Nilgiris contrasts very strikingly with the deep narrow gorges of the Himalayas, where the rapid erosion, following the geologically recent elevation of the mountain range, has left the slopes so near the angle of repose of the broken rock, that landslips are of daily occurrence, whilst the vegetation is only allowed an insecure and temporary place for development in places where, by local accident, the slope is comparatively gentle. In the Nilgiris the slopes are clothed with thick turf, and the valley "bottoms" often covered with deep peat bogs.

Weathering.

In consequence of this protection from rapid erosive action the weathering of the rocks has gone on by simple decomposition *in situ* to depths often of 40 or 50 feet. Road cuttings through this decomposed material show the average products to be a soft, yellow or red clay, in which, on account of the variations in original composition, the basic portions can, though reduced to a mere clay, be easily distinguished from the acid contemporaneous veins which contain more pure kaolin and are seen to ramify in all directions through the rock. Often in a neatly cut slope of this clay small local faultings are beautifully displayed with diagrammatic clearness.

In the midst of this deep covering of decomposition products, rounded boulders of the fresh rock are frequently found without any apparent regularity of relation to their depth from the surface. The onion-like shells of partially decomposed material around these boulders are seldom more than a few inches thick, so the passage from the pure clay to the fresh rock is remarkably rapid. It is to this interesting feature that I have referred as an illustration of the differences between the decomposition produced in rocks exposed to the action of unaided atmospheric agents, and the alteration noticeable in rocks which have been depressed below the sea level and submitted to the corrosive action of water charged with carbonic acid and salts acting under pressure (*vide* p. 197). Sections taken from the rock of the Nilgiris within a few inches of the clay decomposition products are seen, on microscopic examination, to be most remarkably fresh, the felspars being perfectly clear and free from kaolinization. The same thing is true of the olivine-crystals in the norite dykes which cut through the charnockite series in the same area. Even in small boulders olivine-crystals are generally without the slightest signs of serpentinization, although the dykes are converted into a yellow clay where they come to the surface.

South-eastern face of the mass.

The south-eastern face of the Nilgiris is a steep, precipitous scarp with an average direction of E.-N.-E.—W.-S.-W., which is the direction also of foliation in the hill. The rocks are much more definitely foliated near this face than further towards the centre of the plateau, and the foliation is accompanied by a considerable development of garnets. In the neighbourhood of Coonoor the marked foliation and the great development of garnets (see No. 9·307) are especially noticeable. It appears to me to be in keeping with the few geological data available to regard this great southern scarp as approximately coincident with the original limits of the mass in this particular area, just as the corresponding southern scarp of the Shevaroys is possibly a corresponding line limiting that particular intrusion. In any earth movements which may have taken place, it is natural to expect the great, solid masses of compact rock forming the Nilgiris to sever connection with the very different material which forms the schists and gneisses of the Coimbatore plains, and this southern scarp probably, therefore, now indicates also the direction of a great fault plane. Naturally the weather has scored out many deep marks in this southern face and considerably modified its original outlines; but the sides are still more precipitous than one would expect as the simple result of differential denudation. In a separate memoir the evidences for a similar state of affairs will be detailed for the Shevaroy Hills (*Mem. Geol. Surv. Ind.*, Vol. XXX, part 2).

Pegmatoidal pyroxene plagioclase rocks.

One of the most interesting features in connection with this southern margin of the Nilgiri mass is the occurrence of large, lenticular inclusions of heavy, basic, pyroxenic rocks of a very peculiar type. The lenticles are often as much as 15 feet long and 5 feet across; they are disposed in bands parallel to the foliation of the charnockite series in which they are included, and are sometimes cut through, like the charnockites themselves, by the narrow dykes of olivine norite, such as occur, for instance, in the river-bed below the Coonoor bridge.

The inclusions referred to are formed of extremely tough rocks, with a specific gravity varying between 3·13 and 3·25. They often exhibit a remarkable lustre-mottling due to the development of pyroxene crystals measuring sometimes six inches across. Under the microscope thin sections of the pyroxene are quite colourless and appear to be changing into a peculiar pale-yellow hornblende. Eyes of clear plagioclase occur enclosed in the pyroxene, and as several apparently isolated sections of this plagioclase show simultaneous extinction, they are probably in crystallographic continuity with one another (No. 9·302). The structure is, therefore, due, not to ophitic development of the pyroxene, but to a pegmatoidal intergrowth of the two minerals. Sometimes the pegmatoidal structure is destroyed and the rock becomes granulitic (No. 8·760). Much of the pyroxene is rhombic and in thick sections shows a very faint pleochroism. The hornblende shows its characteristic prismatic cleavage which facilitates the determination of its optical properties. The extinction angle is 18° (*c* : 𝔠). The pleochroism is well marked though not so strong as in common hornblende—

𝔞 = very pale yellow.
𝔟 = brown-yellow.
𝔠 = yellow.

The optical properties of this mineral agree with those of the 3rd variety of hornblende in Lacroix's "pyroxenic gneiss *b*" (*Rec. Geol. Surv. Ind.*, Vol. XXIV, page 182), which was likewise found in a rock with pegmatoidal pyroxene and felspar. Unfortunately, however, Lacroix has given no hint as to the geological relations of the rocks described, so this partial agreement in microscopic characters might be purely fortuitous.

The biotite which invariably occurs in these inclusions is a highly pleochroic variety varying from deep yellow-brown to very pale yellow. Flakes examined in convergent polarized light show a narrow optic axial angle with a negative bisectrix. Neither free iron-ores nor garnets have been observed in the peculiar lenticular inclusions, although they are abundant enough in the associated ordinary members of the charnockite series.

At present I am unable to recall any precise parallel for these peculiar inclusions. Their lenticular shape and their occurrence in trains along the same band of the charnockite series suggests that the lenticular shape is the result of the "pinching" of a once continuous band. The conversion of a band of tough basic rock into lenticles, instead of the mere spreading out of the constituents into a thinner band, illustrates very prettily the various degrees by which different rocks yield under pressure. As a general rule the more basic rocks are, under pressure, less plastic than acid ones and so take on simple foliation less readily; it is in consequence of this fact, Adams thinks, that basic masses are so frequently found in trains of fragments included in thinly foliated siliceous forms instead of forming thin basic leaves.[1]

Western margin of the mass.

The western margin of the Nilgiri mass appears to be as precipitous as the southern; but in the north it slopes away through the portion known as the Nídumalai range till it reaches the lower-lying plateau of the Mysore State. In the Wainád to the north-west and in Malabar on the west the average strike of the foliated rocks is N.-N.-W.—S.-S.-E., but we have no details as to the connection between the physical geology and the change of strike which probably occurs near the line of junction between the Nilgiri mass and the gneisses of the Wainád and Malabar. The disturbances recorded by Dr. W. King [2] in the former locality, and those described by Mr. Lake in the Malabar District,[3] would be of much greater interest if we possessed more precise data than is obtainable from a mere macroscopic description of the rocks. The interesting questions connected with the geological relations of the Nilgiris to the surrounding low countries must, therefore, be left for a while in this incomplete condition.

[1] See *Amer. Journ. Sci.*, Vol. L (1895), p. 62.
[2] *Rec. Geol. Surv. Ind.*, Vol. VIII, p. 37.
[3] *Mem. Geol. Surv. Ind.*, Vol. XXIV, plate II.

Schlieren.

Another feature of interest in connection with the charnockite series in the Nilgiri Hills is the frequent display of basic *schlieren* of norites within masses of more acid composition, and, what is strictly analogous to this phenomenon, numerous veins of the acid variety running through the basic portions after the manner of the so-called "contemporaneous veins."

According to the relative abundance of the basic and the acid varieties of the same series, we may have, either the basic rock occurring as small islands in an acid matrix, or the latter may occur only as small veins cutting through, and subordinate in quantity to, the former.

Primary breccia.

Perhaps the most interesting case is that in which the acid and basic varieties occur together in about equal proportions, and a very interesting example of such has been exposed on the roadside under the Convent and near the Boat House of the Gymkhana Club in Ootacamund.

In this pretty instance the basic fragments are scattered through an acid matrix to form a pseudo-breccia; but the linear disposition of the angular, inequiaxed fragments of basic rock, as well as of the acid material in which they lie, indicates the direction of flow previous to consolidation. We have thus a case of what the late G. H. Williams called *protoclastic* structure in imitation of Lossen's term *Primärtrümer*, and of Sederholm's terms, *Primärbreccia* and *Eruptivbreccia* (see fig. 7, and p. 218).

COORG.

The Western Ghâts.

The charnockite series occur on the west of Coorg, where they constitute the Western Ghât ridge, and again on the east, where a large mass, and perhaps several smaller ones grouped around, form lenses, which locally appear as bands, in the biotite gneiss. The direction of foliation is very constantly N.-W.—S.-E. or thereabouts. The former exposures run south-eastwards into the Wainád and probably join up with the Nilgiri mass. The eastern margin of these rocks is quartzose and highly garnetiferous as well as graphitic ; it is along this band of peculiar rocks that the charnockite series march with the Mercara group of gneisses and schists, and the phenomena here displayed are regarded by Dr. Walker and myself to be due to contact metamorphism, though it is difficult to decide the exact boundary line between the two great formations and so distinguish endogenous from exogenous products.

Dykes.

The chief feature of interest in connection with the eastern occurrence in Coorg is the frequent display of narrow bands of basic charnockites in the biotite-gneiss. Careful examination of these has revealed the curious fact that they all possess fine-grained basic and hornblendic selvages which are almost certainly the result of chilling at the margins. These bands must, therefore, be regarded as dykes intruded into the older biotite-gneiss. They vary very greatly in width, sometimes being merely a few inches in thickness and at other times swelling out to large masses. Several of these are very clearly exposed in the bed of the Cauvery at Fraserpet (see plate XIII). In their mineral composition and structure they display the essential features which characterise the charnockite series and like them often contain garnets (Nos. 12·395 to 12·405). Their association with larger masses of the more normal types leaves little doubt about the conclusion that these dykes are true members of the charnockite series and under the circumstances must be regarded as strong evidence in favour of the conclusion that these rocks are igneous in origin and intrusive in their relations to the older gneisses.

Madura and Tinnevelli.

Palni Hills.

In the Palni Hills we have a mass of the charnockite series, as large as that of the Nilgiris. The Palni mass is 54 miles long from east to west and 15 miles broad; including Aujinad, it covers 798 square miles. The plateau is at an average elevation of 7,000 feet above the sea, and is characterized by scenery similar to that on the Nilgiris. In all the hill masses composed of the charnockite series the gentle undulations of the plateaux facilitate the production of lakes of considerable dimensions with very slight artificial assistance. At Ootacamund on the Nilgiris, at Yercaud on the Shevaroys, at Kodaikanal on the Palnis, and at Neuralia and Kandy in Ceylon, lakes of considerable size have been formed by taking advantage of the facilities offered by the gently undulating surfaces of the plateaux formed of the rocks which are grouped together in this series.

The Palnis are physically connected with the Anaimalais and are probably also geologically a continuation of these hills; but this area lies principally in the Coimbatore District and is only now in the course of being surveyed.

Our principal information concerning the distribution of this series in the remaining portions of Madura and Tinnevelli is due to Mr. R. B. Foote,[1] who described the leading member of the series as a "granitoid gneiss", which, from its occurrence near Cape Comorin, was designated the "Cape Comorin type" (*Op. cit.*, p. 28).

Cape Comorin type of gneiss.

The "Cape Comorin granitoid gneiss" appears to be interbanded with granular quartz rock, and in the Madura district these rocks, according to Mr. Foote, form six distinct groups, associated in a few places with coccolitic marbles. In the Tinnevelli District both the granular quartz rock and the crystalline limestone are found again in association with the Cape Comorin type of granitoid gneiss.

Many of the prominent hills in these two southern districts are composed of the charnockite series ("Cape Comorin type of granitoid gneiss"). The southern ghâts, which are partly included in the State of Travancore, are practically composed of these rocks, Mahendragiri, the most southerly of the great peaks of the range, being a noteworthy example, attaining an altitude of 5,419 feet.[2]

[1] *Mem. Geol. Surv. Ind.*, Vol. XX, p. 1.

[2] For further details concerning the crystalline rocks of Travancore see W. King, *Rec. Geol. Surv. Ind.*, Vol. XV, p. 87, and Foote, *Ibid*, Vol. XVI, p. 20.

CHAPTER VI.

General Considerations.

On account of the large are acovered by the charnockite series in the southern portion of the Madras Presidency, the predominant features which they present must necessarily affect our generalisations concerning South Indian petrography and geology.

Four such points considered below deserve special mention :—

(1) The abundance of magnesian minerals.

(2) The preservation of old pyroxenic rocks.

(3) The limited amount of hydration suffered by the rock-constituents.

(4) The nature of the so-called "trap-shotten" gneiss.

Abundance of Magnesian Minerals.

The most remarkable feature which has been revealed by recent microscopic study of the crystalline rocks in South India is the very great predominance of the pyroxenes (and especially of the rhombic forms of that group) amongst the ferro-magnesian silicates. In addition to the series described in this paper, which is probably the most abundant of all the rock-groups in the southern portion of Peninsular India, and in every variety of which hypersthene is a constant and characteristic constituent, the central and eastern parts of the Madras Presidency are cut through by an enormous number of basic dykes, in which rhombic pyroxene also is a leading mineral. Judging thus by the mineralogical composition of the rocks, which is confirmed by the few chemical analyses that have so far been made, the bases magnesia and ferrous oxide must take an unusually prominent place amongst the chemical constituents of the southern portions of the Peninsula. Besides occurring as a constituent of the enstatites, which are so widely distributed through the Madras rocks, magnesia occurs even in larger proportions in the peridodites, which, either as dunites, saxonites, picrites or their decomposed forms magnesite, serpentine and steatite, are now known to be far more abundant than was suspected at the time of the first recognition of these highly magnesian, ultra-basic rocks near Salem in 1892.

Prevalence of Pyroxene.

More remarkable than the prevalence of magnesian compounds is great predominance of the pyroxenes amongst the rock-forming minerals of the south. The pyroxenes are essential constituents of the charnockite series which make up the chief mountain masses and cover large areas in the low-lands; they characterise the basic dykes which cut the older crystalline rocks in all directions, and the soda-bearing members of the group have recently been found in the augite-syenites of the Yelagiri hills and associated intrusives.

These are all geologically old rocks, probably not later than lower palæozoic in any case, and the perfect preservation of such unstable minerals as the pyroxenes forms an interesting corroboration of now established conclusions as to the long quiescence of Peninsular India, a geological quiescence which was inferred by the older geological surveyors from stratigraphical evidence alone.

Although the dyke-rocks of supposed Cuddapah age are preserved with perfect freshness, there is abundant evidence to show that the previously formed Dharwars suffered from dynamo-metamorphism, and the pyroxenic dykes and flows of the earlier period have been largely changed to hornblendic schists.

Knowledge of the profound dynamo-metamorphism suffered by the Dharwar transition rocks, naturally provokes a search for evidences of similar action on the associated and presumably older Archæan formations in the same area; and here the enquiry comes home to us, for the charnockite series are assumed to be Archæan.

Before this enquiry can be satisfactorily undertaken there are several points on which further information is essential. In the first place, the lower limit of the Dharwars is not sufficiently defined to warrant the assumption that all the Dharwars are younger than all the Archæan gneisses and schists. In other words, the break between the biotite gneisses and the Dharwar rocks, which Mr. Foote recognised in the Bellary District, has only a local value.[1] No unconformity has so far been found between the charnockite series and the Dharwars. On the other hand, members of the charnockite series occur as lenticular masses or bands associated with ferruginous quartzites which do not differ greatly from the ferruginous quartzites so abundant in the lower stages of the Dharwar system. The ferruginous quartzites referred to are those which occur so frequently in the central and southern districts of the Madras Presidency, Kanjamalai and Godamalai being conspicuous and well known examples in the Salem District for instance; these rocks are composed of magnetite, hematite, and quartz with a pale-green hornblende, and they only differ from the rocks of similar mineral composition in typical Dharwar areas in their more perfect crystallization and in, perhaps, the predominance of magnetite over hematite—points which merely indicate differences in degree of metamorphism, not necessarily differences of age.[2] As far as these magnetic iron-ore beds are concerned, there is not the slightest reason for considering them to be younger than the charnockite series. On the contrary, if our views as to the origin of the charnockite series are sound, it is more likely that the latter are younger and have attained their present

[1] Manual of Geology of India, 2nd edition, pp. 49, 50; R. B. Foote: "The Geology of the Bellar District," *Mem. Geol. Surv. Ind.*, Vol. XXV (1895), pp. 28, 74.

[2] The suggestion that these southerly iron-ore beds are merely altered outliers of Dharwar age has been made in a separate memoir descriptive of the rocks in the immediate neighbourhood of Salem (*Mem. Geol. Surv. Ind.*, Vol. XXX, part 2). The discovery of large proportions of hematite in the magnetic ores of the south and of magnetite in hematitic ores of the Dharwars considerably reduce the previously recognised differences between the two groups of rocks.

position by intrusion. Even if we reverted to the old idea that all these rocks are regionally metamorphosed sediments, the interbanded charnockites could not be older than the magnetic iron-ore beds, for the latter occur below as well as above the former.

Unfortunately, the question of greatest importance—the petrology of the Dharwar conglomerates—is the subject about which we are still most ignorant. Pebbles of "schist, quartz, quartzite, grit, banded hornstone and gneiss" have been referred to in connection with these conglomerates, but their microscopic characters have not been described. Recently, through the kindness of Dr. J. W. Evans, State Geologist of Mysore, we received pebbles from a Dharwar conglomerate which occurs in the Kolar Goldfield. Microscopic examination of these shows them to be indistinguishable from the old biotite-gneiss which is corroded by tongues of the charnockite series near Salem (*vide infra*, p. 226). From these facts we conclude that the charnockite and the particular Dharwar conglomerate from which these pebbles were obtained are both younger than the biotite-gneiss near Salem, but we still have no clue as to the relative ages of the Dharwars and the charnockites. It is to be hoped that every effort will be made in future to collect and identify pebbles from the lower Dharwar conglomerates with a view to the elucidation of this important point.

Although we have no clear proof of their antiquity, we must be prepared for the conclusion that the charnockites are quite old enough to have suffered from the tangential pressures which have left their mark so plainly on the highly folded Dharwar strata. Under such circumstances, the preservation of so much pyroxene would require explanation.

Stability of pyroxene at high temperatures.

Concerning the anorthosites of Canada, which have much in common with some forms of the charnockite series, Adams has made some very suggestive remarks about the stability of the pyroxene during the granulation which is sometimes carried far enough to produce a thorough "Rutschmehl." "The cataclastic structure is not," Adams says, "developed along certain lines, but may be observed more or less distinctly throughout the rocks. Where it occurs there is neither saussurite nor uralite—although the granulation of the pyroxene may be carried so far that only the smallest remnants of the original individuals remain." From this, as part of the evidence, he concludes that "these movements probably took place when the rock was still so far beneath the surface of the earth and so weighted down by the overlying rocks that breaking and shearing with the movement of the resulting masses was impossible. Such a motion would present certain resemblances to that of a very tough pasty mass ....while the rock was still very hot and perhaps even near its melting point. This would explain why pyroxene, which, according to the experiments of Fouqué and Michel-Lévy, represents the stable form at a high temperature, is not changed into amphibole which represents the more stable form at a low temperature.[1]"

All these remarks are applicable too to the charnockite series, and with regard to the last point it is not unlikely that the great prevalence of pyroxenic rocks in these old protaxes, like Canada and Madras, where denudation has proceeded uninterruptedly for such long ages, is due to the exposure of relatively low portions of the earth's crust, lower portions comparatively than those which have been protected by sedimentary coats, and low enough to permit such a regional rise of temperature that the pyroxenes, for instance, are crushed without amphibolization.

The prevalence of garnets in some members of the charnockite series which show no signs of dynamo-metamorphism, suggests that although the pyroxene is the stable form near fusion point and hornblende the stable form of the same compound at low temperatures, there is an intermediate, but high, temperature, short of fusion, at which either hornblende or pyroxene breaks

[1] Adams. "Report on the Geology of a portion of the Laurentian area lying to the north of the Island of Montreal." *Annual Report of the Geol. Surv. Canada*, Vol. VIII (1896), part J, pp. 114 and 115. There are many interesting points of resemblance between the old Canadian protaxis which has been exposed to continuous denudation since Potsdam days and that of Madras.

up into a more basic garnet and a more silicious bye-product, quartz or felspar—a kind of liquation process facilitating the segregation of basic and acid extremes from a body of intermediate composition. It is to such a cause that the prevalence of garnets in these old pyroxenic rocks should be ascribed.

The means by which the pyroxenic and garnetiferous rocks have been brought to the surface have been in action for long geological ages, during which Peninsular India has suffered from no serious earth-movements. The deep-seated rocks have thus been brought to the surface without undergoing any form of crushing at intermediate levels, and so the original characters of our charnockite series are probably preserved in an unusually perfect manner.

Limited degree of Hydration.

Besides the freedom from crushing due to absence of earth-movements since Cuddapah times, the peninsular rocks have escaped general hydration in a most remarkable way. The freshness of South Indian rocks is not confined to the charnockite series: the olivines in the basic dykes of Cuddapah age scarcely ever show a sign of serpentinization, and even in the large number of dunite areas serpentine occurs only in small quantity.[1]

Another striking example is offered by the elæolite-syenites recently discovered in the Coimbatore District, where the mineral elæolite, quite as susceptible to hydration as olivine, has been preserved in a perfectly fresh condition although the rock is probably as old as any sedimentary formation in South India, and was even described as a member of the crystalline schists.

And yet these rocks, which are internally so remarkably fresh, are, in common with all rocks exposed to the moist, warm climate of tropical countries, changed near the surface into a soft clay to depths of 50 feet or more. Near Coonoor in the Nilgiri Hills both

[1] Dunites and other peridotites of South India are frequently changed in large quantities to magnesite. In another paper reasons are given for ascribing this change to the deep-seated action of carbonic acid and not to subaërial agencies.

the charnockites and the olivine-norite dykes are changed to considerable depths into a red or yellow clay, and yet when the clay is removed and the hard rock revealed, a microscopic section taken from quite close to the weathered surface shows that even such a susceptible mineral as olivine scarcely ever shows any signs of alteration to serpentine (see Nos. 11·350, 11·351, 11·353, 11·356). It seems therefore, that mere subaërial action is insufficient to account for the marked hydration which olivine generally shows in rocks that are not quite recently formed, and the only reason for accounting for the remarkable freshness with which our South Indian rocks have been preserved since lower palæozoic times is based on the fact that they have not been depressed below the sea-level. The action of water would naturally be accentuated by the greatly increased pressure following depression below the sea, and the action of the water itself would be accentuated by the presence in solution of carbonic acid and salts of lime, magnesia aud the alkalies. Except for narrow marginal portions along the coast, we have no evidence of any great changes of level in South India since Cuddapah times, and it is extremely unlikely that the central portions of the Madras Presidency have, since that time, been depressed below the sea-level. Our rocks have, therefore, been exposed in all probability to undisturbed subaërial action for many geological ages. Peridotites occurring in other parts of India — the Andamans, Burma and the North-West Himalayas — which have been submerged below the sea in Tertiary times, are, like the common instances in Europe, largely changed to serpentine, and although there may be some other reason for such hydro-metamorphism, the only apparent difference between Peninsular India and the other areas lies in the circumstance that the former area has not been subject to submarine conditions.

"Trap-shotten" gneiss.

Messrs. King and Foote were the first to recognise this peculiar phenomenon, which is now known in several exposures of the Salem gneisses. On the supposition that the black compact strings and shreds were due to injected basic trap they suggested the name "trap-shotten gneiss[1]."

Microscopic examination of the rocks, however, does not offer evidence in support of this theory, although, judging from macroscopic characters alone, the conclusion is a most natural one. In the first place, the black substance possesses none of the peculiar microscopic structures which characterise "trap" or any substance which has resulted by direct consolidation from thorough fusion; it is on the other hand, composed of a black dust, through which angular fragments of quartz and other transparent minerals are disseminated, and the whole rock is highly crushed, with the production of mylonite and frequent microscopic faulting of the constituents. Very often this brecciation is quite evident in the field and is accompanied by a well-marked "strain-slip" cleavage in the neighbouring rocks. In fact, the phenomenon is essentially a form of brecciation due to dislocation of the rocks along definite lines.

But the production of the strings and tongues of compact, black mylonite is a peculiarity for which I can recall no exact parallel amongst crush phenomena; for the rocks are often acid in composition and that at first makes the black colour of the mylonite a matter of considerable surprise. Careful exmination by the microscope shows that where the quartz crystals have been smashed and granulated, the granular bands often include innumerable minute opaque, black bodies which suggest either sublimation by heat or introduction of material in solution. Herein comes the significance of King and Foote's observation that the so-called trap-shotten phenomena are accompanied occasionally by true trap-dykes. Where trap-dykes are actually associated with this structure it is possible that compounds may have been sublimated into the adjoining breccia; but it is quite certain that the black substance is not a bodily injection of molten material: the black material has essentially the microscopic structure of an indurated dust, never that of a

[1] *Op. cit.*, p. 271.

rock cooled from fusion. Besides, the structure is more often found well beyond the range of any known trap-dyke.

In some cases examination of very thin sections with a one-tenth inch objective reveals the beginnings of an internal crystal organization in the black dust; but they are no more definite than may often be seen in an indurated volcanic ash, and never of the nature of a microlitic igneous matrix. The transparent fragments lying in the black dust have generally the characters of quartz, all traces of the felspars having in general been utterly destroyed. When members of the charnockite series display this "trap-shotten" aspect, microscopic examination of the fragments forming the breccia often shows actinolitic fringes (similar to the so-called "reaction rims") around the hypersthenes, a phenomenon seldom exhibited in the normal rock. Sometimes shallow bays in the quartz crystals are filled with the black dust as if corrosion had commenced. Several such phenomena indicate that the breccia has been highly heated, but nevertheless not to a temperature sufficient to completely fuse the dust. To check this idea experimentally, I crushed a specimen of charnockite and heated the rough powder in a furnace to a white heat, sufficient to produce a very imperfect fusion; the result was a fritted black cake having the lustre of a tachylyte and showing in thin sections a black structureless matrix including angular fragments of quartz; in fact, the fritted charnockite powder very closely resembled the so-called strings of "trap" in these breccia bands.

The mere heating of the charnockite dust—and in this experiment the acid form was used—is thus evidently sufficient to account for the black colour of the mylonite in the breccia without any question of introducing material from without.

The source of the heat which has indurated and blackened the mylonite is then the only question left. The fact that there are numerous instances of these "trap-shotten" bands well beyond the range of intrusive dykes shows that the presence of the latter is not essential; and the perfectly unaltered condition of the rocks in the neighbourhood of the brecciation bands shows that the effects of the heat are not general, but are confined to the bands themselves. These facts narrow the issue to the very natural inference that the heat was produced by the process of brecciation itself, which was probably of a much more violent nature than that which produces the commoner and more general phenomena of dymano-metamorphism.

When such deformities as eye-structure, mortar-structure and peripheral granulation of the constituents result from dynamo-metamorphism, the whole, or a large portion, of the rock mass suffers, and the disturbance being more general, the temperature rises only to a limited degree. There are also good reasons for concluding that a general deformation of all the constituents of a rock indicates a gradual and slow application of the dynamo-metamorphic agencies. In these cases, therefore, where the rock has smashed along a particular band or line, the local rise of temperature resulting from the heat of friction is likely to be excessive; first, because of the limited area to which the disturbance is confined, and secondly, because this gives a *primâ facie* reason for supposing that the disturbance must have been unusually violent.

Briefly, it is concluded that this peculiar phenomenon is the direct result of brecciation, and is not due to actual injection of trap; the black colour and indurated nature of the mylonite (which is outwardly so tachylytic in appearance) are probably the result of the heat produced during the violent brecciation of the rock by which a temperature sufficient to frit the mylonite, but insufficient to melt the rock, was produced.

The geographical distribution of this peculiar breccia and the direction of the bands will probably prove to be of some geological interest; but so far all the cases which have been recorded occur within the district of Salem. Messrs. King and Foote called attention to the fact that the bands often resist the weather more effectually than the surrounding unaltered rocks, and so stand up as well-marked ridges. Besides the case they refer to near Ahtur, a very striking instance is exhibited at about half a mile north-east of Kagankarai in the Tirupatur Taluk, running, like the Ahtur ridge, north-by-east for at least 6 miles. The Kagankarai ridge is very nearly in line with that near Ahtur, and as an example of the breccia is exposed at an intermediate point (south-west of Mankunju hill), further examination along the line should be made. Other examples of the brecciation bands occur near Munakhal and Mallur, 8 miles south of Salem; on the western spur of the Jarugamalais, near the Namakal-Salem road; 3 miles south of the latter place, and further south on the western side of the same road; south of the Gundur spur of the Shevaroys, as well as in the Shevaroy mass itself, 2 miles north of Yercaud. Similar phenomena have recently been observed by Mr. Hayden and myself in the Monghyr district where the mylonised bands are bordered by more pronounced strain-slip cleavage, and the mylonite itself shows less signs of having been raised in temperature; it is hardened but not blackened.

PART II.

ORIGIN OF THE CHARNOCKITE SERIES.

In investigating the origin of the charnockite series one naturally considers first of all those conclusions which have been established for the previously known foreign relatives of the rocks; for what has been established about them will form the first working hypothesis for indicating the lines of most profitable research amongst the Madras occurrences. This part of the paper is consequently devoted, firstly, to a brief discussion of the affinities shown by the charnockite series to foreign types, and secondly, to a summary of the evidences obtained so far by field work in the Madras Presidency.

CHAPTER VII.

Correlation with Foreign Rocks.

(1) *Comparison with the "Pyroxene-granulites."*

The Saxon granulite area.

Rocks of this nature have been found to have a wide distribution as members of the Archæan crystallines, and their mode of origin has formed the subject of much discussion. Naumann[1] considered the Saxon granulites to be eruptive in origin, and J. Lehmann, in his great work *Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine*, brought forward an abundance of evidence to show that the granulites and pyroxene granulites had consolidated like granitic rocks at great depths and assumed their present gneissose structure on account of the pressures caused by ancient sediments; and thus in a modified sense, Lehmann confirmed the conclusion of Naumann. But between the date of the publication of Naumann's papers (which only supported with more detailed evidence the conclusions originally stated by Weiss in the commencement of the century) and the appearance of Lehmann's memoir in 1884, various contradictory views were expressed concerning the Saxon granulites and pyroxene-granulites as well as about the similar rocks in Bohemia, Bavaria, Austria and Scandinavia. In all these cases, however, the pyroxene granulites appear to have been regarded as members of the Archæan crystalline series, and none of them has been found to be intrusive into rocks of undoubtedly sedimentary origin.

Canadian pyroxene-granulites.

Whilst admitting that the evidence is too incomplete to permit a definite conclusion, Adams has described some occurrences of pyroxene-granulites in Canada which suggest their igneous origin.[2] The pyroxene-granulites of the area described by Adams differ

[1] Lehrbuch d. Geognosie, Vol. II, p. 184.

[2] "Report on the Geology of a portion of the Laurentian area lying to the north of the Island of Montreal." *Ann. Rept. Geol. Surv. Canada* (1896), Vol. VIII, Part J.

from those of Saxony chiefly in being a little coarser in grain, and in possessing, as a general rule, a more or less indistinct schistose structure, whilst garnet is less abundant. In these points the Canadian pyroxene-granulites agree with many occurrences in South India. In one case Adams has figured a dyke-like arm protruding into the leaf-gneisses from the pyroxene-granulites, but the arm has been folded up with the gneisses through which it cuts.

Of the numerous other occurrences of pyroxene-granulite, now known in various parts of the world, many have been regarded as probably igneous in origin, purely on account of their mineralogical resemblance to gabbros, norites and other known eruptives; but no direct field evidence has been discovered to prove the true nature of these peculiar rocks.

Lacroix's correlation with French gneisses.

Under the name "pyroxene-gneiss" Lacroix has described a number of specimens which were collected in the Madras Presidency as long ago as 1819 by Leschenault de la Tour. Some of these are evidently identical with members of the charnockite series. On petrological grounds alone they are correlated by Lacroix with the gneisses distinguished by the letter ζ^1 in the geological map of France, and are regarded as older than the associated hornblendic, chloritic and mica schists. At the same time the pyroxenic rocks are looked upon as members of the upper part of the gneissose series. The facts that the specimens described by Lacroix only imperfectly represent the large assemblage of pyroxenic rocks which field observations, as well as microscopic evidence, show to be genetic relatives in the Madras Presidency, and that their localities have been imperfectly recorded without field notes, detract seriously from the geological value of a memoir, which, as a contribution to our knowledge of Madras mineralogy, is highly appreciated by the Geological Survey of India. As nearly as the few data would permit I have attempted to identify the localities of the rocks described by Lacroix, and my researches in the field confirm his conclusion that the pyroxene-granulites are amongst the youngest of the foliated crystalline rocks in South India; their peculiar position amongst the old gneisses is due, however, not to sedimentary superposition, but to intrusion and transgression after the fashion of igneous rocks.

After Ceylon, the nearest foreign relatives of our charnockite series are the few known exposures of pyroxene-granulites on the mainland of Africa and Madagascar. It will be interesting to follow up the comparison of South Indian with African and Malagasy rocks in view of the probable existence of the pre-tertiary Indo-African continent. This stretch of dry land probably had a great crystalline protaxis of which fragments are now preserved in South Africa, Madagascar, Ceylon, Peninsular India and perhaps Assam.

Pyroxene-granulites in Madagascar.

So far as we know from the specimens collected by the Rev. R. Baron, the rocks from Madagascar described by Hatch [1] as "pyroxene-granulites" very closely resemble our Indian charnockite series, and there also they are associated with pyroxenites and quartz-magnetite and quartz-actinolite schists [2] like those of South India. There is no doubt from Mr. Baron's notes that a precise comparison of Madagascar with Peninsular India would bring out some very interesting similarities in many other rocks as well as in these pyroxene-granulites.

(2) *Comparison with ancient Pyroxenic eruptives.*

In none of the numerous extra-Indian occurrences of pyroxene granulites has an undisputed origin been established by direct evidence. But in a few old crystalline areas pyroxenic formations occur which, though formerly regarded as ordinary members of the crystalline schists, are now generally considered to be eruptive, although they are too old to be given a place in the stratigraphical succession. The norites and hyperites of Scandinavia, the anorthosites of Canada, and the Cortlandt series of the United States are well known examples of such rocks.

[1] *Quart. Journ. Geol. Soc.*, Vol. XLV (1889), p. 344.

[2] See R. Baron, "Geological notes of a journey in Madagascar." *Quart. Journ. Geol. Soc.*, Vol. LI (1895), pp. 59 and 60.

Notwithstanding their greater resemblance to the foreign examples distinguished as "pyroxene-granulites" and regarded as ordinary members of the crystalline schists, it is but fair to state that mineralogically the charnockite series often show close affinities to the old pyroxenic eruptives just referred to. In the Cortlandt series, for instance, there are pyroxenites, amphibolites, hornblende, augite and biotite-norites which resemble in composition those of the complex at Pallavaram. G. H. Williams has also recorded the association of hercynite and corundum with the Cortlandt series and these minerals we know too are frequently found in connection with the charnockite series.[1]

The Cortlandt Series.

Williams[2] found similar rocks in the neighbourhood of Baltimore, Maryland, whilst in Pennsylvania, at a point intermediate between the Cortlandt series of Peekskill on the north-east and Baltimore on the south-west. Prof. J. F. Kemp described, from the supposed Archæan strip that crosses Bucks County, a mass of norite containing hypersthene, green monoclinic pyroxene, brown hornblende, garnet, magnetite and apatite. Near this rock occurs a limestone with an abundance of accessory minerals such as light-green pyroxene, titanite, rutile, orthoclase with microperthitic albite, zircon, apatite, pyrite, scapolite and plagioclase. Kemp points out the similarity existing between the minerals occurring at this point and those of the Cortlandt series at Peekskill to the north-east, and again at Baltimore and North Delaware to the south-west. He also points out that these rocks resemble many of those in the Adirondacks where the basic rocks contain titanic ores.[3]

The description of these rocks by Kemp might very well apply to some exposures of the charnockite series in the Madras Presidency, and yet, as he says, they strongly resemble also the eruptives of the Cortlandt series. Cases of this kind show how closely the pyroxene-granulites approach true eruptives in the

[1] See Williams' papers, *Amer. Journ. Sci.*, 3rd Ser., Vol. XXXI (1886), pp. 26-41 Vol. XXXI (1887), pp. 135-144, 191-199 and 243 ; Vol. XXXV (1888), pp. 438-448.

[2] *Bull. U. S. Geol. Surv.*, No. 28 (1886).

[3] *Trans. N. Y. Acad. Sci.*, Vol. XII (1893), p. 71.

peculiarities of composition and mineral associations which they display.

Although there is such a complete correspondence in the mineral lists it is generally not difficult to distinguish a microscopic section of a typical basic pyroxene-granulite from one of these eruptive norites. The most constant of these differences is displayed by the plagioclase-felspars: in the distinctly eruptive norites the twin-bands are sharp and clearly defined, whilst in the pyroxene-granulites the twinning is less definite and the bands show a strange tendency to thin out like wedges instead of traversing the whole crystal. Recently, Dr. Walker and I found an instance in Coorg of a mass of coarse norite, showing these well-twinned felspars, in the midst of a large area of the charnockite series (pyroxene-granulites). It was perfectly easy to distinguish a typical section of the norite from the general style of the charnockite series, but we nevertheless found it quite impossible to discover a boundary between the two formations; for the coarse-grained, massive norite became granulitic and gneissose near what should have been its boundary with the charnockites.

Anorthosites of Canada.

The differences between the typical norite of Coorg and the charnockite series around are just the differences which mark off the anorthosites of Canada from the pyroxene-granulites in the same area; but in Canada the anorthosites make up the main formation and the pyroxene-granulites are comparatively restricted in their development, whilst in Madras matters are reversed and we have but this small exposure of norite to compare with great mountain masses of the charnockite series. I have recently identified a series of anorthosites (labradorite rocks) and norites near the south border of the Raniganj coal-field. The norites are fine-grained and granulitic, sometimes foliated and sometimes showing an occasional garnet. The labradorite rocks are very variable in the size of their crystals; the ferromagnesian constituents which occur in comparatively small quantities, include an occasional olivine with well-defined reaction rims.

Norites of Scandinavia.

Whilst the American anorthosites and norites resemble the basic members of the charnockite series in their mineralogy, a much more striking analogy can be found in Norway, where Vogt [1] has described a group of hypersthenic rocks in which the basic varieties are associated with an acid form composed of potash-felspar, quartz, rhombic pyroxene and a small amount of plagioclase, thus resembling most perfectly our charnockite (*c f.* p. 134). What makes the analogy more complete in all these cases is the similarity of the mineralogical habit, so to speak, of the chemical compound ; thus we never find sphene in the unaltered members of the charnockite series, but the titanic oxide always seems to be in the form of ilmenite, and this is true also of the rocks described by Vogt. These rocks have recently been more fully described by C. F. Kolderup in the Ekersund and Soggendal areas. The types represented vary from the ultra-basic ilmenitite, through pyroxenites, norites, labradorite rocks, monzonites, banatites and adamellites to a bronzite-granite. The resemblance of these to our Madras rocks, which was indicated by Vogt's brief description of them, is brought out more strikingly by Kolderup's details, and by his direct comparison with specimens from Madras.

Reviewing the whole evidence, we must conclude that we are not yet in possession of sufficient facts to define the precise difference between these old norites and the pyroxene-granulites. Most probably they were originally similar formations, which, on account of secondary changes induced in the presumably older pyroxene-granulites, are now distinguishable by differences more easily recognised than described. However, the one important point to be considered by us at present is that between the norites which are certainly eruptive and the pyroxene-granulites whose origin is doubtful there are so many points of resemblance still left that we have good *primâ facie* reasons for expecting evidences which will show that the two groups of rocks are really similar in origin.

[1] *Zeitschr. für. prakt. Geol.*, 1893, p. 4.

CHAPTER VIII.

Petrographical Evidence in South India.

The attempt to settle the origin of the charnockite series by correlation with its foreign equivalents leads, therefore, to results which are not conclusive. In the first place, they present certain similarities to rocks whose eruptive origin is now considered to be established, such, for instance, as the norites and related rocks of Scandinavia, the anorthosites of Canada and the norites of some parts of the United States. In the second place, they present a much more perfect resemblance to the pyroxene-granulites of Saxony, concerning the origin of which very diverse opinions have been published, whilst Lacroix has correctly indicated the resemblance they bear to the French pyroxene-gneisses.

The origin of the charnockite series must consequently be settled purely by evidence obtainable on the spot, and without regard to the results obtained for mineralogically similar foreign rocks. In dealing with a comparatively young and only slightly altered formation, one would naturally look to the local and direct evidence first as the least complicated and most straightforward order of procedure; but with the ancient crystalline rocks, conclusions based on analogy are generally our best, sometimes unfortunately our only, evidence as to origin. The processes of metamorphism tend to reduce the points of difference between rocks of diverse origin, and the consequent tendency for them to become similar to one another is real as well as apparent. Some rocks, like the limestones and sandstones, may successfully resist any changes but those of a purely structural character, and consequently are not difficult to distinguish from rocks of igneous origin; but others, like the shales, and especially the impure shales, may, after metamorphism, imitate igneous types too perfectly to permit safe identification; consequently a large number of the members of the great mass of our crystalline schists may never have their original nature satisfactorily settled. With the many theories which have been propounded to account for all the results of metamorphism, this paper does not profess to deal. The writer wishes merely to point out the evidences upon which he has based his conclusions as to the igneous origin of the charnockite series, and to indicate briefly how far the observations made are reliable data. There seems to be no reason why the knowledge we have acquired as to the properties which distinguish known igneous from unequivocal sedimentary rocks should not be applied to the old Archæan crystallines. That these very ancient rocks present peculiarities not found in any younger metamorphic rock may be true, and, on account of their great age, should be expected. That *all* their original structures have been changed beyond possible recognition may also be true locally; but it is hardly likely (and no approach to proof has been offered) that this destruction of original characters is universal. On the contrary, it is more likely that the rocks we call Archæan have undergone very different degrees of alteration in different areas (some of them thereby retaining relics of original characters), and as long as this likelihood remains undisputed, it will be more scientific to assume that the law of uniformity holds, and that we may profitably apply the experience gained from younger rocks towards the elucidation of the phenomena presented by the old crystalline gneisses and schists. At any rate, such a proceeding has greater claims upon the student of ancient crystalline regions than any single untried sweeping generalization based on a purely speculative assumption as to the origin of these rocks. A recognition of the fact that the Archæan rocks have undergone profound alterations is not necessarily inconsistent with an objection to enveloping such a large fraction of our exposures in an impenetrable mystery beyond the range of our present methods of petrographical research.

The determination of the origin of any particular formation amongst the crystalline schists depends upon (1) the physical form and internal structures recognisable in the field, and, (2) its microscopical and chemical characters.

With younger, undisturbed, igneous masses the field relations of the rocks offer more direct and reliable evidence, whilst with the crystalline schists the field characters are more often destroyed and the question of their origin is then based on their microscopical and chemical resemblances to known igneous types: the argument is thus reduced to mere analogy. With many formations in crystalline areas the microscopical and chemical evidences are all we get or can ever expect; but with the charnockite series we have very straightforward field evidence in favour of their igneous origin, and this circumstance we have to attribute to the remarkable state of quiescence, as well as the uninterrupted and prolonged denudation, which has characterised Peninsular India for many geological ages. On this account it is less surprising to find features presented by the charnockite series which have never been noticed in the case of the pyroxene-granulites and related rocks in other parts of the world, where they have been subjected to repeated and intense dynamic metamorphism, or insufficiently uncovered by denuding agencies.

Field Characters of the Charnockite Series.

The geological features which indicate the igneous origin of the charnockite series may be conveniently classified as follows :—

(*a*) Form and structure of the great *massifs*.

(*b*) The existence of dykes and apophyses proceeding from the main mass through adjoining formations.

(*c*) Contact metamorphism of the surrounding rocks.

(*d*) Inclusions of older foreign rocks and the changes they show.

The first of these four points forms an argument based purely on analogy: we are acquainted with the usual external form and internal structures of known eruptive masses, and the presentation of similar features by the great masses of the charnockite series in South India would be regarded as *primâ facie* evidence in favour of their igneous origin also. The last three considerations, however, are direct tests of origin and include the special phenomena through which our ideas of igneous rocks generally have been derived.

(*a*) *Form and structure of the great massifs.*

Size of the great masses.

The pyroxene-granulites of Saxony occur in the form of bands or lenses, which, compared with the great masses of the charnockite series in South India, are extremely small. The plateau of the Nilgiris covering over 700 square miles is composed almost wholly of this series. The Shevaroy hills, covering 100 square miles, represent another large mass which is extremely uniform in composition throughout, at least quite as uniform as any great igneous *massif*, say of granite or diorite, is ever found to be. Probably still larger masses occur in the Western Ghâts. There is a great difference between masses like these and the small lenses and bands of "pyroxene-granulites" of the better-known occurrences in Europe, where the small bodies more commonly vary from a few inches to a few yards in thickness. The main "granulite formation" of the Saxon Mittelgebirge is a lens some 31 miles long by 11 broad, or covering about half the area of the Nilgiris ; but instead of being a similar uniform body it is a complex including, besides the different varieties of ordinary "granulite," bands of pyroxene-granulite, biotite-gneiss, cordierite-gneiss, garnet-rock, amphibolite, zobtenite and serpentine.

Shape.

These great masses of the charnockite series are either quite irregular in shape or show a roughly lenticular form. In the case of small masses the lenticular shape can often be made out very distinctly. Several small hills of the basic varieties occur around Salem and in the Salem-Ahtúr valley which show this characteristic. In one of these instances, $\frac{3}{4}$ mile E. N. E. of Karipatti in the Salem-Ahtúr valley, a river cuts through the end of one of the lenses, giving a very clear section of the tapering edge of the lens in the highly crushed schists.

Lenticular habit.

As a general rule the rocks immediately bordering these lenses are highly crushed, often crushed beyond all possible recognition of individual minerals, whilst those which form the lenses may show merely a directional disposition of constituents parallel to the long axis of the lens, but otherwise show no signs of having been subjected to exceptional pressure; sometimes, indeed, they are quite massive. Two alternative explanations naturally suggest themselves by these phenomena: either the lenses are bands pinched out by pressure, or they are the result of intrusion between the already foliated schists. In some cases it can be shown quite distinctly that the lenses are not arranged along the same band of the schists; that in fact, they are disposed *en echelon* with their long axes parallel to one another though not in the same line. Such instances are seen to the north of Karipatti, and indicate that the first explanation is probably not applicable to all cases. The second explanation, namely, lenticular intrusions between the schists, is more generally satisfactory. Reyer would probably regard these lenticular masses as *Kuppen*, as he does in the case of the roughly lenticular granulite complex of Saxony.[1]

Homogeneity.

But whether these rocks occur as small lenses, or whether they form the larger boss-like masses, the one important point is the uniformity of average composition and character throughout, an uniformity of the kind with which we are familiar in large bosses of igneous rocks, but of which we have no parallel amongst those of sedimentary origin. Amongst sedimentary rocks our most uniform types are the marine limestones which are formed in the deep sea, where considerable changes of level are required to bring about noticeable variety in the lithological characters of the products. Under the conditions prevailing within short distances of the coastal region small

[1] Theoretische Geologie, 1888, p. 533.

oscillations of level may give us rapid alternations of shales, sandstones conglomerates, marls and carbonaceous deposits, and no amount of metamorphism short of complete fusion could ever produce uniformity of composition throughout such a complex formation of beds.

In old metamorphic rocks like the Dharwars and so-called upper division of the schists, we get beds of quartzites, hornblende-schists, mica-schists, iron-ore beds, conglomeratic schists and crystalline limestones—rocks which form comparatively narrow bands wholly distinct from one another and clearly diverse in origin and in age. There is no equivalent amongst formations like these for a homogeneous mass of rock measuring 15, 20 or 30 miles across the direction of foliation. To regard the enormous thickness of the charnockite series as the result of repeated foldings of one formation would be no help out of the difficulty, but on the contrary would leave us with the still more difficult task of finding the evidences of folding. Traverses across the foliation lines reveal no regularly repeated succession in composition and structure; for the foliation is generally a microscopic structure and the banding seldom continuous for more than a few inches (*infra*, p. 221).

Schlieren structures.

But whilst, like plutonic bosses, the masses of these rocks are uniform in their general average characters over large areas, they are seen on close examination to present precisely the heterogeneity of structure and composition which is characteristic of igneous masses—masses in which there has been sufficient freedom of molecular movement to permit local differentiation of the compounds, or segregative consolidation of the mineral constituents.

Such local departures from the average composition of the rock are spoken of by German geologists as *Schlieren*, a term which for want of an exact equivalent we might profitably borrow. Because the word *Schliere* merely indicates a structural phenomenon without regard to the ultimate cause of its origin, it is likely to convey only its structural meaning, and is therefore preferable to the equivalent expressions *segregations* and *concretions* which are used in various senses. The fact that the word *Schliere* (or its plural *Schlieren* for which form our Anglo-Saxon plurals should prepare us) is a foreign word, will contribute to the preservation of its precise technical meaning, and I would, therefore, propose that it be used in the sense in which it is used in Germany.[1] *Schlieren* may thus be defined, as any portions of a great eruptive mass which show a definite departure, either structural or mineralogical, from the average rock, or main mass; but which nevertheless are connected with, and show their genetic relationship to, the main rock-mass by gradual passage forms. Schlieren are not sharply marked off from the rock in which they occur like inclusions of foreign rocks generally are, but, on the contrary, show under the microscope an interlocking of the constituents across the junction line. Schlieren phenomena may be due to concentration of any portion of the constituents, as in the case of the basic highly hornblendic patches so common in syenites, and the ultra-acid so-called "contemporaneous veins" in the granites; or they may be due to structural departures from the average rock, as for example the glomero-porphyritic patches in some dolerites. In other words, they may be due to variations in *composition* or variations in *structure*. These statements are quite independent of any theories as to the mode of formation of schlieren; whether they are the result of original heterogeneity of the magma, or due to subsequent segregative consolidation, is of no immediate concern to us; the important point for the present is the recognition of the features which show the genetic relationship of the schlieren to the rock in which they are found, and the distinction between them and included fragments of foreign rocks which have been picked up by accident. Both features,

[1] "Eine Schliere ist eine Partie eines Körpers, welche von der übrigen Masse differirt, mit derselben jedoch durch Uebergänge verbunden ist" (Reyer, Theoretische Geologie, p. 81). "Mit dem Namen *Schlieren* bezeichnet man die Erscheinung, dass in einer grösseren Eruptivmasse untergeordnete Partien vorkommen, welche mineralogisch oder structurell beträchtlich von der Hauptmasse abweichen, aber mit ihr durch Uebergänge verbunden sind . . Da sie keine scharfen Grenzen zeigen, sondern ganz allmählich in die Hauptmasse verlaufen, so ergeben sie sich als integrirende Theile der letzteren und dürfen somit durchaus nicht mit fremden eingeschlossenen Bruchstücken verwechselt werden; ihre Bildung hängt auch mit derjenigen der Gesteinsmasse, in welcher sie vorkommen, unmittelbar und untrennbar zusammen" (Zirkel, Petrographie, 1893, I, p. 787).

however, are points of evidence in favour of the igneous origin of the rock-mass; for the included fragment shows that the rock in which it occurs was in a molten condition, whilst the schlieren structures show that the magma must have been in a condition of free molecular movement akin to that of molten material.

When the production of schlieren results in the formation of well-defined bodies included in the normal rock (as, for instance, the dark patches so common in granites), such bodies might conveniently be named *autoliths* in contradistinction to the term *xenoliths* applied by Professor Sollas to picked-up fragments of foreign rocks (*vide infra*, p. 234). Inclusions of rock similar, and perhaps related genetically, to that in which they are included Lacroix proposes to distinguish as *homogeneous* (*enclaves homœogénes*).[1] But the peculiar meaning which we generally attach to the word *homogeneous* prevents our adoption of Lacroix's expression; the term homogeneous applied to a body would to most people (following the usage of mathematicians) imply similarity or uniformity throughout its own parts, not similarity to its neighbours, or the matrix in which it is embedded.

Basic Schlieren.

In the charnockite series a common form of schliere (autolith) appears as a dark-coloured, fine-grained, basic fragment in the ordinary grey rock, which, on microscopic examination, shows the same constituents as the main-mass, but with a smaller proportion of the white (acid) constituents, quartz and felspar. An increase in the proportion of the peculiar green-brown hornblende is an interesting feature very frequently seen in these basic schlieren, interesting because a similar increase of this hornblende always characterises the border facies of the basic types in this series, the selvages of the Coorg dykes for instance (p. 228). Like the border forms, these basic schlieren are thus products of the earlier stages of consolidation (see Nos. 11·910, 11·911, 11·917).

[1] Lacroix, "Les enclaves des roches volcaniques, 1893."

In some of the basic types, the norites, we come across lenses or bands from which all felspar has been excluded, and the rock is composed of augite, hypersthene and hornblende, with sometimes small quantities of olivine, iron-ores and green spinel (Nos. 11·891, 11·904). But in all these cases microscopic sections across the junction of the ultra-basic schliere and the less basic main-mass show no sharp line of division (specimen 9·667).

Primary eruptive breccia.

The early-formed basic material may be broken into by the residual magma and divided into angular fragments, which, cemented by the more acid subsequently intruded magma, give the rock the appearance of a breccia—the *Primärbreccia* of Sederholm and *Primärtrümer* of Lossen. Sometimes we merely meet with isolated fragments of the basic rock floating in the general main-mass; at other times the fragments of basic rock are separated by thin films of the acid variety, and at other times again an exposure may show about equal quantities of the basic fragments and more acid cement.

The late Prof. G. H. Williams proposed to use the term *protoclastic structure* for these phenomena.[1] This term has, however, been used in a slightly different sense by Brögger for describing the elæolite-syenite of South Norway, in which the mineral constituents have sometimes been crushed and broken by movement during the process of consolidation, the granulation being often accompanied by foliation and the production of eye-structure (*primäre Augenstructur*). The use of the term *primary breccia*, or more fully *primary eruptive breccia*, in imitation of Lossen and Sederholm, instead of the term protoclastic structure, will thus reduce the chances of confusion, and at the same time clearly express the nature of the phenomenon under consideration. A

[1] Fifteenth Ann. Rep., U. S. Geol. Surv., 1893-94, p. 662. "We know......that basic secretions are a common feature of slowly solidifying granitic magmas, while a partially solidified portion of such a mass may be broken into and brecciated by a subsequent intrusion of the residual magma, whose composition has slightly changed, thus producing a sort of protoclastic structure" ("Criteria for the recognition of ancient plutonic rocks in highly metamorphosed terranes", G. H. Williams).

very pretty example of this primary breccia is shown near the boat house on the shore of the Ootacamund lake in the Nilgiri hills.

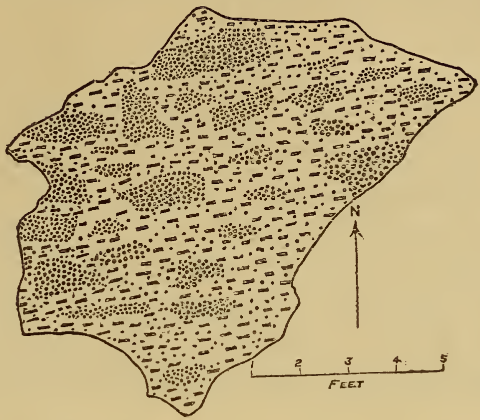

FIG. 7.—*Primary breccia: plan of exposure near the lake, Ootacamund.*

In a small exposure which has been blasted for the road cutting, some scores of angular fragments of dark-coloured, basic, fine-grained rock are seen to lie in a matrix of lighter-coloured, more quartzose and coarser charnockite. There is a fairly distinct linear disposition of the acid rock, whilst the basic fragments have their long axes also arranged, stream-fashion, parallel to the general flow (fig. 7). Although at a distance the dark fragments are plainly distinguished from the more acid matrix, close examination increases the difficulty of determining the exact line of separation of one type from the other, whilst microscopic sections show a perfectly gradual, though rapid, transition between the two. This is a constant and an essential feature in these primary eruptive breccias and is shown equally well by the junction-lines between isolated schlieren (autoliths) and the normal rock in which they lie.

Acid "contemporaneous veins."

Besides these basic autoliths, which are in general the products of an early stage in the processes of consolidation, almost every mass of the charnockite series shows instances of the acid schlieren, which generally take the form of veins, and represent, as in our ordinary eruptives, the consolidation of the more siliceous residual portions of the magma. The old Cornish geologists described these as "contemporaneous veins" to distinguish them from "true veins" which were either distinct subsequent intrusions, dyke-fashion, or valuable mineral lodes filling fissures formed in the previously consolidated rock. These "contemporaneous" veins are the *hysterogenetic Schlieren* of Zirkel,[1] and the special form of *Schlierengänge* which Reyer distinguishes as *Secret-Gänge* or *Secret-Blätter*.[2] The essential point expressed by these terms is the genetic relationship between the acid vein and the rock it cuts, and it was this idea which led to the subsequent replacement of the expression "contemporaneous veins" by "segregation veins," a term which Boase says was introduced by Professor Sedgwick at the suggestion of Whewell.[3]

In the charnockite series these contemporaneous, or segregation veins are, in common with those well-known in plutonic masses, usually coarser in grain as well as more acid than the main rock mass which they traverse. Very clear instances are seen in the small hill on the west side of St. Thomas' Mount, Madras, where coarse-grained veins are seen cutting through the type-mass of charnockite (p. 145). The contemporaneous veins only differ from the charnockite in which they occur by this coarseness of grain and the almost complete absence of the ferro-magnesian silicate, hypersthene, which characterises the charnockite. The quartz is the same peculiar blue-grey quartz, and the felspar is the same kind of blue-grey microcline, whilst granules of iron-ore occur in both the charnockite and the slightly more acid contemporaneous veins

[1] Lehrbuch der Petrographie, 2nd Ed., 1893, p. 791.

[2] Theoretische Geologie, 1888, p. 101. The term *Blätter* so often used by Reyer instead of *Gange* expresses more precisely the form of these bodies which we habitually call "veins" because of the vein-like aspect of their outcrops on any surface. In the same way we speak of *lenses* because of the lenticular shape of the sections of bodies which are often limited by cylindrical, not spheroidal, surfaces. This additional precision is, however, of little value as long as no confusion is caused by the use of the term "vein".

[3] H. S. Boase.—"A treatise on Primary Geology," London, 1834, p. 355; Sedgwick, *Phil. Mag.*, Vol. IX, p. 284.

Professor H. Louis adopts this old view of the term "segregation" in his classification of ore deposits in the 2nd Edition of Phillips' "Treatise" (1896, p. 11, foot-note).

(Nos. 9·658 and 9·659).[1] As usual with schlieren these veins, although quite distinctly shown on weathered surfaces, are so closely united with the fine-grained charnockite that the junction line loses its sharpness in microscopic sections.

The phenomena of contemporaneous or segregation veins is not confined to the non-garnetiferous varieties. In the Nilgiris where the charnockite series are so often garnetiferous, the coarse-grained veins, composed of quartz, felspar and well schillerized hypersthenes, also include fine well crystallized garnets often as large as walnuts. A good instance is shown by a mass of rock exposed behind Oaklands, Ootacamund, and several more were revealed by blasting below Oaklands.

Schlieren phenomena are thus of two principal kinds—isolated *autoliths* which are generally more basic than the normal rock they lie in, and *contemporaneous veins* which are generally more acid than the ordinary rock they traverse.

Deformation of Schlieren and the origin of banding.

Directly connected with the schlieren phenomena, but of a special kind, is the banding so often, or rather generally, exhibited by the charnockite series. It is very seldom indeed that the bands can be traced for any considerable distance; they are, more strictly speaking, highly distorted, drawn-out lenses which give the weathered surfaces of the rocks a streaky appearance. The slight differences of composition between adjoining streaks give rise to different powers of resistance to the action of atmospheric agents, with the result that the so-called banding is always especially noticeable on weathered surfaces; indeed, it (and the foliation) is often not recognisable at all in fresh hand-specimens. As in the case of the ordinary schlieren, it is impossible under the microscope to find a sharp junction line between the dark-coloured and light-coloured bands. I believe the banding to be due merely to distortion of the imperfectly formed schlieren by flow of the magma during the process of consolidation,

[1] I have often noticed in these rocks that the highly quartzose contemporaneous veins also contain considerable quantities of iron-ore which is sometimes titaniferous. A conspicuous instance is exposed near the "Castle," Yercaud, Shevaroy Hills. It is not at all uncommon to meet with instances which show that the iron-ore is reserved for the final stages of consolidation.

and thus comparable to the banding which often characterises rhyolites in which patches of crystallites, or of coloured material, are drawn out to thin streaks by distortion of the viscous lava along one prevalent plane, the plane along which the lava flows and which is at right angles to the direction of the maximum pressure ; that is, in the case of the rhyolitic lava, at right angles to the direction of gravity which produces the flow.

Whether the magma became "schlierig" by molecular differentiation *before* crystallization commenced, or whether it was the outcome of segregation *during* the processes of consolidation, is a matter of secondary concern as long as it is understood that the distortion occurred before the rock was sufficiently solid to show crush structures.[1] It is important to keep this point in mind because, whilst this kind of banding is more generally due to the mere distortion in one direction of a "schlierig" magma, there is another form of banding of a much more perfect kind, which, in some cases at least, is due to *lit-par-lit* injection (*infra*, p. 223).

This imperfect, discontinuous, lenticular kind of banding is a strong argument in itself against the idea that the banding in these rocks represents relics of an original sedimentary structure,[2] whilst

[1] Apparently, from the illustrations he employs, Reyer thinks that the "schlierig" character of a magma is developed whilst it is still in the molten condition : "Nur selten sind grössere Massen eines Körpers wirklich homogen ; bei der Auflösung eines Salzes treten verschieden concentrirte Partien der Salzlösung als Schlieren nebeneinander auf, welche sich durch verschiedenen Salzgehalt, spez. Gewicht, Lichtbrechung, etc., unterscheiden. Das Meer ist schlierig ; es besteht aus verschieden concentrirten und verschieden warmen Wassermassen ; die Luft ist schlierig, weil sie partienweise verschieden mit Wasserdampf, Staub, etc., vermischt ist ; schlecht gemischter Teig, Lava-massen, Granite sind gleichfalls schlierig ; kurz wohin wir blicken, die Liquida, sowie die festen Korper sind ungleich gemischt, sie waren seit jeher schlierig" (Theoretische Geologie, p. 81).

[2] That the banding of the gneisses has any necessary connection with original sedimentation is probably held now by very few geologists ; but the idea, promulgated by the genius of Lyell, naturally dies hard, and probably still influences, if unconsciously, our forms of expression. It is not rare to find, for instance, that the unconformity of the transition schists is said to be shown by their beds being found to overlap "the upturned edges of the gneiss". To those who regard the old gneisses as "portions of the primeval crust of the globe, traces of the surface that first congealed upon the molten nucleus", or who hold any such sweeping, but necessarily speculative, theory, the banding (bedding) of the gneisses may convey a concrete meaning ; but it is probably more profitable to work out each gneissose formation for itself, and then to draw the simple inferences which are usually permitted for similar phenomena presented by rocks whose characters are better understood and which permit of safe deductions. There seems no adequate reason, so far, for excluding the old gneisses to the limbo of the mysterious.

the notion that it is due to mere distortion of schlieren structures by movement akin to flow, is a much simpler explanation and one which has many parallels amongst rocks whose characters are better understood.

That banding of a kind indistinguishable from that exhibited by the gneisses occurs in undoubted eruptives is shown by the striking instances occurring in the tertiary basic igneous rocks of West Scotland. On account of the resemblance of these banded rocks to some of the old gneisses and pyroxene-granulites of the adjoining areas, they were at one time considered to be portions of the old Archæan complex; but Sir A. Geikie and Mr. Teall have shown that the rocks are merely local modifications of the well known tertiary gabbros.[1] After considering two explanations, namely, differentiation *in situ* and successive intrusions, Geikie and Teall concluded that the banded structure of these gabbros is the result of the intrusion of a heterogeneous, that is, as Reyer would say, of a "schlierig," magma.

Lit-par-lit injection.

That banding may be produced, however, in some cases by successive injection is shown by the gneisses in the neighbourhood of Tirrupur, Coimbatore District. But in these rocks the banding is of a much more definite nature than that usually exhibited by the charnockite series. Although they present the essential features of the charnockite series, the rocks in the neighbourhood of Tirrupur contain an unusual amount of hornblende, and the non-felspathic forms might almost be described as hornblende-rocks. The latter occur as numerous, narrow, well-defined bands, separating the basic or intermediate felspathic forms, and giving the whole rock an extremely distinct banded structure, with a constant W.-N.-W.—E.-S.-E. strike. When the black hornblende bands, however, are carefully followed, they are found to run with the general foliation for some distance, then suddenly break across the folia and again continue their original direction, though in a different line. In a few cases the

[1] *Quart. Journ. Geol. Soc.*, Vol. L (1894), pp. 645-659.

black bands were found to bifurcate and so form two distinct bands. Both instances are shown in plate IX. Although there is no question about the fact that the hornblende rock is a distinct injection along the foliation planes of the gneiss, it never shows a chilled selvage; but on the contrary its crystals, though slightly coarser in grain than the otherwise similar hornblende of the gneiss, interlock across the junction after the manner of the schlieren already described. The hornblende bands and hornblendic gneiss which they traverse are, from the character of their constituents, clearly relatives and derived from the same magma, and the former must have been injected whilst the latter was still hot. A somewhat similar relation between the pyroxenite and norite has been observed at Pallavaram and elsewhere; but the Tirrupur case is quite the most striking instance I have seen showing that banding may be produced by successive injection of slightly different, but genetically related, rocks.

(*b*) *Apophyses and Dykes.*

Destruction of evidence.

As a general rule attempts to recognise apophyses and dykes proceeding from any large massive constituent of the crystalline schists will be attended with failure, for the very good reason that any dykes or veins originally existing will generally be squeezed out to form apparently independent parallel bands or lenticular masses without determinable connection with the main formation. The deformation of a series of radiating veins by pressure exerted in a direction at right angles to the general foliation will thus increase the resemblance to the common banding of gneisses. Moreover, there is a natural tendency for an intrusive rock to follow the cleavage and foliation planes, which is the direction of least resistance (*vide supra*, p. 223 and plate IX).

Fortunately the charnockite series appeared in South India after the close of the most severe earth-movements, and the original vein and dyke structures have not been wholly obliterated by the subsequent, feebler dynamo-metamorphism.

Transgressive tongues.

Important light is thrown on the nature of this series by a section exposed near the Namakkal road, $3\frac{1}{2}$ miles south of the town of Salem. The quarry in which this section is exposed occurs at the junction of the charnockite series, which forms the great mass of the Jarugamalais lying to the east, and the old biotite-gneisses which stretch away to the west and crop up at intervals in the well cultivated plain. On the freshly exposed rock surface, tongues of the charnockite series, proceeding from the direction of the great Jaruga hill mass, are seen to protrude into the biotite-gneiss, running obliquely to the foliation planes of the latter. The charnockite forming these tongues is slightly more basic than the ordinary "intermediate" form, having a specific gravity of 2·80. The biotite-gneiss contains much quartz and is distinctly more acid in composition. In petrological characters, also, the two rocks are quite distinct: the charnockite is a compact, blue-grey, fresh-looking rock, whilst the biotite-gneiss is mottled by patches of a dark-green micaceous mineral lying in dirty-white felspar and pale-blue quartz, with, frequently, lumps of pyrite. Under the microscope the charnockite is found to be composed of hypersthene, pale blue-green augite, felspar and a little quartz with lumps of magnetite—all showing a type of rock quite common amongst the charnockite series, and displaying practically no signs whatever of dynamo-metamorphism. The biotite-gneiss, on the other hand, is not only highly crushed, but its minerals all show signs of alteration of a kind not seldom found in definite contact cases: epidote and muscovite are formed in the felspars, pyrite and rutile are fairly abundant, whilst the ferromagnesian silicates have completely lost their individuality, being replaced by an indeterminate felsitic product, patches of which are surrounded by a radiate fringe of green micaceous and hornblendic minerals, now far gone in the processes of chloritization.

If these two rock-masses, the biotite-gneiss and the charnockite, merely existed as adjacent formations, it is possible that one of them might suffer dynamo-metamorphism without noticeable alteration of its neighbour; but when thin tongues of the two are so completely dove-tailed, it is difficult to see how the charnockite could escape the metamorphism which has been so evidently disastrous to the tongues of the gneiss. The most straightforward inference to be drawn is, it seems to me, that the charnockite attained its present position *after* the crushing of the gneiss, that, in fact, it has trespassed across the foliation planes of the latter. This implies that the charnockite has behaved after the fashion of an igneous rock, and that it is younger than this particular biotite-gneiss near Salem.

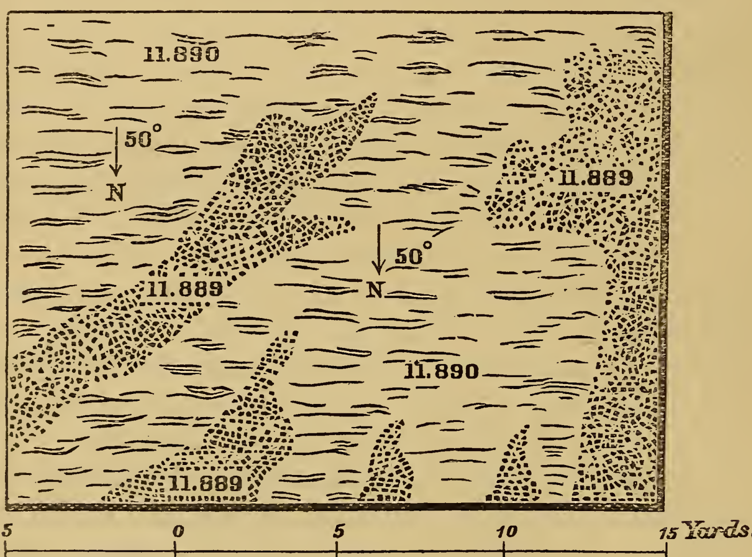

FIG. 8.—*Plan showing tongues of unaltered charnockite (11·889) corroding crushed biotite-gneiss 11·890, 3½ miles S. of Salem.*

So far the evidence is simple enough; but there are other points which must be taken into consideration:—Whilst the tongues of charnockite are easily, at a glance, distinguished from the gneiss they protrude into, close examination of the junctions show that, instead of there being a sharp line between the two rocks, there is a very rapid, though gradual, transition from one to the other. Besides this, dark patches occur in the charnockite parallel to the dark patches of micaceous mineral which in the biotite-gneiss indicates its foliation. The charnockite veins look, therefore, as if they were pseudomorphs very imperfectly retaining the structures of the rock they have corroded and replaced. Although, therefore, there is little doubt about the charnockite having trespassed on the gneiss after its consolidation and crushing, the precise nature of this trespass is less easily defined: the interlocking of constituents at the junction-line, the absence of chilled selvages in the charnockite, the imperfect pseudomorphism of the banded structures are points which distinguish this "trespass" of the charnockite from the more usual kind of simple intrusion of one rock along fissures in an older neighbour. The tongues of charnockite, however, radiate from a large mass of the same rock and enter the gneiss without regard to the direction of the foliation planes in the latter. As I can recall no other case precisely similar to the one now described, we have no previous experience to guide us to a safe interpretation of the facts; and the only explanation I can offer is that the intrusion occurred at great depths when the biotite-gneiss, being also at a high temperature, became corroded by the molten charnockite. Another explanation might be offered by those who hold ultra-metamorphic ideas, namely, local alteration and refusion of the biotite-gneiss. In view however, of the fact that the two rocks are totally different in mineralogical and chemical composition, this alternative theory seems to be unnecessary and less likely; besides, the way in which the tongues proceed from the large adjoining mass of charnockite, and the clear marks of contact action impressed on the old biotite gneiss[1] indicate that there has been a distinct trespass by the charnockite, although the action is not precisely of the kind we are

[1] A gneiss extremely like this biotite-gneiss occurs as pebbles in the Dharwar conglomerates of the Kolar gold-field. This indicates that the gneiss is older than that stage of the Dharwars. When we know more about these conglomerates it is likely that some valuable negative evidence will be obtained; for I feel very much inclined to believe that, among the rocks which we have grouped together as Archæan gneisses, there are formations very widely differing in age, and careful work should enable us to discriminate between older and younger, between sedimentary and igneous.

more accustomed to deal with when an igneous magma intrudes into a cold rock and reveals the fact by showing chilled selvages.

Dykes with chilled selvages.

The conclusions as to the igneous origin and intrusive habit of the charnockite series, based on the rather slender evidence of these trespassing protrusions in the neighbourhood of Salem, receive very material support from observations which, in company with my colleague Dr. T. L. Walker, I have recently made in the province of Coorg, on the eastern slopes of the Western Ghât range, where actual chilled selvages have been observed in dykes of rocks belonging to the charnockite series.

In the north-eastern portion of Coorg the fundamental rocks are banded, crushed and well foliated gneisses, chiefly biotite-gneisses. Between Somwarpet and Jambur the chief rocks are, however, members of the charnockite series, forming apparently a great mass which is fringed on the south-west and on the north-east sides by bands of the same series. Although these bands are sharply defined, they run parallel to the foliation of the biotite-gneiss in which they lie, and on this account are easily distinguished at once from the younger systems of basic dykes which cut the gneisses without regard to the foliation. On account of the constant way in which these dark bands follow the foliation of the gneisses, I at first regarded them as further instances of the puzzling, but common, cases of interbanding so often observed in the old gneisses; at the same time their compact nature and jointed condition give them very much the appearance of basic trap dykes. Under the microscope they were seen to be composed of the typical constituents of the charnockite series, and were often found to be garnetiferous, and to possess a granulitic structure with the peculiar water-clear, but badly twinned, plagioclase which seems to characterise the members of this series. Subsequently, in a well exposed section of some four or five of these bands cutting through the biotite-gneiss in the bed of the Cauvery river, Dr. Walker detected the compact nature of their selvages. Microscopic examination of these selvages showed them to be finer in grain, more basic and more hornblendic than the central portions of the bands, and similar phenomena were subsequently carefully examined and confirmed in other bands near Somwarpet on the north-eastern fringe of the main mass of the charnockite series (Nos. 12·395—12·405).

Although the selvages are not now glassy, or even felsitic, and one would hardly expect them to be so after such an enormous lapse of time, they are distinctly more compact and contain less of the white constituents than the central portions of the bands. Like the chilled selvages of ordinary dykes, too, the transition from the compact to the ordinary form is very rapid, and there is no noticeable difference between specimens taken a few inches from the selvage and those taken near the centre of a 15-foot band. The increase in the quantity of hornblende at the margins is a common characteristic of the border facies of the norite family, with which these dykes—as they must now be considered to be—are closely related in chemical and mineral composition.

Some dozens of these dykes may be counted between Somwarpet and a few miles west of Fraserpet, and four or five of them, which are sufficiently exposed, show the chilled selvages most distinctly. Those which are exposed so well in the bed of the Cauvery river at Fraserpet are found to vary considerably in thickness as they are traced in the south-east direction across the river, but no constant average diminution in either the north-west or south-east direction could be definitely determined in the short distance of about ¼ mile for which they are exposed in the river bed. One of them, which measured 2 feet 8 inches in width on the left bank, diminished rapidly near the centre of the river to less than a foot, but as quickly widened out again before the right bank was reached. Similar, but not constant, variations were noticed in the larger parallel dykes. From the size of the small one just referred to these dykes may vary up to 100 yards or more in width.

Garnets are found in most of them; sometimes concentrated in patches of indefinite outlines, at other times arranged along lines or scattered through the rock as isolated granules. The remaining constituents of the rock are characteristic for the basic members of the charnockite series: green-brown hornblende, pale blue-green augite, hypersthene, water-clear felspar with very undecided twin bands, and iron-ores. The structure is granulitic almost invariably, but the rocks are finer in grain than the average massive form of the charnockite series; the difference in grain, however, is just the same in degree and kind as we should expect to find between, say, a large stock of gabbro and a dyke of its corresponding diabase.

Here then we have a rock which shows its intrusive, igneous origin as plainly as any diabase dyke ever does, and yet in composition and structure it shows all the essential points of the charnockite series. The instances examined are sufficiently numerous to show that we are not dealing with a merely local accident in describing what is considered to be the chilled selvages of these dykes. No one probably would be rash enough to assert that all the pyroxene-granulites we know belong to one formation, one petrographical province, but here we have rocks unquestionably igneous in origin yet similar in all essential respects to the adjacent typical pyroxene-granulites (charnockite series). With, therefore, as good ground as we usually get in petrography it is safe to accept this as a corroboration of the other evidences which point to the igneous origin and intrusive behaviour of the charnockite series.

(*c*) *Contact metamorphism.*

Imperfection of evidence.

The recognition of distinct contact zones amongst the old crystalline rocks, will, from the nature of the case, be always extremely difficult. In the first place, rocks already crystalline are seldom susceptible to the action of an invading igneous mass, and, secondly, subsequent metamorphosing agencies would obliterate the results of contact action in the oldest rocks. The difficulty of distinguishing between the results of the old contact and the subsequent metamorphism will always, of course, make the discrimination of these phenomena amongst the crystalline schists a doubtful matter.

In the case of the charnockite series the evidence of distinct contact action is extremely limited. There is the case of alteration of the old biotite-gneiss near its contact with the charnockite tongues in the neighbourhood of Salem (p. 226). This might be considered the result of contact action if we had first established the intrusive character of the charnockite; but in itself it is insufficient proof.

Altered forms of the Mercara series.

In Coorg we have perhaps more satisfactory evidence. The Western Ghât range is composed of the charnockite series which march for some thirty miles with a group of schists and gneisses distinguished as the Mercara series. The Mercara series includes a very complex succession of highly metamorphosed rocks, many of which, judging from their composition, are almost certainly altered argillaceous sediments, whilst others, quartzites for instance, are probably altered sandstones Bands of "greenstones" are fairly common in the Mercara series and probably represent original dykes, sheets, or flows of diabase. The point of immediate importance to us, however, is the very composite nature of the Mercara series, which indicates that its constituents represent a variety of origins although they are grouped together as one formation for stratigraphical purposes. The adjoining large formation of the charnockite series, on the other hand, presents no greater variations than are usually met with in a great intrusive "stock."

The zone separating these two series of rocks has, therefore, more probably derived its "contact" features by the action of the charnockite on the Mercara series than the converse. Every continuous section across the junction of the two shows the peculiar rocks which characterise the zone of contact; and although on a small-scale map the junction would be represented by a sharp line, it is impossible to define in the field the exact point which would separate the endogenous from the exogenous phenomena. Besides the graphite, sillimanite (or kyanite) which might have been formed by any metamorphic agency, this zone is characterised by the abundance of a peculiar purple garnet which is also found in other less doubtful cases of contact action as, for instance, when the Mercara series is altered by the great granite stock which protrudes through it in the central portions of Coorg.

Although, naturally, the testimony of these cases of apparent contact action would be insufficient in themselves to prove the igneous nature of the charnockite series, their value is accentuated by their agreement with the other evidences.

As the charnockite series never comes into contact with unaltered sedimentary rocks, but is always bordered by rocks already crystalline, contact phenomena are naturally rare ; the chances of studying such instances as do actually exist are still more reduced by the frequency, almost constancy, with which the junction lines are hidden by detrital material or the thick jungle which invariably clothes the foot regions of the charnockite hill-masses in South India.

Scapolitic granulites and calciphyres.

The frequent association of the charnockite series with scapolitic rocks and with the crystalline limestones, cipolins and calciphyres containing an abundance of accessory minerals, would naturally call for a place in this discussion of contact phenomena ; but the field evidence bearing on the relation of these rocks to the charnockite series is altogether too imperfect to settle the question as to whether the crystalline limestones have developed their accessory minerals as part of the metamorphism of ancient sedimentary limestones, or whether they are the extreme results of alteration in the pyroxenic rocks themselves.

That this association is accidental is in the highest degree improbable, for the scapolitic rocks, cipolins and calciphyres are found associated with the pyroxene-granulites in many parts of the world.[1] One's first impulse is to regard the accessory minerals in the limestones as exogenous contact phenomena and the scapolites, anorthites, lime-augites and sphenes in their pyroxenic neigh-

[1] *Cf.* Lacroix, *Rec. Geol. Surv. Ind.*, Vol. XXIV, pp. 157 and 199.

bours as the results of endogenous contact action, due to the absorption of lime from the calcareous rocks which have become invaded ; but the field observations are of too fragmentary a nature so far, to permit safe criticism of this point. And unfortunately for this apparently simple conclusion the elaborate study by Professor Judd of the similar rocks in Burma has led to results which rather indicate that the calciphyres are the results of extreme alteration of the pyroxenic rocks, the formation of the scapolite being merely a stage in the process. Professor Judd is, at the same time, inclined to consider the pyroxene-granulites, which are associated with, and possibly in part changed to, the scapolitic and crystalline limestones, to be of igneous origin.[1]

Although, therefore, the results obtained by Professor Judd necessitate the exclusion of these scapolitic rocks and crystalline limestones from the category of contact products until the field relations for each particular occurrence have been studied in detail, they are not antagonistic to the arguments here advanced in favour of the igneous origin of charnockite series.

The phenomena which we can safely regard as unequivocal contact effects caused by intrusion of the charnockite series are thus very meagre ; but it is very interesting to notice that few as they are they are remarkably similar to contact phenomena produced by the intrusion of pyroxenic rocks whose igneous nature is now disputed by no one.

In the case of the Cortlandt series, for example, the late G. H. Williams has traced out the action of the norites and related diorites on the associated crystalline schists. The intrusive rocks grouped together in this area cover some 25 square miles, and are surrounded by different crystalline rocks—gneiss on the north, limestone on the west and mica schist to the south. The gneisses are not noticeably affected at the contact ; but the mica schists and limestones are strikingly altered. The contact phenomena are of an endogenous (inverse) as well as of an exogenous (everse) kind. In the case of the

[1] "The Rubies of Burma and associated minerals," *Phil. Trans.*, Vol. 187 (1896), p. 151.

mica schist the quartzose lenses with garnet and other contact minerals, staurolite, kyanite and sillimanite, are developed as the intrusive rock is approached. At the immediate contact, the rocks become felspathic and their structure changes to a harder, more massive form. The eruptive rocks take on alumina and lime with simultaneous loss of silica and alkalies to the schists, and develope garnets, scapolite and other reaction minerals. The limestones become bleached and develope hornblende and pyroxene, whilst the invading rocks become simultaneously more calcareous, and the rhombic ferromagnesian pyroxene, hypersthene, is replaced by the monoclinic lime-bearing diallage.[1]

(*d*) *Included fragments of foreign rocks.*

The tendency for fragments of foreign rocks to lose their individuality by contact metamorphism when immersed in a plutonic mass becomes accentuated when the latter suffers subsequent metamorphism itself. In all attempts to prove the igneous nature of any formation amongst the crystalline schists it is consequently only natural to expect that evidence on this score will be comparatively difficult to obtain. But there are cases of bodies included in the charnockite series which I should consider to belong to this category, and the ellipsoidal masses of corundum-bearing rock found within, but near, the border of the charnockite series in the Salem District are probably examples.[2]

[1] Williams' papers on the Cortlandt series, appeared in the *Amer. Journ. Sci.*, Vol. XXXI (1886), pp. 26—41; Vol. XXXIII (1887), pp. 135—144 and 191—199; XXXV (1888), 438—448. The references made to them here are not intended to imply that the charnockite series are strictly comparable to the Cortlandt series; but the comparison of phenomena presented by known eruptives should guide us to an interpretation of those which characterise mineralogically similar rocks whose origin is under investigation. In many points the mineralogy of the charnockite series presents close analogies to that of the rocks which have been worked out so exhaustively by Williams in the Cortlandt area.

[2] These corundum-bearing bodies have been described by Mr. Middlemiss as lenticles, but the word ellipsoid is more accurate and indicates an essential difference in meaning. Lenses are eye-shaped in section; that is, they have pointed ends, and inclusions of this shape, which are so common in the gneisses, are regarded as drawn-out schlieren or pinched-out bands; but the rounded ends of these corundum-bearing inclusions and the peripheral concentration of biotite indicate corrosion and reaction with the surrounding rocks.

Similar bodies, with fine ruby-red corundum, have recently been found near the margin of the Bargur charnockite mass at Badavadi in the Mysore State (11°50; 77°6′).

Xenoliths and schlieren (autoliths).

A distinction must of course be drawn between inclusions of older foreign rocks which bear no family resemblance to the rocks by which they have been picked up, and the schlieren (generally basic) which are formed by segregative processes during the consolidation of the rock, and which always present some signs of relationship to the rock in which they appear to be included. It is with the former bodies, *xenoliths*, as Sollas[1] aptly calls them, that we have to deal with now; the others are discussed on another page (217).

Corundiferous xenoliths.

These corundiferous bodies were originally described by Middlemiss as local modifications of the "biotite gneiss" in which they are included.[2] Subsequently the same author mentioned the hypersthene which occurs with the biotite in this gneiss, and then so far modified his previous nomenclature as to regard the rock as a passage form between the ordinary charnockite series and the Hosur biotite-gneiss.[3] In another section of this memoir I have given my reasons for concluding that the rock in which these corundiferous bodies occur is in no genetic sense related to the Hosur biotite-gneiss, but is a normal member of the charnockite series, the prevalent form belonging to the "intermediate" type.

The ellipsoidal bodies are not, in my opinion, the results of mere re-arrangement and alteration of the minerals composing the rock in which they occur, but on the contrary are composed of totally distinct minerals, possess an altogether foreign structure

[1] *Trans. Roy. Ir. Acad.*, Vol. XXX (1894), p. 493. Inclusions of rocks similar, and perhaps related genetically to the rock in which they are included, Lacroix proposes to distinguish as *homogeneous* (*Enclaves homœogenes*); but the peculiar meaning we generally attach to *homogeneous* prevents our adoption of Lacroix's expression. The word *autolith*, in contradistinction to *xenolith* would have been a better term than *homogeneous inclusion*.

[2] *Rec. Geol. Sur. Ind.*, Vol. XXIX (1896), p. 44.

[3] *Ibid.*, Vol. XXX (1897), p. 119.

and are almost certainly altered inclusions of some foreign rock. The most abundant constituent of these inclusions is a microperthitic or cryptoperthitic felspar with which is associated a series of typical "contact" minerals—corundum, sillimanite, rutile and green spinel (pleonaste or hercynite). At the periphery of each of these inclusions there is generally a concentration of biotite, flakes of which exist in smaller quantities also in the charnockite around. The corundum forms larger crystals than any of the other constituents of these xenoliths; they have an elongated barrel-shape, about three times as long as they are broad, and vary in size from crystals 6 or 7 inches long down to microscopic granules. Each large corundum crystal is surrounded by a distinct crystallization "court" of granular felspar, slightly coarser in grain than the rest of the matrix, and practically free of the other accessory minerals. The felspars of the xenoliths are perfectly granulitic in structure, the granules being crossed by streams of sillimanite needles, which, as usual, disregard the crystal-boundaries of their host and strike across the boundary lines from one granule to another. The charnockites in which these inclusions occur are well foliated, and the long axes of the ellipsoids are arranged approximately parallel to the foliation. The concentration of biotite around the periphery of each corundiferous xenolith is probably the result of reaction between the charnockite and the foreign rock.

I can recall no cases exactly parallel to these remarkable corundiferous xenoliths. Corundum, sillimanite, green spinel and rutile have frequently been found in foreign fragments enclosed in volcanic rocks, and in most cases they are regarded with good reason as the results of contact-metamorphism.[1] But it is of course inadmissible to compare the metamorphism of inclusions in a volcanic rock with the effects produced on fragments caught up in plu-

[1] See Lacroix: "Les enclaves des roches volcaniques," 1893; and Lagorio: "Pyrogene Korund, dessen Verbreitung und Herkunft." *Zeitsc r. fur. Kryst*, Vol. XXIV (1895), pp. 285—299.

tonic masses. For the time, therefore, these corundiferous bodies must be looked upon as doubtfully, though for theoretical reasons, probably, foreign material enclosed in and metamorphosed by the charnockites. Their position near the margin of the large charnockite masses also favours this conclusion. Unfortunately this boundary line between the charnockite series and the adjoining biotite-gneisses was not traced out during the course of the survey by Mr. Middlemiss. Besides these examples found near Palakod (12° 18′ ; 78° 8′) in the Salem District, similar instances, with beautiful ruby-coloured corundum, have recently been found by Captain Campbell, R.A., at Badavadi (11° 50′ ; 77° 6′) in the Mysore State, where the xenoliths occur near the margin of the charnockite mass forming the Bargur hills. A fairly close parallel to the phenomena observed in these corundiferous xenoliths occurs in connection with the well known Klausen norites and enstatite diorites described by Teller and von John. These authors have described foreign inclusions in the Klausen rocks composed of andalusite, corundum, biotite, garnet and apparently orthoclase.

Chemical and Microscopical Evidence.

To the petrographer the chemical composition and the microscopical characters of rocks are criteria which rank with the larger features recognisable in the field for importance and reliability. In an area where the deformation of rocks has been carried to a high degree, these features are often the only ones left which give any unequivocal indication of origin. The chemical is more valuable than the microscopical method; for a rock may be so profoundly deformed that all the minute structures have been destroyed and even new minerals formed by internal re-arrangement of the chemical compounds, but the bulk analysis of the rock might still be not far removed from that of the original material. In the following pages these two features are treated in order.

Chemical Composition.

In view of the fact—(1) that there are certain general differences between sedimentary and igneous rocks in composition, and (2) that the bulk analysis of rocks are only altered to a limited degree by metamorphism, chemical analysis of a gneiss, or of any rock metamorphosed by physical processes, should afford a clue to its origin.

By the application of these principles to a number of analyses of gneisses, Rosenbusch found that whilst some agree with known igneous types, other gneisses show no chemical similarity to rocks of igneous origin. He concluded, therefore, that the first class of gneisses, which he calls *orthogneisses*, are merely deformed igneous masses, whilst the other types (*paragneisses*) are composed of altered sediments.[1]

The most general chemical differences between igneous rocks and mechanically formed sediments are due to the removal in solution of the alkalies and alkaline earths during the decomposition of the former. This process is, of course, only partially accomplished when, as is more often the case in cold climates, disintegration exceeds decomposition; so that a metamorphosed arkose may chemically differ but slightly from a foliated granite. Gneisses so formed would, however, be limited in distribution and thickness, and the chemical evidence thus increases in value with the size of the formation.

The few chemical analyses which have been made show that the types included in the charnockite series contain the alkaline bases like their mineralogical equivalents amongst ordinary igneous rocks. In the type mass of charnockites at St. Thomas' Mount which contains much microcline, potash exceeds the soda, whilst in the intermediate and basic types the latter alkali is in excess. In other respects also the four types of the charnockite series present a general chemical likeness to many published analyses of granites, diorites, norites and pyroxenites respectively.

[1] "Zur Aufassung der chemischen Natur des Grundgebirges." Tschermak's min. und petr. Mitth., Vol. XII (1891), p. 49.

MICROSCOPICAL CHARACTERS.

As with the chemical composition, so also with the microscopic structures : certain general characters distinguish rocks of igneous from rocks of sedimentary origin, and they are often only partially masked by the results of metamorphism. Though the deformation of igneous masses may result in the complete destruction of the microscopic characters, traces of the old structures can often be detected with the microscope. Such characteristic igneous structures as basic schlieren, contemporaneous veins and primary breccia have already been described in the charnockite series, and it is only locally that they are deformed sufficiently to permit the destruction of these features.

In extreme cases of metamorphism, the development of new minerals by molecular re-arrangement of the chemical compounds may result in the formation of a rock mineralogically distinct from the original material, but still the alteration products of an igneous would present certain contrasts to those of a sedimentary rock. Hornblende, almandine garnet, epidote, sphene, and muscovite are examples of common secondary minerals manufactured by alteration of igneous rocks, whilst the metamorphism of calcareous sediments produces wollastonite and colophonite, and of clays or other aluminous materials, kyanite, sillimanite, hercynite, corundum and rutile are characteristic products.

A review of the charnockite series with these points in mind discovers no features which indicate a sedimentary origin, but nevertheless brings out the fact that they differ from normal igneous rocks in two important structural details—(1) igneous masses of any great size generally show at some point or other a porphyritic phase; and (2) generally exhibit a more or less definite order of succession amongst the constituent minerals. These two points are interdependent and may be considered together.

Even-grained structure and oscillations in order of crystallization.

A well defined porphyritic structure has been observed in the charnockite series in one case only, the porphyritic crystals being orthoclase set in a matrix resembling the ordinary charnockites (No. 13·177). Lacroix[1] has referred to the oscillations in the order of succession which characterise these pyroxenic gneisses and which distinguish them from normal igneous rocks. Exactly why there should be this difference between simple eruptives and the old crystalline rocks has not been fully explained; but in this case, as in the case of the elæolite-syenite of Sivamalai,[2] the general absence of idiomorphism and the apparent contradictions in the order of crystallization may in some cases be explained by movement of the magma during the process of consolidation, just as, according to Professor Judd, the ophitic frameworks of augite around plagioclase break up to form a granulitic aggregate when dolerites and basalts are disturbed by movement during the process of crystallization.[3] In many of these very ancient rocks a panidiomorphic structure has been produced by recrystallization of the minerals. Stages of the process are often observed in the old dyke-rocks of South India.

Becker[4] has suggested that the production of the porphyritic structure of some lavas and dyke-rocks is favoured by the freedom of molecular translation arising from a high degree of fluidity, whilst the even-grained texture of massive rocks is due to consolidation of a less perfectly molten magma in which molecular movement is comparatively restricted. For this reason Becker thinks that the porphyritic crystals are formed when the magma is very mobile, whilst the granular groundmass of the same rocks is formed when, by reduction of temperature, the viscosity of the magma becomes increased. The extension of this interesting speculation to the charnockite series would form a partial explanation both of the absence of porphyritic structure and of the limited degree of differentiation which has taken place in the great masses.

But the banding and foliation, without crush structures, amongst

[1] *Rec. Geol. Surv. Ind.*, Vol. XXIV, p. 162.
[2] To be described in *Mem. Geol. Surv. Ind.*, Vol. XXX, part 3.
[3] *Quart. Journ Geol. Soc.*, Vol. XLII (1886), pp. 68, 76, and plate V.
[4] *Amer. Journ. Sci.*, Vol. XXXIII (1887), p. 50.

other features which characterise so many of the charnockite masses, show that deformation has occurred whilst the magma was still in a plastic condition, and one accompaniment of such deformation would in all probability be the production of a granulitic structure in which groups of granules would represent the break-up of larger individuals of the same species. If this be accepted, we have a simple explanation for, not only the granulitic structure, but also for the constant tendency there always appears to be for the minerals to present themselves in groups of like kind. This feature has been noticed in many of these ancient, foliated igneous rocks, in the elæolite-syenite for instance of Coimbatore.

Phenomena resulting from the crushing of a solid rock and structures resulting from deformation during the process of consolidation are not, however, distinguishable from one another with sufficient certainty to permit dogmatic conclusions on this score. It is difficult, if not impossible, to distinguish between the granulation of constituents already formed and the formation of crystals from many centres due to disturbance of the molecules during crystallization. Probably in all cases of movement during the process of consolidation, the ultimate phenomena are the combined result of these two processes acting simultaneously.

CHAPTER IX.

SUMMARY.

It is proposed to employ locally the term *charnockite series* for a group of hypersthene-bearing rocks which form the largest single section of the Archæan gneisses in Peninsular India. The nearest foreign equivalents of the types included in this group are found amongst the rocks known to German petrographers as "pyroxene-granulites" and to the French as "pyroxene-gneisses;" but in many points members of the charnockite series present analogies also to the "hyperites" and "norites" of Scandinavia, as well as to the "anorthosites" of America. In consequence of these facts, and with a view to facilitate the description and mapping of our Archæan sub-divisions, a distinct name with a purely local application is given, and this is not intended at present for use outside India.

The members of the charnockite series are considered to be igneous in origin, and to present intrusive relations to the associated older schists and gneisses. Although the evidences on this score, as might be expected with any very ancient eruptive, have been partially obliterated and masked, the remarkably long geological quiescence experienced by South India has afforded rare and unusual chances for the preservation of the original features in our Archæan gneisses. With so many significant characters in perfect accord it is difficult to avoid the conclusion that the phenomena presented by the charnockite series are really original features due to an igneous origin and an intrusive habit, not merely fortuitous or produced by subsequent metamorphism.

The following features—for which we have no reasons to regard as other than original—indicate an igneous origin for these rocks:—

(1) Large uniform masses of the charnockite series, either quite irregular in shape, or showing a roughly lenticular form, stand up in the midst of the more complex groups of gneisses and schists, forming mountain masses like the Nilgiris, the Palnis, the Shevaroys and smaller hills in the

Madras Presidency. Alhough the Nilgiri mass, for instance, covers an area of some 700 square miles with an average elevation of over 7,000 feet, it is composed almost wholly of the charnockite series, which retain their characteristic features throughout and are sharply marked off from the gneisses and schists of the surrounding plains below. No such thickness could be paralleled by a homogeneous formation of any sedimentary rock.

(2) Internally the large charnockite masses show the characteristic structural variations of common igneous massifs—basic, fine-grained, segregative schlieren (*autoliths*), coarse-grained, acid, contemporaneous veins, and primary eruptive breccia—features indicative of the free internal molecular translations which are presumably characteristic of, and restricted to, rocks which have passed through a molten condition. The frequent directional arrangement of the constituents presents no feature at variance with the similar phenomenon seen in igneous masses, and the imperfect banding is no more than would follow the deformation of an imperfectly segregated (schlierig) magma.

(3) Apophyses have been observed protruding from a large mass into crushed, altered and older biotite-gneiss, whilst well-defined dykes—often garnetiferous—have been found with fine-grained, basic selvages, due presumably to chilling at their contacts with the older gneisses.

(4) Although the charnockite series are too old to be found in contact with any but rocks already crystalline, fairly well-defined contact phenomena have been recognised near their junctions with quartzites, and, less certainly, in the neighbourhood of limestones.

(5) Ellipsoidal bodies composed principally of pink microperthite, with corundum, sillimanite, rutile, hercynite and biotite, possessing characters strange to the normal

charnockite series, and apparently of foreign origin, have been found included in these rocks, and are regarded as xenoliths picked up and altered by the charnockites.

(6) In chemical composition the ordinary members of this series have their nearest equivalents amongst known igneous rocks, and from the chemical evidence they would be classified with Rosenbusch's *orthogneisses*.

(7) Mineralogically the basic and ultra-basic types are precisely similar to the igneous norites and pyroxenites; the acid and the common intermediate types correspond in general to enstatite-granites and pyroxene-diorites respectively, though these, especially the former, are too rare to permit general comparisons.

The evidences by which the origin of a rock mass is determined naturally suffer partial obliteration by subsequent geological changes, and in consequence of their great age some of the phenomena referred to above are not as simple and straightforward as would be expected if these rocks had invaded younger sedimentary formations. Although, however, each point of evidence would alone be insufficient to prove the igneous origin of the charnockite series, the consistent agreement of all the ordinarily recognised tests—direct and by analogy—is far too striking to be overlooked. No evidence, moreover, has been discovered which is definitely inconsistent with our conclusions as to the origin of these rocks, though there are some features which are sufficiently unusual in normal igneous rocks to demand a special explanation. For instance,—

(1) The persistent granulitic structure and the almost constant absence of pronounced porphyritic crystals is remarkable for such large masses of igneous rocks. Similar features have, however, been noticed as persistent characters of the gneissose elæolite-syenites of Coimbatore, the anorthosites of Bengal and the norites of Coorg—rocks whose igneous origin it would be ridiculous to question. Stages

in the change from an ophitic to a granulitic structure can be traced very clearly in many of our ancient diabase dykes: it is a secondary change in which the dirty lath-shaped felspar crystals become transformed into water-clear granules, and to such a process the granulitic structure of many old igneous rocks may be due. In some instances, however, granulation may be the result of movement towards the close of the consolidation processes. Although the granulitic (panidiomorphic) structure is so very general, Mr. Middlemiss has called my attention to a well marked porphyritic phase in the charnockite series near Chennimalai, Coimbatore District.[1]

(2) To account for the frequent presence of garnets, sufficient evidence has been obtained to indicate their formation at the expense of the pyroxenic constituents. Assuming that pyroxene is stable at high temperatures and hornblende the stable form of the same compound at lower temperatures, Adams concluded that the persistence of pyroxene in the highly crushed portions of the Canadian anorthosites indicates the action of dynamo-metamorphism at high temperatures. Whilst adopting such an explanation for the preservation of pyroxene in the charnockite series, I would suggest that by continued exposure to some intermediate temperature, a change occurs in the complex ferromagnesian silicate, with molecular segregation into a more basic compound, which crystallizes as garnet, and a more acid compound, which simultaneously forms quartz or an acid plagioclase felspar, and which forms isolated inclusions in, or a graphic intergrowth with, the garnet.

(3) The linear disposition of the constituents, as well as the alternation of mineralogically dissimilar bands, have been so frequently observed in unequivocal intrusive rocks that

[1] No. 13·177. The rock has a specific gravity of 2·74, and contains the ordinary constituents of charnockite with porphyritic orthoclase crystals measuring ½ to ⅝ inch across.

such phenomena can hardly now be referred to as inconsistent with an igneous origin. The "foliation" of the charnockite series is, however, much less pronounced as a rule than that of the accompanying gneisses and schists, and is sometimes practically absent, especially in the central portions of large masses, whilst the "banding" is generally a mere streakiness of aspect due to a definite directional deformation of a schlierig mass, and not due, as in the schists, to continuous bands of dissimilar mineral aggregates.

The charnockite series being so widely distributed and abundant in the southern parts of the Madras Presidency, their study in the field naturally brings one into frequent contact with the associated gneisses and schists. The writer's observations agree with the conclusions of previous workers as to a general division of these rocks into two main types:—

(1) A fairly homogeneous, generally granitoid, gneiss—the *fundamental* or *Bellary type*[1] of gneiss—apparently occupying a stratigraphically inferior position, and, with less satisfactory reasons, considered older than,

(2) A composite group of schists and gneisses made up partly of material resembling deformed igneous rocks (orthogneisses of Rosenbusch) and partly of schists which in composition suggest the metamorphism of sediments (paragneisses of Rosenbusch). These have been referred to as the *upper* or *Salem type*.[1]

Mr. Foote has distinguished a system of less perfectly crystalline schists under the name *Dharwar System*. These rocks form a series of long bands of highly disturbed beds, folded and faulted into the gneisses, with a general N.N.W.—S.S.E. trend, and exposed in the highlands of Mysore and adjacent parts of the Madras Presidency.

[1] These two terms—"Bellary type" and "Salem type" of gneisses and schists—were brought into use by Mr. R. Bruce Foote, and correspond respectively to the divisions "Bundelkhand" and "Bengal" used by Mr. Foote's predecessors and contemporaries in the northern parts of the Peninsular protaxis.

The following points of revision suggested by recent work are purely local in their effects:—(1) The *magnetic iron-ore* beds and associated hornblendic gneisses in the southern parts of Madras are probably altered representatives of the hematitic quartzites and chloritic or hornblendic schists of the Dharwar system. (2) Certain exposures in South India hitherto grouped with the gneisses are now separated and regarded as later intrusives, old enough, nevertheless, to be themselves foliated in the same general directions. They are—

(*a*) the charnockite series,

(*b*) the elæolite-syenites and augite-syenites of Coimbatore,

(*c*) the porphyritic augite-syenites and ægirine-granites of Salem,

(*d*) the central granite and the norite masses of Coorg.

In addition to the above, the old rocks of South India are traversed by intrusive rocks sufficiently young to have escaped sensible deformation, namely,

(*e*) the mica-bearing pegmatites of Nellore,

(*f*) the Sankaridrug and Namakal granite,

(*g*) the older diabase dyke rocks generally following the foliation lines and often slightly amphibolized.

Still later than these there are intrusives quite independent of the foliation directions, and altogether undisturbed by mechanical movements, namely,

(*h*) peridotite masses, quartz bosses and quartz-barytes veins,

(*i*) olivine-norite, augite-norite and diabase (augite-diorite) dykes of presumably Cuddapah (older palæozoic) age,

(*j*) olivine-norites and diabases of presumably Deccan Trap age.

There is direct evidence in favour of regarding the charnockite series as younger than the two divisions of the gneisses and of the schists which are considered to be the altered equivalents of *some* of the Dharwars. There is also proof that the charnockite series is older than the groups *h*, *i* and *j*, and probably older than *e*, *f* and *g*. But no facts have so far been obtained to show its relations to the other foliated eruptives, *b*, *c* and *d*. The writer agrees with the older workers in regarding the charnockite series as part of the Archæan complex, and in placing them in the upper division of these rocks; but he considers that their position has been obtained by intrusive trespass, like that of the anorthosites of America and like that of the hyperites and norites of Scandinavia.

Study of the charnockite series has brought the writer into frequent contact with the peculiar stucture referred to by previous workers in South India as "trap-shotten". The so-called "trap-shotten" bands coincide with lines of dislocation, and the black tongues and films which superficially resemble compact "trap" have the microscopical characters of mylonite which has been hardened—fritted and rarely half-fused—by the heat generated through the dislocation being confined to narrow bands, and thereby causing a higher local rise of temperature than would result from a general deformation of the rock-mass.

The phenomena of schlieren (p. 215) are frequently displayed by the charnockite series. Sometimes acid, coarse-grained contemporaneous veins (p. 219) are found cutting through intermediate and basic masses; sometimes basic segregations are cemented in an acid matrix to produce a kind of primary eruptive breccia (p. 218) or merely occur as isolated bodies in a more acid matrix. Such included bodies differing in composition from the general rock masses, but nevertheless derived from the same magma and thus genetically related to the latter, the writer would, for the reasons given on p. 217, distinguish under the name *autoliths*, in contradistinction to the term *xenoliths* suggested by Professor Sollas for inclusions of a foreign rock. In most rock-masses such autoliths will be more basic than the matrix in which they are included, but they are not necessarily so.

As is the case with all large magma bodies, the contacts of the charnockite series with adjacent crystalline formations take the form of more or less wide reaction zones, in which the peculiarities of the charnockite series on the one hand and of its neighbour on the other are found to be intermingled. But it is not difficult, nevertheless, to distinguish between such apparent passage forms, which separate dissimilar igneous types, from real transitions, which join genetically related, adjacent, igneous masses. Marginal interpenetrations and wide zones of contact products may increase the difficulties of delineating the boundaries of large crystalline masses on large-scale maps, but such border difficulties do not detract from the individuality of the main-mass as a geological unit. Near the junction, for instance, between the charnockite series and the great gneissose granite of the Baramahal division of Salem, there might be local difficulties in drawing a sharp boundary line, but, by all the points which constitute rock individuality, the contrasts between these two formations are unmistakeably marked.

The average composition, and by far the most prevalent type, of the charnockite series has an intermediate silica percentage (see p. 146), and the occurrences of anything approaching large masses of acid or basic types are comparatively rare, whilst pyroxenites never form more than narrow bands or small lenses. Although these four distinct types belong to separate rock groups, if regarded from the purely lithological point of view, there is no doubt about their consanguinity; and the writer would consequently refer to the charnockite series as another instance which shows that, from a geological survey standpoint, the recognition of petrographical provinces is a much more natural system of classification than the customary subdivision of rocks according to silica percentage, which is true only for hand-specimens and of value only in the laboratory, but possibly still a convenient system for imparting lithological information to elementary students.

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G. I. C. . O.—No. 18 D. G. Survy.—1-8-1900.—580.

Plate VII.

Microscopic characters of the four chief types.

Fig. 1 represents the acid type or charnockite proper, which is composed of colourless quartz and microcline with a small amount of hypersthene and opaque black iron-ores. Specimen No. 9,658.

Fig. 2 shows the common variety of "intermediate" composition from the Shevaroy Hills. Hornblende and augite generally accompany the hypersthene.

Fig. 3 represents the typical basic variety from near St. Thomas' Mount (No. 9,657), which is composed of water-clear, basic plagioclase, hypersthene, augite, opaque, black iron-ores and smaller quantities of hornblende and apatite.

Fig. 4 shows a section of pyroxenite which is composed essentially of hypersthene and augite, generally with hornblende, hercynite and, rarely, olivine (No. 9,672).

All the sections have been drawn under low powers magnifying about 15—20 diameters.

Fig. 1

ACID

Fig. 2.

INTERMEDIATE

Fig. 3.

BASIC.

Fig. 4.

ULTRA-BASIC.

LEADING TYPES OF THE CHARNOCKITE SERIES.

Reg. No. 261 Dir. Geol. Sur.—June 99.—500

Plate VIII.

Microperthitic structures.

Figures 1, 2 and 3 show three forms of microperthitic structure frequently displayed by the charnockite series. In fig. 1 large, irregular, vermiform inclusions of a striped felspar occur in addition to the finer spindles. In fig. 2 the groundmass is microcline and the microperthitic inclusions are of a felspar having lamellar twinning. In fig. 3 untwinned felspar includes two sets of twinned inclusions.

Fig. 1 is a photograph of	section	No.	1442 × 35	diameters.
„ 2 „	„	„	„	1428 × 60	„
„ 3 „	„	„	„	1876 × 20	„

All photographed with Nicols crossed.

Secondary alterations.

Figure 4 shows the schiller plates in a crystal of hypersthene from coarse charnockite (No. 8,761) obtained near Coonoor, Nilgiri Hills. Section No. 1754 magnified by 20 diameters.

Figure 5 shows the alteration of felspars in a member of the charnockite series which has been invaded by peridotite intrusions in the "Chalk Hills" near Salem. The felspars, except in the immediate precincts of hypersthene crystals, are crowded with minute black inclusions which can be individualized only with a $\frac{1}{10}$ inch objective. The inclusions are arranged in rows parallel to the twin planes of the felspar. Specimen No. 9,689; section No. 1791 magnified by 35 diameters.

Figure 6 shows a spongy garnet corona around hypersthene, with the quartzose by-product forming an intermediate layer between the two minerals (see p. 161). Specimen No. 11,903, Nagaramalai, near Salem. Section magnified by 80 diameters.

Fig 1.

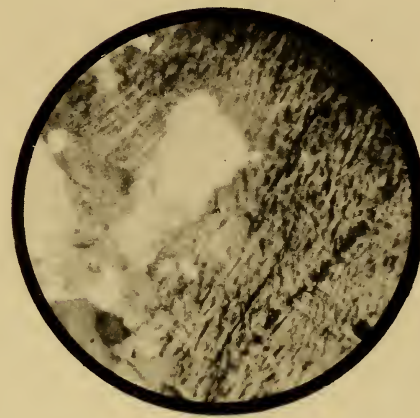


Fig 2.

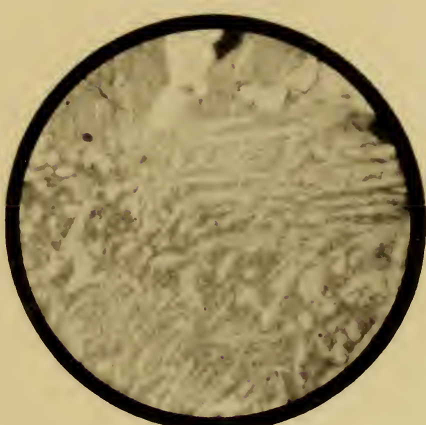


Fig 3.

Fig 4.

Fig 5.

Fig 6.

STRUCTURES OF CHARNOCKITE SERIES.

Photographed by T. H. Holland. Survey of India Offices, Calcutta, October 1899.

Plate IX.

Banding by injection along the foliation planes.

Near Tiruppur in the Coimbatore district the outcrops of the charnockite series are extremely well banded by alternation of felspathic and non-felspathic types. The bands of the latter are sometimes seen to break across the foliation planes and sometimes to bifurcate; they are thus, in all probability, later injections into the felspathic rock, and, though generally following the foliation planes, have betrayed their real nature by occasional departures from this rule. Banding caused by such *lit-par-lit* injections is of a much more definite kind than that caused by the deformation of schlieren (see pp. 183 and 223).

T.H. Holland, Photo.

Photogravure - Survey of India Offices, Calcutta, January 1900.

BANDING BY INJECTION ALONG FOLIATION PLANES, TIRUPPUR, COIMBATORE DISTRICT.

Plate X.

Concentric weathering with formation of kankar in an ultra-basic band.

The ultra-basic bands which have been injected along the foliation planes (see plate IX) often show concentric weathering like basic dykes. In the Coimbatore district, where the climate is moist during the monsoon without great precipitation of rain, the rocks are decomposed, and, on account of the limited circulation of subaërial water, the lime is only partially carried away from the decomposition products. Instead therefore of obtaining a ferruginous product like the laterite which is formed on the Western Ghâts, where the rainfall is heavy, a calcareous and argillaceous kankar is formed by weathering.

T.H. Holland. Photo. Photogravure-Survey of India Offices, Calcutta, January 1900.

ULTRA-BASIC BAND SHOWING CONCENTRIC WEATHERING AND FORMATION OF KUNKUR, TIRUPPUR, COIMBATORE DISTRICT.

Plate XI.

Lens of Garnetiferous Norite near Salem.

The photograph is taken from a mass of old biotite-gneiss (No. 11,892) looking along the strike of the vertical foliation planes. The part of the hill shown is the east-north-east end of a large lens of garnetiferous norite (No. 11,895) whose long axis runs west-south-west. There are other lenses of the same rock further to the west; they have their long axes arranged in the same direction but not in line with this or with one another. A similar rock forms the summit ridge of Kanjamalai which can be seen in the distance on the left-hand side of the photograph. This hill and Kanjamalai are the ones referred to by Leschenault de la Tour in his "Relation d'un voyage à Karikal et à Salem" (*Mem. du Mus. d'Hist. Nat.*, vol. VI (1820), pp. 343, 344).

T.H.Holland, Photo.

Photogravure. Survey of India Offices, Calcutta, January 1900.

LENS OF GARNETIFEROUS NORITE NEAR SALEM.

Plate XII.

View of Yercaud Lake and the Shevaroyen.

The photograph, taken from Arthur's Seat near Yercaud, looks northward across the lake to the highest point (5,300 ft.) on the Shevaroy plateau. The view is intended to give an idea of the scenery formed by the weathering, at an altitude of 4,000—5,000 feet, of a large uniform mass of the "intermediate" varieties of the charnockite series. The plateau of the Nilgiris which is at an elevation of about 7,000—8000 feet is not so well wooded, and consists of a series of undulating turf-covered "downs" with clumps of trees in the hollows.

T.H.Holland. Photo. Photogravure. Survey of India Offices, Calcutta, January 1900.

YERCAUD LAKE AND THE SHEVAROYEN PEAK.

Plate XIII.

Dyke of Charnockite series in Biotite-Gneiss.

In the eastern part of Coorg the charnockite series, besides forming large masses, occur as dykes which are generally garnetiferous. They cut through biotite-gneiss approximately parallel to the foliation strike in a N.W.—S.E. direction, and are often themselves slightly foliated. The rocks which form these dykes are composed of the minerals which characterise the intermediate and basic members of the charnockite series, and are granulitic in structure though comparatively fine-grained. The selvages of the dykes are more compact, more basic and more hornblendic than their central portions.

T. H. Holland, Photo.

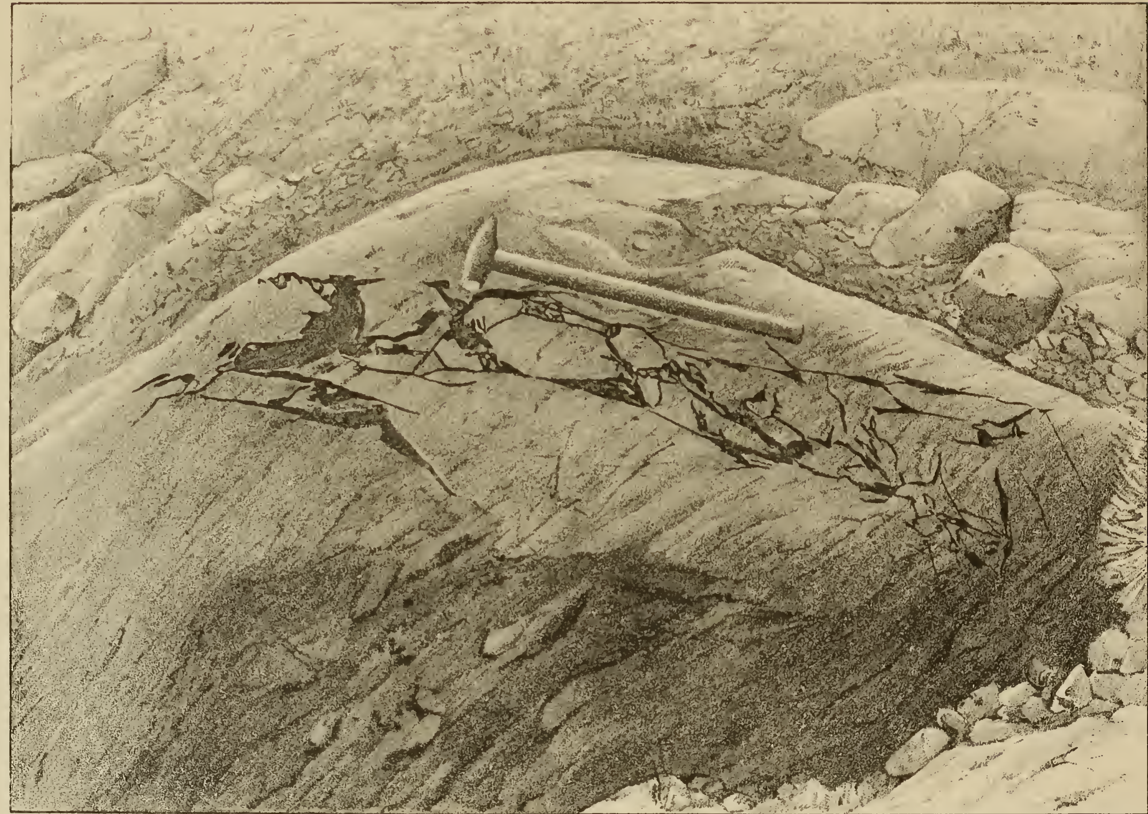
Photogravure-Survey of India Offices, Calcutta, Januaray 1900.

CHARNOCKITE DYKE IN BIOTITE GNEISS, FRASERPET, COORG.

Plate XIV.

Dislocation breccia.

The peculiar phenomenon described on pp. 198—202 under the name "trap-shotten" gneiss was thought by older workers in South India to be due to the injection of compact basic material into the gneisses. But microscopic examination shows the black compact material to have the characters of mylonite, whilst the disposition of these so-called "trap-shotten" bands in the field shows them to coincide with lines of dislocation. The mylonite is extremely hard and brittle, and probably has been highly heated, though not fused, by the heat produced during the dislocation of the rocks; it has a composition similar to that of the rocks it occurs in, and has none of the characters of basic, compact, trap rocks.



From a Photograph by T. H. Holland. Lith., Geol. Surv. of India Office.

SO-CALLED "TRAP-SHOTTEN" GNEISS,

South of Salem.

Plate XV.

Relations of Charnockite to Garnetiferous Leptynite.

In the small hill range east of the railway station of Pallavaram, 11 miles south of Madras, we have an example of the passage of ordinary charnockite into garnetiferous leptynite near its junction with the basic form, norite. The norite passes as a narrow band through the charnockite mass, and the junctions on either side are marked by ridges of the garnetiferous rock which is also slightly pyritous. The mutual relations of these rocks in another precisely similar instance occurring about a mile further east of the railway station are described on pp. 173 and 174. The garnetiferous leptynite is described on p. 142.

(C)

(C)

inuation of the leptynite ridge (B)

Lith., Geol. Surv. of India Office

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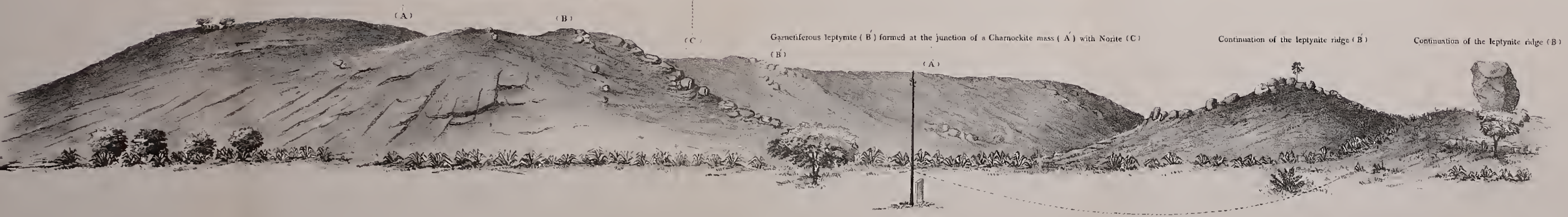
of Leptynite



From a Photograph by T. H. Holland.

Lith., Geol. Surv. of India Office

PANORAMA OF THE HILLS EAST OF THE PALLAVARAM Ry. STATION S. I. Ry.,

Showing the formation of Leptynite at the junction of Charnockite with Norite.