MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA,

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VOLUME XLIV.

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CALCUTTA:
SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY OF INDIA,
27, CHOWRINGHEE ROAD.

1923

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INTRODUCTION.

Political and Physical details of the area.

Idar State is the principal Rajput State of the Mahi Kantha Agency in the Bombay Presidency, having an area of 1,669 square miles, and lying between 23° 6′ and 24° 29′, north latitude, and between 72° 45′ and 73° 39′, east longitude. Physically it comprises the south-western prolongation of the ancient and much worn-down Aravalli hill-range, at a point where the latter is becoming obliterated by and merged into the low-level areas of Gujrat. It thus presents a diversified and picturesque country-side consisting of rocky hills, long sinuous hill ridges, and flat alluvial and sandy plains; and it is well watered by the Sabarmati, Hathmati, Meshva, Majham and Vatrak rivers.

Previous Observers.

Previous to my visit this State had not been examined by the Geological Survey, with the exception of some limited strips on its northern boundary, touched by Mr. C. A. Hacket (late of the Geological Survey of India) during his survey of Udaipur State about the year 1889, and a similar but more limited band to the south near Ahmednagar visited by Sub-Assistant Kishen Singh whilst surveying various tracts in Bombay. The mapping by Hacket extended to sheet 144 of the Bombay Survey (121 of the Central India and Rajputana Survey) as far as latitude 24°. This was coloured by him as his "Aravalli System" in the plains, and as "Delhi Quartzite" in the higher hill areas. Kishen Singh's work near Ahmednagar and

E.S.E. along the edge of the alluvium, as shown on the Bombay Survey sheet 120, comprises only a rim of colour surrounding the Recent alluvium. This was interpreted by Kishen Singh as Vindhyan at Ahmednagar (with a few very small patches of Nummulitic limestone in the Sabarmati river at Dedhrota) together with Archæan gneisses and "Transition" rocks.

I do not know of any published accounts by either of these observers specially referring to the Idar State.

Mr. H. M. Page.

Outside the department, a geological reconnaisance of part of the State was made in 1902 by Mr. Hastings M. Page, then Professor at Poona College. No mapping was attempted during this short trip, but Mr. Page collected a number of specimens, a set of which were determined later by Mr. Vredenburg in the Geological Survey office. I am indebted to Mr. Page for an abstract of his field-notes, which have been of considerable use to me in my preliminary traverses.

Mr. R. B. Foote.

The western edge of the boundary along the Sabarmati has been briefly referred to in Mr. R. Bruce Foote's "Geology of Baroda," and, following him, by Mr. Sambasiva Iyer in his paper on the "Mineral Resources of Baroda State."

My own survey.

My own survey of this State began in January 1911, and was continued at irregular intervals during portions of the cold-weathers of 1912, 1913 and 1916 as opportunity offered amid other duties. It was originally undertaken, partly in consequence of particular obligations entered into by the Department some years before with His Highness Maharajah Major-General Sir Pratap Singh, Bahadur, G.C.S.I., K.C.B., LL.D., and partly as coming ultimately within the programme of the extension into more western districts of the Central India and Rajputana survey party operations, now nearing completion.

It is a pleasant duty to acknowledge the kind assistance of the Durbar in facilitating my work and the personal interest taken in it by His Highness, Sir Pratap Singh, and later by the present Maharajah, Sir Dowlat Singh, K.C.S.I., and other State officials.

Geological features.

The geological description here given depicts, sufficiently concisely, an area that is very typical of this part of India; and, taken in connection with that of other parts of Rajputana recently under description by other members of the Survey,[1] it is hoped that it will serve to clear up some of the obscurity prevailing regarding the rock systems of the Aravalli and other related regions, and form a nucleus for further work in the surrounding districts and States.

Links with surrounding regions.

Although the described area is principally a portion of the metamorphic complex of the Aravalli Range, it also includes certain formations and igneous rocks which link it up on the one hand with Cutch[2] and Kathiawar[3] and on the other with the western or desert portions of Rajputana.[4]

Area surveyed.

The actual area herein described does not entirely cover the whole of Idar State, but it roughly coincides with most of the area of the State that shows solid rock. It is comprised within the following sheets of the 1 inch to 1 mile Bombay Survey, namely, Nos. 118, 119, 120, 143 (120), 144 (121), 145 (122), 146 (123), 147 (124), 178 (149) and 179 (150)—the alternative numbers in brackets referring to the same sheets numbered according to the Central India and Rajputana Survey.

LIST OF FORMATIONS.

The following formations, according to my identification, are present in Idar State, arranged in descending order :—

FORMATION.	AGE.
Soil, blown sand, scree accumulations, river gravels, alluvium with kankar and kaolin deposits	Recent
(Laterite and Deccan Trap — not actually visible in the described area, but seen on the southern margin)	
Ahmednagar (Himatnagar) Sandstone Series — the probable equivalent of the Umia of Cutch, the Drangadra Freestone of N. E. Kathiawar and the Songir Sandstone of Baroda . .	Cretaceous
Phyllite Series — with Vein Quartz	Purana ?
Delhi Quartzite Series — sparingly intruded by Aplite Veins, Quartz-porphyry and with a magnesian phase (Dolomite, Steatite and Serpentine) at certian localities	Purana ?
Aravalli system — consisting of Calc-gneiss, Biotite-gneiss, Amphibolites, Mundeti Series, Muscovite-biotite schist, Hornblende schist and Gneiss — freely intruded by Aplite Veins, Quartz Veins, and massive stocks of Idar Granite and Quartz-porphyry and rare Basic Dykes	Upper Archæan ?

[1] Heron, *Mem., Geol. Surv. India,* Vol XLV, pt. 1.
[2] Wynne, *Mem., Geol. Surv. India,* Vol. IX, pt. 1.
[3] Fedden, *Mem., Geol. Surv. India,* Vol. XXI, pt. 2.
[4] LaTouche, *Mem , Geol. Surv. India,* Vol. XXXV, pt. 2.

In the above sequence of formations it will be seen that immediately below the surface soil, blown sand, alluvium and other river deposits of Recent age, the whole of the Tertiary system of India is conspicuous by its absence, a feature in which the present described area agrees with the rest of Peninsular India to the south (of which it constitutes a sub-marginal part), and is in strong contrast with all Extra-peninsular regions, including the neighbouring areas of Cutch and Kathiawar which lie west and south-west of it. It is possible there may be some slight exception in the bed of the Sabarmati River, where some lateritised shales and sandstones have been interpreted by Foote (Geology of Baroda, p. 65) as doubtfully Eocene, and also at the locality near Dedhrota which is marked Nummulitic limestone on Kishen Singh's map; but these occurrences have not been substantiated by later work.

Although no laterite or Deccan Trap is actually known in the described area, these formations are plainly developed a little further south in the Meshva and Majham drainage areas on the road from Talod railway station to Modasa. Probably both these formations, that are so characteristic of the neighbouring peninsular areas to the east and south-east, have here just found one of their limits of extension on the border of Idar State, although they are well represented further west and south-west in Cutch and Kathiawar.

Of Mesozoic rocks below the Deccan Trap, the sole formation, rather scantily represented, is the Ahmednagar Sandstone of presumed Umia age (Jurassic to Cretaceous). Unfortunately it has yielded no fossil remains, and we can only hazard a guess from its lithological features that it more nearly approaches in character the rocks of Cutch and Kathiawar, of generally marine facies, than those of the uppermost Gondwanas. I do not think Kishen Singh's reference to these as Vindhyan need be seriously entertained.

Below this, again, the Geological Record is entirely unrepresented by any fossiliferous deposits, either marine (of extra-peninsular type) or freshwater (Gondwana or peninsular type); and the hiatus in sedimentation is continued by the absence of all the great Vindhyan formation, both Upper and Lower. Furthermore, the rocks next in order below, which do make their appearance, and which constitute the bulk of the solid geology of the State, are so lacking in data for correlation purposes, that beyond enabling one to place the Phyllite series and the Delhi Quartzite doubtfully with the Purana group, and the Aravallis probably rather high up in the Archæan, it is necessary to arrange these two systems according to a purely local classification only, or at least to one that they share in common only with Rajputana.

This poverty in formations of the ordinary Geological Record does not, however, connote dearth of interest, except in the domain of palæontology; for these representatives of the Purana and Archæan, together with the igneous rocks penetrating them, as laid bare in this part of India, present a wonderful variety of type both mineralogically and structurally, and afford fascinating problems in the study of the earth's deeper crust that become the more absorbing as we realise the great principles at stake in the matter of their complex origin.

ARAVALLI SYSTEM.

Preliminary Remarks.

A difficult and elusive complex.

In the interests of an orderly geological description progressing upwards from the older to the younger rock series, it will be necessary to open the descriptive part of this paper with what is certainly the most difficult, most complicated, and perhaps the most elusive of all the rock systems exposed in Idar, namely, that phase of the metamorphic and crystalline Archæan complex for which the name "Aravalli System" has here been intentionally reserved, in spite of certain vaguenesses in the later application of the term.

The name "Aravalli."

The term Aravalli System was established by C. A. Hacket[1] for certain rocks exposed in the Aravalli Range of hills, of a highly metamorphic and crystalline character. Furthermore, the above author, not only applied the term to those rocks as above stated, but actually carried his mapping continuously along the line of strike from that, their first-described home among the roots of the old Aravalli range, down into connection with those herein named Aravalli in Idar State. It is, no doubt, also true that the same observer similarly correlated other more doubtful sequences of metamorphic rocks,

[1] *Rec., Geol. Surv. India*, Vol X, p. 84 (1877).

lying far off this line of strike, with his original Aravalli; and so, to some extent, depreciated the value of the term. Nevertheless, since some name is necessary for these rocks, I think we are justified in taking that which seems most properly to have belonged to them in the first instance, or very nearly the first instance, since we naturally accept an early modification of the term as matured by Hacket himself whereby the Delhi Quartzite is removed from the Aravalli system and elevated into an independent higher system (a modification the soundness of which has stood the test of time). In other words the Aravallis here are, in the main, Hacket's Aravallis as matured by him, with sundry exceptions found necessary by later exploration. For further remarks on the present status of the term "Aravalli" the recent memoir by Mr. A. M. Heron on the Geology of Western Rajputana (*Mem. G. S. of I., Vol. XLV, pt. 1*) may be consulted.

A mixed assemblage of foliated crystalline rocks.

Under the title of Aravalli, then, comes all that assemblage of mineralogically and petrologically interesting components of the Archæan crystalline complex that are discoverable in this region as forming the lowest accessible portion of the earth's crust there exposed. They are grouped together, and only partially distinguished by separate colouring on the map, mainly for that reason most cogent to the field geologist; namely, the impossibility of always separately delineating their individual boundaries and not necessarily because they are imagined as having had a single mode of origin. Although few obvious signs of any sedimentary origin obtrude themselves in their now highly altered condition, it is reasonable to suppose that several of their members were originally of the nature of stratified, or chemically precipitated, sediments of some kind (paragneiss); whereas others appear to bear the mineral constitution of igneous gneissic material. Hence although one might theoretically draw hard and fast lines between much that is of one order and of the other, still, in the practical business of geological mapping such distinctions are here found to be impossible, because:—(1) there are always some phases of the one or of the other that might be regarded indifferently as either of igneous origin or of metamorphic sedimentary origin, (2) these phases are often so intermingled (kneaded together as one might say) that no map of any available scale could accommodate all their boundaries, and (3) nearly all lie so close to the base-level of erosion for this part of India that they are generally hidden under a thick mantle of Recent sediments, from beneath which their outcrops are only here and there discernible as isolated patches, and in occasional stream-beds.

No serial order discernible in the complex.

Another general feature of this Aravalli complex that had better be referred to now is that which is implied by the expression "complex." Locally one may easily detect small series and sequences, but as a whole one cannot certainly predicate any serial order for the whole set. There is no recognisable top, middle or bottom to the Aravalli system as a whole. When later on we come to discuss the remaining less ancient formations present in Idar in their relation to these underlying Aravallis, namely, the Delhi Quartzite and the Phyllite System or Series, it will be found a task of no small difficulty to establish conclusively even their order of superposition. Intimate deformation of the finer structure, shearing, and differential slipping of platy layers over one another in consequence of deep-seated earth stresses that must have operated very low down among this ancient Aravalli mountain range, can frequently be shown to have seriously blurred the lines of ordinary sedimentation, even in such resistant material as Delhi Quartzite. Much more so then must we be prepared to find the task of unravelling the complicated banding and foliation of the underlying Aravalli schists to be even more difficult or impossible. We cannot tell exactly how these mineralised formations have responded to the presumably intense earth stresses brought to bear upon them. The comparatively simple appearance of their foliation planes dipping steadily in one direction or bent into anticlines or synclines almost certainly does not express their full history, which most likely has been much more involved, and it may be necessary to contemplate the existence of a zone of rocks on which has been superinduced deformation by flowage (rock flow) producing gneissic foliation and mineral banding that simulates original bedding.

Hence one is compelled to describe the Aravallis as a *complex* having here and there in patches certain serial orders of banding, but we are entirely unable to unravel their now hopelessly blurred folds, and arrange them in a definite sequence of strata having a proper superpositional order among themselves.

The same impediments in the way of visualising the folds and sequences of this complex also prevent us from gauging its total thickness and from drawing continuous horizontal sections. The Aravallis, like much of the Archæan rocks in other parts of India, and like for instance, the Grenville series in Canada described by Adams and Barlow,[1] betray their real lack of any intelligible stratigraphical sequence by this one fact more than any other, namely, the impossibility of ordinary illustrative sections. An endeavour to calculate the total thickness of the Grenville series along certain lines of section, we are informed (p. 33, *loc. cit.*), resulted in a total of 94,000 feet, out of which 50,000 feet were limestones, which is manifestly too large, being more than four times that of any later rocks of Huronian type—and yet much of this was supposed to be definitely bedded limestone!

But its varieties appear to cohere together into one system.

Notwithstanding the above, the petrological varieties of this complex in Idar State, as presently to be described, judging by their surface distribution, all have the appearance of cohering together into one great system that probably arose during an equally extended and continuous period. For all practical purposes in this area they embrace everything in the way of undifferentiated or dubious metasedimentary material, with included ancient igneous material, that is deemed to underlie and to be older than the great and similarly coherent rock masses of what will be described as the Delhi Quartzite.

General correlation.

In general terms, comparing them with other so-called Archæan systems, we may apply to these rocks the words of Chamberlin and Salisbury, quoting or paraphrasing Van Hise (Bull. 86, *U. S. Geol. Surv.*, p. 476) which are as follows:—"While, therefore, the variations in the rock of the Archæan complex are great, there is, nevertheless, a certain homogeneity in the heterogeneity of the whole. No one considerable part of the system is very different from any other considerable part, and no definite and orderly relationship between the different parts has been made out over any considerable area. There appears to be no traceable succession of beds and no definite stratigraphical sequence, such as can be made out in any great series of metasedimentary rocks, however, much folded and metamorphosed. So similar are the rocks of the Archæan throughout the various areas where the system occurs, that a suite of unlabelled specimens from

[1] Geology of the Haliburton and Bancroft Areas. *Canada, Department of Mines, Mem.* No. 6 (1910).

one region could hardly be asserted not to have come from any other."

Reason for a separate name.

There can be but little objection to the utilisation or re-application of the old and hitherto vaguely defined name of Aravalli for these rocks if it be understood to be merely a means to an end, the end being an intelligible description of the things themselves. If there be any real objection, it is likely to lurk in the fact that at the other end of the old Aravalli range in Rajputana the same term is being contemporaneously applied to other extensions of what are supposed to be the same system, but which, as time goes on, may prove to be either somewhat more or somewhat less comprehensive than in my case. Should this eventually be shown to be so, it may then be necessary to discard the use of the term Aravalli as a moderately general term, and to rely on fresh local names for all phases of the older crystalline complex that cannot certainly be actually traced into, and manifestly correlated with, each other. I believe nothing is gained by basing the general use of a wide classificatory word on conjecture and surmise, or as a mere expression of personal and often provisional opinion concerning widely separated areas. For the time being the object sought in applying the local name Aravalli to these rocks is merely to distinguish them from other varieties and groupings of similar rocks elsewhere developed in India. This seems a better policy than rashly to classify them as say Dharwarian or anything else that would necessitate a speculative mental leap, even though the guess might eventually turn out to be a good one.

Descriptive Details.

Subdivisions.

The sub-headings under which sundry varietal and geographically distinct members of this Aravalli facies will now be described are categorically as follows :—

(1) Calc-gneiss of Vadali, Khed Brahma and Golwara areas;
(2) Non-calcareous biotite-gneiss, associated with the calc-gneiss;
(3) Aplite and pegmatite veins intrusive in the calc-gneiss and biotite-gneiss;
(4) Origin of the calc-gneiss, biotite-gneiss and their plexus of aplite veins;

(5) Amphibolite limestones of Kherod;

(6) Mundeti Series;

(7) Other areas of Aravalli rocks:

(*a*) Bodi area.

(*b*) Bamanvada-Jesangpur area.

The general geographical distribution of this assemblage of formations will be easily grasped by reference to the map. The different outcrop areas all become visible here and there in the low-lying tracts of country that are disposed west and south-west of the rampart of the Delhi Quartzite hills; and, whenever the latter send out digitations and lobes into the low country, one or more groups of the Aravallis follow round their winding base.

(1) Calc-gneiss of Vadali, Khed Brahma and Golwara areas.

Distribution: surface features.

The separate colour allotted to this formation on the map will show its general distribution in the western and northern areas of the State, where it appears forming slightly and rather gently elevated and undulating country, consisting of rough and broken hills and hillocks. These contrast sharply, on the one hand, with the plain alluvial country, and on the other with the elevated mountain masses of the Delhi Quartzite and the more rugged hills of Idar granite. It is generally too rough for village sites or for cultivation, except in the intermediate hollows, and supports only grass and low scrub jungle.

In the localities north of Vadali, at Dharol hill (5 miles N. W. of Vadali), in the neighbourhood of Golwara (near the Sabarmati river) and in the country lying between the Vadali exposures and Khed Brahma the outcrops of the calc-gneiss are particularly broken and isolated by large stretches of alluvium, whereas north of Khed Brahma they close up into more connected stretches of rolling country. In the former areas they frequently bear the aspect of short strike-ridges and groups of ridges, more or less connected together, the crests and summits of which only appear above the alluvium which isolates them generally from one another and also from other types of Aravalli rocks, whereas in the latter areas (N. of Khed Brahma) the large expanse of calc-gneiss gives continuous exposures till they rather suddenly end near Kherod against the somewhat different Kherod series of amphibolites, and again in the opposite direction near Walren, where they appear to pass into the biotite-gneiss.

The term "calc-gneiss."

The calc-gneiss here described contains much of the carbonate in the form of calcite, as well as several of the typical calcium-bearing silicates, which latter are ordinarily sufficient along with other characteristics of such gneisses to allow the prefix "calc" to be applied to them. Very often the rock is a coccolitic marble, similar to the classical British example of the Tiree marbles; but, as other parts of the great series contain much less of the carbonate and would not ordinarily be alluded to as limestone or marble, I prefer to speak of the rock generally as a calc-gneiss.

Banded character.

It must be understood to be a rock very well banded in layers of varying composition. Hence it appears to possess what may have been original stratification (though there is no real evidence of this) in well-marked beds, usually of white, grey and dark greenish grey colours, weathering much darker and sometimes almost black. Some laminæ under surface influences become deeply eroded relatively to the associated laminæ, and give rise at the surface to those extremes of relief and corrosion always so characteristic of metamorphic calciferous and scapolitic rocks—as for instance the well known calc-gneiss of the Coimbatore neighbourhood in Madras.

Permeation by aplite veins.

It is constantly and often very closely permeated by aplite veins of from a foot or less in width to sometimes as much as 50 feet, and very exceptionally to even greater thicknesses (see Pl. 1, fig. 1). These veins of more or less acid rock will be described later (see p. 31), but it may here be remarked that they generally follow the original banding (? bedding) of the calc-gneiss with occasional transgressions, and that the two rocks thus in combination are frequently found together in any fairly continuous outcrop—so completely has the permeation of the one rock by the other been carried out. Notwithstanding the above, the two rock bodies have every appearance of being in their essentials entirely distinct, the one being a typical banded gneiss, and the other apparently a sharply contrasting granite vein or aplite, General mineral composition.

In general terms the calc-gneiss or schist is a roughly equidimensional, granular aggregate of frequently large amounts of calcite (when the rock becomes an impure marble, much quarried recently for building purposes on the Khed Brahma extension of the railway). Along with the calcite there occur varying amounts of quartz, felspar (which is generally orthoclase or microcline, although plagioclase is also found), diopside (coccolite), occasionally and locally changing to uralitic hornblende, and sphene in relatively large grains. Besides the above, there is locally found a fair amount of biotite, a little graphite and pyrite, and in some few specimens much scapolite, zoisite, wollastonite and minute pale garnet grains. These features of mineral composition sufficiently stamp the rock as being in general terms a crystalline granular calc-schist, gneiss or granulite, such as those which in other parts of India are associated with rocks belonging to the Archæan group.

Type areas N. of Vadali.

The area 2 miles north of Vadali and the neighbouring detached ridges may conveniently be taken as the chief type from which a selection of specimens will now be described. The former restricted area is somewhat irregularly elongated in the direction of the strike, and comprises about 2 square miles of country entirely surrounded by alluvium and rising at its highest point to an elevation of 971 feet, or about 200 feet above the general level of the plains at its foot. The main road to Khed Brahma, and likewise the new railway, cut through a portion of it. From the railway and from several quarries on its western scarp abundant rock material is laid bare, as also in many of the hill undulations themselves which are fairly well exposed, especially in the dry, hot season of the year when the long grass has been either burnt or cut for storage.

From the point of view of the banding of the rock, the western edge of these rolling hills is generally a scarp with dip of foliation about 60° E.S.E., increasing to verticality on the eastern edge of the mass. The N.N.E.—S.S.W. strike veers rapidly at the south-west end of the hill mass so as to carry the outcrops towards the north-north-west in the direction of the Morad and Dharol exposures.

The markedly banded appearance of the rock is seen in detail to be due to the layers ($\frac{1}{4}$ to 4 or 5 inches wide) of more purely calcite rock, alternating with those in which quartz and felspar and the various calc-ferro-magnesian silicates (especially diopside) are more strongly developed. It is helped out by the interleaved white bands of aplite. The banding is frequently puckered after the manner of contorted mica-schist.

A particularly clear and interesting section in the railway cutting, 1 mile south of Khed Brahma, is illustrated in Pl. 1, fig. 2. It is there seen that the streaky banding of the calc-gneiss is exactly comparable, in the mode of arrangement of the minerals, to that of many forms of Archæan schists or gneisses: that is to say, the layers are sometimes due to differently proportioned amounts of one or more of the dark minerals among the light minerals, or (within limits) to different degrees of coarseness of grain, and lastly these layers may vary in thickness. Thus, as in the hand-specimen from the locality referred to above, one may detect a $\frac{1}{4}$ inch layer of very pure calcite with just a few grains of coccolite scattered through it. There may be others of closely packed coccolite, and other subsidiary bands where biotite is prominent forming $\frac{1}{8}$ inch, very dark layers. Others again with pyrite, graphite and so on. There is endless diversity in detail as we progress from band to band, and the same is true when quartz and felspar play a more leading rôle. A similar diversity on a larger scale is also found among more thickly bedded masses and between nearly related outcrops of still wider dimensions.

Other calc-gneiss areas.

As regards the other Aravalli areas characterised by calc-gneiss, a brief reference is all that will be given here before proceeding to the petrological descriptions of characteristic varietal forms. In the neighbourhood of Golwara, near the Sabarmati R., occur first some little isolated hills of the calc-gneiss. These coalesce at Golwara into a well-developed branching ridge which passes northwards, *viâ* Chandap and Nawawas, into a set of low-lying and more straggling groups which in turn veer to the N.N.E. towards Babsar and Mhor. The alluvium of the Harnav and Sabarmati junction hides their further continuation in this direction until in the neighbourhood of Gadra they once more emerge, first in straggling low ridges, and then coalescing into the fairly continuous exposures in the country between Khed Brahma and Kherod.

Over all these areas the general type of rock is very similar as a whole, although diversified in detail—so uniform in fact that no further subdivisions of the series can be made for mapping purposes, One is impressed by the wide expanse of this formation, whose flowing slopes and steadily winding strikes with a moderate foliation dip, seem to imply great thicknesses (amounting to thousands of feet) of a rock-type singularly uniform as a whole, though not in detail. It is only when the collections from the various parts have been subjected to microscopical examination that differences appear. These are best exemplified in the areas where quarries and railway cuttings have assisted in the work of exposure. Hence the majority of the petrological types whose descriptions follow are from the neighbourhood of Vadali or Khed Brahma, but it is believed that those types may be taken as thoroughly illustrative of the whole of the calc-gneiss areas.

Microscopic details.

Under the microscope a specimen of the more calciferous variety from the quarries on the railway $1\frac{1}{2}$ miles north of Vadali ($\frac{25}{377}$)[1] shows the main part of the slide (12130)[2] to be crystalline grains of calcite of rather large size. These were proved by Lemberg's staining method to be all calcite without any dolomite. Along with them is a considerable amount of almost colourless pyroxene in irregularly rounded smaller grains clustered together. The variety of pyroxene here present (it may parenthetically be remarked) is peculiarly characteristic of this geological region, and we shall find it giving the dominant note to a number of rock-types of the State. In this particular group of calc-gneisses it appears to the eye in hand-specimens as little blebs, or groups of blebs, without crystal faces, and of a colour varying from pale to dark grey or greenish grey or to a brighter bluish green, becoming very pale tints of the same in thin section. In the specimen just quoted its general appearance together with its high index of refraction, rather strong double refraction, absence of pleochroism and its type of cleavage are easily presumptive of pyroxene. The lack of definite crystal outlines makes the determination of its other optical constants rather uncertain, but in numerous related specimens some of the sections, which present a single well-developed set of cleavage traces parallel to the long axis of the grains, may be presumed to be in the prism zone, and the extinctions here with reference to the axis of lesser elasticity ($Z \wedge c$) reach values of from 38° to 44° which are sufficiently characteristic of the diopside class of non-aluminous

[1] Number in G.S.I. register of rock specimens.
[2] Number in G.S.I. register of microscope slides.

pyroxenes rather than of the aluminous augites. Its colour and general habit, and its presence in a matrix of so much calcite, are in accordance with this. In the scapolitic variety ($\frac{25}{385}$, 12138) from Proia, presently to be described, some richer bands of pyroxene (12139) and sphene present typical elongated, and generally idiomorphic, grains of this mineral from which it can more definitely be determined as diopside (see p. 16).

Returning to the rock 1½ miles north of Vadali ($\frac{25}{377}$), there is also some small amount of dark mica in isolated plates sometimes more or less gathered together, giving pale yellow to light brown pleochroism. Sphene is also a prominent mineral component in irregular elongated grains with rounded edges, and there are a few grains of scapolite. The iron ore sparingly developed is pyrite. Felspar is almost absent in this particular rock, but there are a few grains of microcline and some quartz in relatively small amount.

From this summary of the mineral contents the rock clearly emerges as a grey impure marble with diopside as the chief accessory.

Although felspar is absent, or nearly so, in the above rock, in another specimen from the same locality ($\frac{25}{378}$, 12131), and which to the eye is very similar, there are fairly abundant grains of microcline, whilst biotite is absent (Pl. 8, fig. 1, nicols crossed).

Some 5 miles away to the north-west, at the south end of the Dharol hill, occurs a variety of the calc-gneiss ($\frac{25}{379}$, 12132, Pl. 8, fig. 2) in which a very large proportion of the diopside is replaced by uralitic hornblende in hypidiomorphic grains, and there is a large amount of quartz, orthoclase and plagioclase (? labradorite), but no microcline, although calcite still remains a prominent mineral. The uralitic hornblende, which sometimes shows its crystal outline fairly well, gives extinction angles ($Z \wedge c$) up to about 18°, and the pleochroism comes near that of actinolite, being Z pale bluish-green, Y yellowish-green and X pale greenish-yellow. The orthoclase, though perfectly clear, is frequently easily distinguished by characteristic cleavages from the quartz, but there are some small grains of one or both that remain undifferentiated. There are also detected in the thin slice of this rock a very few ragged and irregular or corroded plates of a mineral with a considerably high refractive index, near or a little above that of the diopside in the same slide. Its interference colours are of a very low order, being a pale indigo or pale violet-gray, and which, working from the quartz in the same slide, indicate a birefringence of about ·006. It contains numerous inclusions, but is much better developed in another specimen ($\frac{25}{385}$, (12138) from Proia) from which it has been referred to zoisite.

A specimen from the quarry on the railway just south of Vivau ($\frac{25}{380}$, 12133 to 12135, Pl. 8, fig. 3) is remarkable for the large amount of biotite present and the general absence of quartz and felspar. The calcite is as before and calls for no mention, the Lemberg staining method revealing no dolomite. Diopside is rather rare over much of the rock, and there is a little scapolite in slides 12133 and 12134. Rock No. $\frac{25}{383}$ (12137, Pl. 8, fig. 4), from the same locality, is similar, but shows lines of cataclastic structure with bending of the calcite plates and a finer granulation. There is also graphite in the rock. Another specimen from the same quarry ($\frac{25}{387}$, 12136) is represented in Pl. 8, fig. 5. Its equidimensional granúlar character is beautifully shown.

Another variety of the calc-gneiss is $\frac{25}{385}$ (12138) (12139, Pl. 8, fig. 6), from Proia village on the Harnav river. This rock is well banded in pale and darker bands. The paler bands (12138) and indeed the whole rock contains only a very small amount of calcite, the bulk being composed of a finer grained aggregate of felspar and quartz, zoisite in irregular areas or interrupted acicular parallel aggregates, large irregularly bounded and frayed out plates of scapolite (meionite), the usual diopside in grains sometimes showing crystal outlenes, and sphene also in small lozenge-shaped grains. All the minerals are beautifully clear and fresh. The felspar and quartz form a mosaic of grains scattered about and among the other constituents. The zoisite is very characteristic, enabling one by analogy to refer similar mineral occurrences in other specimens of the calc-gneiss (see $\frac{25}{379}$ *ante*). Besides its high refractive index and weak double refraction giving abnormal interference tints of a rich violet grey, its extinctions parallel to the elongated prisms and its biaxial figure in convergent light all point unmistakably to zoisite, a conclusion also borne out by the general habit and appearance of the mineral. It is developed in considerable quantity in discontinuous plates and more or less regularly oriented acicular prisms in the quartz-felspar mosaic. The large meionite plates are not bounded by crystal faces but by a perfectly irregular wandering edge. The low index of refraction and strong birefringence (about ·035, working from that of the known diopside) of this mineral is in great contrast to the zoisite. The cleavage, presumed to be parallel to *a* (100) is well seen by parallel cracks in many examples which all give extinction angles near 0° and 90°. One section in the slice is isotropic and gives the black cross in convergent light. The well-developed prominent cleavage is parallel to the general elongation of these areas, and the axis of lesser elasticity is seen to be at right angles to this, so that the mineral has negative elongation and may be presumed to be negative. The diopside in this rock besides being generally distributed over the rock is also specially aggregated along with the sphene into layers an inch or more in thickness. Here the diopside, showing bluish-green tints, is characteristically developed in good hypidiomorphic lath-shaped and other sections from which, in combination with the cleavages, its optical characters can quite easily be deduced (12139, Pl. 9, fig. 1).

One and a half miles south of Gota a specimen, $\frac{25}{382}$, (12140, Pl. 9, fig. 2) is remarkable for innumerable small irregular grains and aggregates of grains forming an imperfect mesh work of colourless garnet (grossularite). Quartz and felspar are abundant in this rock There is a fair amount of hypidiomorphic, distinctly coloured diopside, much sphene and less calcite than usual. Along with the quartz-felspar layers there are long lath-shaped sections of a pale mineral with pearly lustre, a single prominent cleavage and positive elongation. Its moderate refractive index and rather weak birefringence point to wollastonite (see specimen $\frac{25}{388}$ to follow).

From the calc-gneiss hills east of Golwara comes a rock ($\frac{25}{388}$, 12141, Pl. 9, fig. 3) from which calcite is almost absent, the darker layers being made up very largely of diopside, large aggregates of granular white garnet (grossularite), some sphene, and, along certain layers a large amount of the colourless mineral of the last-described rock. It is quite soft under the knife and has a pearly lustre. It appears under the microscope in short lath-shaped sections with one prominent cleavage and parallel fibration, giving generally parallel extinctions and positive elongation, a moderate refractive index (not so high as the diopside) and rather weak birefringence. These data, as in the rock above, point to wollastonite, a conclusion verified by etching with acid and staining on the uncovered thin section. Quartz-felspar layers, in which microcline is prominent, cut through the rock in fine white vein-like bands, much of the felspar of which has been altered into a brownish, dusty, amorphous, isotropic substance.

In the sections laid bare in the railway cutting 2 miles S.S.W. of Khed Brahma, where the more calcareous form of the calc-gneiss is in evidence ($\frac{29}{337}$ to $\frac{29}{340}$, 12142 to 12146) there occur a few narrow straight bands, running parallel to the foliation, and of a darker smoky grey colour (seen to the right of the railway cutting, Pl. 1, fig. 2). Here all the stages are seen in the progress of mylonitisation of the calcite ground-mass, from one with simply bent cleavage flakes as in (12137), Pl. 8, fig. 4 to one in which the calcite has become converted into a microcrystalline medium in which larger grains of quartz, felspar, diopside, sphene and zoisite appear to be left as 'eyes,' or like corroded phenocrysts in a granite porphyry (12145). This mylonitised ground-mass of minute calcite grains is of a dull, dark grey colour, and shows a rude flow structure round the larger grains, especially well marked where the graphite has been drawn out into long smudges.

The zoisite in these examples is full of inclusions, or is in ragged interrupted plates as if crowded with, or intergrown with, the ground-mass of quartz-felspar mosaic, and shows abnormally brilliant interference colours of a very beautiful shade of deep violet-grey or sapphire-blue, in place of the ordinary steel-grey as exhibited by most minerals a little below the yellow of the first order. In slightly thicker sections the yellow of the first order in this mineral appears of a slightly greenish, or primrose, yellow, instead of the usual yellow ochre. In slide No. 12144 of this rock the zoisite apparently passes over by gradation into epidote. Slide 12146 shows much diopside, and is typically equidimensional as to grain.

The calc-gneiss from 2 miles north by east of Khed Brahma ($\frac{26}{322}$, 12147), at the locality of the allanite granite, has much calcite, a fair amount of quartz-felspar mosaic (orthoclase and a very little microcline), diopside and zoisite, all in grains. There is a considerable amount of distinctly pleochroic sphene and green hornblende in hypidiomorphic and very attenuated sections, graphite in ragged tufts, and no mica.

From 1 mile north of Vadali, among the varieties of the banded calc-gneiss, comes a compact, fine-grained, mylonitised specimen in which there is hardly any calcite, some quartz-felspar mosaic, ragged (?) diopside plates, garnet in large irregular aggregates of minute grains. Zoisite and also sphene can be detected ($\frac{26}{319}$, 12148).

A specimen ($\frac{25}{376}$, 12149) from the northern edge of Asai hill, is remarkable for the bright emerald-green pyroxene, besides wollastonite, sphene and other ordinary calc-gneiss minerals. There is also a replacement of sundry minerals by dark, dusty, amorphous silica (?); specimens $\frac{26}{320}$ and $\frac{26}{327}$ (12150), from the S.E. extremity of the same hill, are very similar. One from the western side of Dharol hill $\frac{25}{387}$ (12151) is remarkable for the large amount of quartz felspar mosaic in addition to diopside, calcite sphene, etc.

Dharol hill.

A few localities where special points of interest appear will next be mentioned. Dharol hill area and that of Vasna are also remarkable for the instrusion through them of the massive Idar granite which will be described later (see p. 119). At the former place, which is 5 miles north-west of Vadali, the stock of Idar granite stands up in a bold mass, with rugged sides and summits reaching to an altitude of over 1,000 feet, or 300 feet above the plain, the southern and western flanks being composed of the calc-gneiss with its usual plexus of veins. The sections near the junction are of particular interest because of the way in which the Idar granite conspicuously truncates the calc-gneiss and because of what one must accept as the special metamorphism induced in the latter by that granite. The first is well seen about ½ mile north by west of Dharol village in the general direction of the pathway to Nadri. Here the strike of the calc-gneiss is N.W.—S.E., a direction which naturally brings it into abrupt discordance with the N.—S. edge of the granite boss, though there is a slight bending round of the former as it nears the actual line of contact (see plan, text fig. 1). A less good example

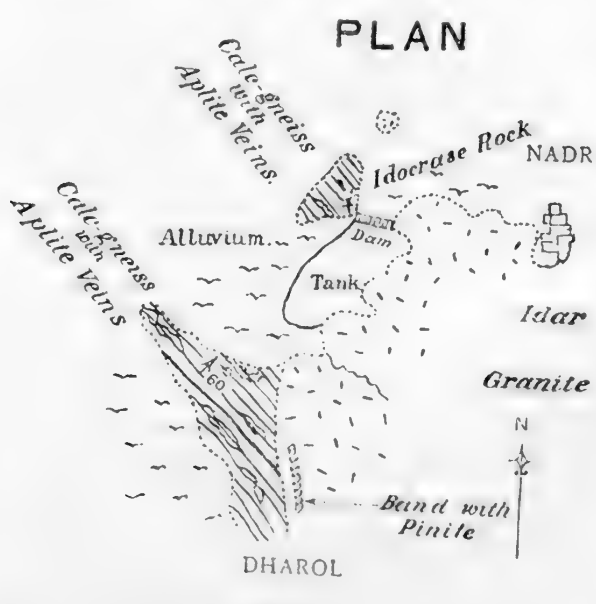


Fig. 1

is furnished by the southern end of the hill where the position is as follows (in the section below text fig. 2). The evidence is sufficiently

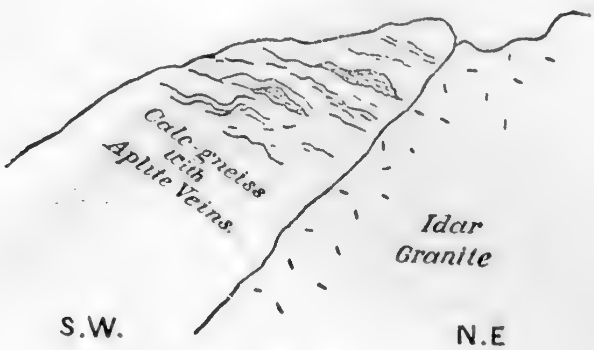


Fig. 2.

conclusive for the age of the calc-schist and also probably for its interbanded aplite veins being distinctly older than that of the Idar granite.

Idocrase rock

The second feature characterising the junction section is the production in the calc-gneiss of rich and thick bands of idocrase (vesuvianite) rock. Idocrase is a common mineral developed in limestones by contact metamorphism of this kind, but the record of this mineral in India is a very insignificant one. Beyond being simply mentioned in lists of minerals from the Nilgiris (see H. Congreve, *Madras Journ. Lit. and Science*, Vol. XXII, p. 248) and also from Manbhum (*Mem., Geol. Surv. India,* Vol. XVIII, p. 103) the only place whence specimens are represented in the Survey Museum is Tonk State, where from a quarry at Rer a specimen of "egeran" was obtained (see Mallet, *Man. Geol. India,* Mineralogy, p. 93) its registered number being H. 779. Mr. Vredenburg, in his determination of specimens collected by Prof. Page (see *ante* p. 2), doubtfully recognised the mineral microscopically in the Idar granite, a statement which so far I have been unable to verify. From the fact that I have now found it so abundantly as a contact phenomenon in the zone of calc-gneiss bordering the Idar granite, it is quite likely that Mr. Vredenburg's determination is correct.

In the present instance the calc-gneiss ($\frac{26}{325}$, 12152) contains, in addition to idocrase, all the ordinary minerals that compose the calc-gneiss elsewhere, namely calcite, quartz, microcline, diopside, etc. The idocrase occurs as bands several inches across, exhibiting large shining poikilitic cleavage plates surrounding and enclosing all the other constituents. Thus the rock is not pure idocrase, the percentage of this mineral to the rest being about 5 to 1. The specific gravity of the impure rock is 3·31. The mineral has not been chemically analysed as yet (on account of the enclosed impurities this would be a difficult operation). Its determination is based on its physical and optical characters, which are as follows :—hardness about 6·5, dark clear brown colour, vitreous lustre, uniaxial (some isotropic sections giving a black cross and rings in convergent polarised light), refractive index high, double-refraction weak, extinction angle straight with the cleavage and general elongation of the crystal areas which are negative. No combination of crystal faces was seen, but the characteristic striated prism faces were observed in one or two places in the rock specimen. I think from the above that there is no reasonable doubt that the mineral is idocrase. Its hardness and other features distinguish it from corundum and its refractive index from gehlenite; its uniaxial character distinguishes it from zoisite. The locality is at the base of the east slopes of the calc-gneiss hill, ¾ mile west of Nadri, and not far from where the tank (reservoir) dam joins the hill-side.

Another locality near this, and lying ¾ mile N.N.W. of Nadri, shows the rock ($\frac{26}{327}$, 12154) composed of a few bands of idocrase associated with quantities of grossular garnet in very small grains, besides other typical calc-gneiss minerals. The grossularite, as is common in contact metamorphosed rocks, has anomalous double refraction.

Similar calc-gneisses from other parts of India.

From the above account of the calc-gneisses of these areas it will be seen that the carbonate, as well as the silicates, composing them are essentially calciferous rather than magnesian. I have detected no dolomite and none of the more specially magnesia-bearing silicates such as forsterite, brucite, serpentine, and no tremolite. In this respect these calc-gneisses are very similar to those recently described by Dr. Fermor from the Central Provinces[1] and recently again reviewed by him.[2] They also bear a considerable resemblance to the pyroxene-scapolite granulites and calciphyres of the Salem and Coimbatore districts (*MS.*

[1] *Rec., Geol. Surv. India*, Vol. XXXIII (1906), pt. 3, p. 159.
[2] *Genl. Rep., Geol. Surv. India*, Rec. Vol. XLV, pt. 2 (1915), pp. 100-2.

report by the author) in regard to the content of quartz, microcline, plagioclase, bright green augite (diopside), sphene, scapolite and calcite. But in these latter rocks garnet is represented by melanite or colophonite instead of grossularite, and epidote takes the place of zoisite, whilst there is a much greater development of scapolite. Typical examples of these from near Madukarai railway station near Coimbatore are nos. $\frac{12}{152}$, $\frac{12}{153}$ and $\frac{12}{157}$, collected by the author.

Similar calc-gneisses undoubtedly occur in Vizagapatam.

Question of origin deferred.

It would be premature to offer any remarks yet on the question of the origin of the calc-gneisses of Idar. The particular question relative to these examples is necessarily bound up with the general question of the origin of the calc-gneisses of other parts of India, certain important conclusions regarding which have recently been stated by Dr. Fermor,[1] so that the subject requires comprehensive treatment. Anticipating, also, that any explanation offered of the Idar occurrences must also include a consideration of the associated gneisses as well as of the intrusive aplite veins that are found penetrating them, it will be well to postpone remarks under this heading until after those other important and connected rock masses have been described.

(2) Non-calcareous Biotite Gneiss, associated with the Cal-gneiss.

General distribution.

Here I propose to describe a gneissic rock series, of rather limited extension, that is developed in close association with the calc-gneiss. Flanking the chief calc-gneiss areas on their eastern margins, and in juxtaposition with them, there come smaller areas of generally non-calcareous gneiss or schist, composed in the main of biotite and quartz. The foliation planes of the gneiss are perfectly concordant with those of the calc-gneiss, and they follow on them in a way which suggests direct sequence. This is apparently confirmed by the general appearance and lie of these rocks and the kind of undulating country which they compose, as well as by the fact that they are penetrated by intrusive veins of granite aplite

[1] Progress Report for 1912-13 and 1914-15 summarised in the *General Report* of the Survey for 1914, *Rec., G. S. I.*, Vol. XLV, pt. 2.

to an extent about equal and similar to their companion formation, the calc-gneiss.

Outcrops.

In addition to this eastern marginal appearance of this rock series (which will presently be described in more detail) there are a few other bands developed as follows—(1) a band east of the Golwara calc-gneiss, running N. and S. past Chandap and near Nawawas, (2) a small area south of Wasan, and (3) a poorly exposed band in the valley between Matora and Semlia. All these areas are very scattered and isolated from each other and sometimes from all other rocks by the all-pervading alluvium, just as was found to be the case with the more southerly exposures of the calc-gneiss.

Eastern exposures.

The eastern exposures are, however, the fullest and most interesting, and these must be considered in some detail. We find them best developed in a string of outcrops a few miles N.E., E. and S.E. of Khed Brahma in the neighbourhood of Walren, Dijio, Derol, Damavas and Medh, localities which will be easily picked out on the map by the separate tint allotted to these rocks. In spite of their scattered exposures it can be seen that they lie generally occupying an intermediate position between the calc-gneiss formation to the west and the foot of the Delhi Quartzite hills to the east.

A sudden change.

Although following thus directly on the calc-gneiss, with actual junction sections, as seen a little west of Walren, and with but a small intervening space, as near Medh, and although agreeing in the strike and dip of their foliation planes—which latter is about 30° in an east or south-east direction—there is no evidence of any interbedding of the calc- and non-calc-series, the junction being somewhat sharp and the change sudden and final from the one rock to the other. The relationship of the non-calc-schists to the Delhi Quartzite in the other direction is also of the nature of a sudden change with a distinct line of junction; but in this case the junction is much more complicated, and in certain features resembles an eruptive unconformity, or at least one of great plastic deformation. About this more will be said anon.

Walren and Dijio.

At the scattered Bhil villages of Walren and Dijio, where the largest exposure occurs, the outcrop of the non-calc-rocks has a width of about 1 mile and a length of about 3 or 4 miles. This may be taken as the type area. The rolling country is very irregular and considerably wooded, but numerous footpaths and cattle-tracks may be found traversing the area from Walren and Dijio to Talau, whereby it may be visited and examined in spite of the confusing details of the topography and the ever-present jungle. In this respect it is much easier of access than the quartzite hills to the east which are much wilder and steeper.

Mineral composition.

The biotite-gneiss of this formation is in every respect a well-foliated, medium-grained, black and white rock, thoroughly gneissic in texture. It never becomes of granitoid texture, nor are the distinctive and varying laminæ of different mineral composition suggestive of a crushed and foliated granite, from which it differs also in other important details of composition. These laminæ are frequently wavy or contorted, as regards the foliation planes. Specimen No. $\frac{29}{371}$ (12289, Pl. 9, fig. 1), from about 1 mile E.N.E. of Dijio, in the stream-bed, may be taken as a typical sample of one variety of the rock. Biotite and quartz are the principal, and most prominent, minerals visible to the eye. Under the microscope the same is seen to be true, the biotite appearing in great plates giving pale greenish-yellow and dark chestnut-brown pleochroism, much the same as that in some specimens of the calc-gneiss. There is also a quite perceptible amount of colourless mica in smaller aggregates of plates. The quartz is in large areas of interlocking grains, but distributed among it is a fair sprinkling of, sometimes more or less regularly bounded and isolated, short felspar grains. These show broad polysynthetic twin lamellæ on the albite plan. In sections giving approximately rectangular cleavages, and therefore nearly at right angles to the base (001) and the composition plane (010), the extinctions of the twin lamellæ on each side of their trace make angles of about 20° and 37° respectively, the average being 28°. A good cleavage across one of these sets of plates gives an angle of about 97° or 96° with the trace of the lamellæ and another across the other set gives an angle of about 90° with that set, the average being about 93°. This may be presumed to represent the true angle, α, between the base and the second pinacoid, (001) $\wedge$ (010). In sections showing no twin lamellæ, and which may be presumed to be parallel to the plane of composition *b* or (010), the extinction angle is from 26° to 32° with the basal cleavage. These data agree in indicating a lime-soda felspar with the composition near Ab_1 An_1, or coming between the andesine and labradorite groups. They are also confirmed by the birefringence, which gives interference tints of grey and pale yellow, as compared with the purple, blue and yellow of the associated quartz. The refractive index as indicated by the movement of the Becke line is greater than that of the Canada balsam.

There is a very small amount of calcite and some minute zircons in the slide. No iron ores except a little in the biotite.

There is no garnet and no diopside in this specimen, these minerals elsewhere being fairly common in rocks of this formation. Other specimens from near Walren are $\frac{26}{429}$ and $\frac{29}{430}$.

Junction of biotite-gneiss and Delhi Quartzite.

The biotite-gneiss of the Walren-Dijio area, whose mineral composition has just been under description, becomes of special interest when considered in its tectonic relations to the outcrops of the Delhi Quartzite to the east. Very fortunately, the country just here, and also to the north of Derol, gives actual examples of this junction in several clearly seen exposures. It is advisable to mention these now, and before the Delhi Quartzite itself has been described, because of their immediate interest and the assistance they give in comprehending the not very simple rôle played by the biotite-gneiss. If we follow the boundary in a southerly direction from the Walren-Talau main road at a point ¾ mile W. by N. of the 1,150-ft. hill, it is not difficult to trace it continuously in spite of the low jungle and involved hilly slopes. The Delhi Quartzite appears as composing all the spurs ascending up to the 1,150′ hill, and can be ascertained to be really *in situ*, though frequently and generally much shattered and without definite dips. Round the base of these spurs, where the angle of slope eases off into the lower-lying country, the well defined and "slabby" foliation dip-faces of the biotite-gneiss wind their way with great regularity, occupying most of the lower extremities of the spurs. The line of junction is generally complicated by intrusive vein granite (biotite-bearing aplite), but the point of chief importance is that it wanders along, sometimes V-ing up stream-beds and at other times behaving quite irrationally, but always as if a floor of the biotite-gneiss were unevenly undulating under the quartzite. In tracing this continuously to the river-bed east of Dijio, I was at first struck by the appearance of transgression of the overlying Delhi Quartzite series across the lines of foliation of the biotite-gneiss, but it was impossible to be sure that this was not deceptive and due to small undulations of the latter.

At one place, 1 mile due east of Walren, there is a detached outlier of the Delhi Quartzite forming a capping to a little N.—S. ridge and entirely surrounded and underlain by the biotite-gneiss.

Blocks of Delhi Quartzite in the biotite-gneiss.

In certain places along the main junction,—and especially $\frac{1}{2}$ to $\frac{3}{4}$ mile E.N.E. of Dijio—the edge of the alluvium of the river-valley is bounded by low cliffs of the biotite-gneiss, whose upper layers over wide areas are roughly horizontal and undulating with the foliation of the rock. These upper layers are intruded by the aplite, varying in coarseness, and among it are forced or included tongues and numerous patches of the gneiss. Among them both also, and prominently among the biotite-gneiss, are innumerable small and large included blocks and masses of the Delhi Quartzite, which as a formation, a little further along comes normally into the section *in situ* above this junction layer. Some of these blocks and masses were found to be 1 foot or so across and looked like great "eyes" followed round by the foliation of the gneiss, others were long and narrow, 4 to 5 feet long, lying with the foliation, and others again oriented in any direction. But the most characteristic were the large masses (several yards across) of the quartzite, arranged with their original bedding vertical, and as it were "planted" thus among the nearly horizontally inclined foliation of the biotite-gneiss (see Pl. 2, figs. 1 and 2). The original bedding of the quartzite was always well shown in the blocks by ordinary stratification banding and also by rows of cavernous pittings and hollows, coated with limonite, which represent lines of weathered-out minerals (see text figs. 3 and 4). These characteristic cavernous hollows were seen to be not only a marked feature of the blocks distributed in the upper layers of the biotite-gneiss, but also of the lower layers of the Delhi Quartzite which comes *in situ* above it up to a height of 10 or 20 feet at least. One may walk for hundreds of yards over uninterrupted outcrops of the Delhi Quartzite, finding quantities of this cavernous variety of the rock.

Secondary minerals developed in the blocks.

Specimen, No. $\frac{29}{372}$ (12290, Pl. 9, fig. 5) is an example of a portion of one of these blocks, broken out from the central portion of it so as to get below the skin of weathered rock. Besides the predominant quartz or the rock, a thin section of it shows a large percentage of secondary contact-minerals developed in it, garnet being very

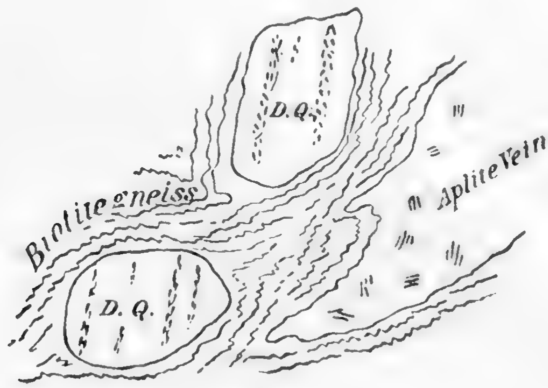


Fig. 3.

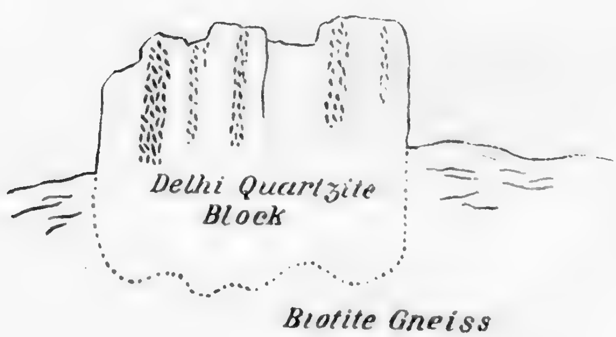


Fig. 4.

noticeable in irregular interlocking areas, diopside and probably zoisite, in similar areas and also in rather rounded grains, and wollastonite in elongated fibrous laths much intergrown with calcite. The central parts of the garnet areas are frequently composed of some aggregate of doubly refracting minerals which have not been determined. Some of this is of a rose-pink colour and appears to be pleochroic in pink and dirty yellow colours. It can be detected also in the hand-specimen. There are some very small grains of sphene distributed through the rock. No iron ores are present.

Eruptive unconformity or zone of plastic deformation indicated.

Without entering here into any elaborate discussion of the phenomena just presented, the description may halt for a moment to point out that it seems clear that the junction described is not a case of simple unconformity of the visible base of the Delhi Quartzite on the biotite-gneiss. The foundered blocks of the former, which appear to have been stoped away and engulfed among the biotite-gneiss, and the contact minerals developed in them and also in the lower visible but undetached masses of the Delhi Quartzite, undoubtedly indicate that the plane of junction is of the nature of an eruptive unconformity, or of one due to plastic deformation in a zone of rock flowage, as contrasted with ordinary shearing with cataclastic structures which do not appear.[1] The Delhi Quartzite blocks in the gneiss never show any sign of deformation or rolling out in themselves nor any form of shearing. They are just irregular blocks that, so far as their internal evidence goes, might equally well have been xenoliths torn off by ordinary igneous action.[2]

Knoll E.S.E. of Dijio.

Continuing the description of these eastern outcrops, the steep little knoll just E.S.E. of Dijio and across the stream, exposes a fringe of the biotite-gneiss at the base; and above it, occupying the knoll, its junction representative as regards the Delhi Quartzite, is a rather peculiar quartzite, $\frac{29}{373}$ (12291), coarser than usual with a sprinkling of biotite, a little white mica and some isolated grains of orthoclase and microcline. All the beds dip rather steeply at about 45° to E.S.E. In the next lower knoll to the east, ordinary Delhi Quartzite of the usual type makes its appearance ($\frac{29}{374}$). It is conceivable that the coarser quartzite of the first knoll may represent a basal variety of the Delhi Quartzite, but all evidence of original clastic structure has disappeared. No wollastonite, garnet or diopside are seen. All the quartz is very dusty with inclusions. There is only a trace of iron ore.

Section at Derol.

These formations then disappear under alluvium for a few miles, their next exposure being 1 mile north of Derol, where a low little platform of the Delhi Quartzite is partially surrounded by a rim of the biotite-

[1] See *Mem., Geol. Surv. Gt. Britain*, Structure of N. W. Highlands, 1907, p. 598.

[2] The author has recently (1916) seen even more striking discordances of this nature in Ajmer between the Delhi Quartzite of that area and the underlying calc-gneisses.

gneiss, especially at the southern and more elevated end. The biotite-gneiss is also seen in the river cliff at Derol ($\frac{25}{490}$). In the hill north of Derol a section is as in text fig. 5 but the arrangement

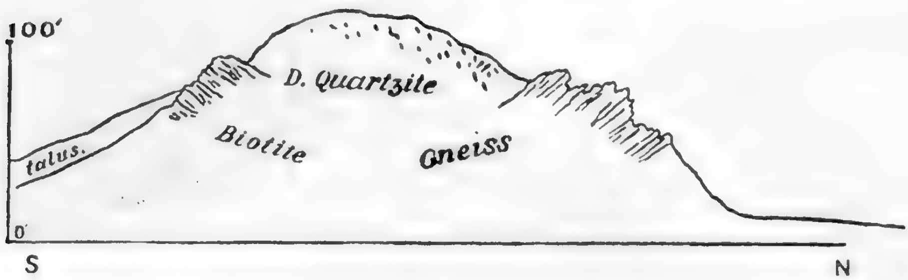


Fig. 5.

east of this becomes considerably confused, and suggestive of an irregularity of some sort at the junction. Though there is no exposure of included blocks along the junction, the Delhi Quartzite coming above the gneiss ($\frac{29}{375}$, 12293) shows, under the microscope, many characteristics of a contact-affected rock, including granular and irregular areas of garnet, diopside, zoisite and minute zircons. There is also some calcite, and the whole mass of the interlocking quartz mosaic is dusky with crowded minute inclusions.

In examining the thin sections of these and many related rocks, one is much struck by the general similarity of appearance of many of the minerals when viewed in ordinary transmitted light. Owing to the lack of distinctive colouring, the frequently granular shape and practically identical refractive index and consequent relief, the garnet, diopside and zoisite all resemble each other exceedingly. It is only with polarised light and higher magnification powers that the characteristic birefringence, position of the axes of elasticity and cleavages enable one to separate them into their proper species.

Damavas outcrops.

After crossing the Harnav river, south of Derol, there is a small exposure of the biotite-gneiss to the south-east of Kalol, and then the interesting examples near Damavas next claim our attention. The 858 ft. hill, $\frac{3}{4}$ mile E.N.E. of Damavas is a bare little prominent hill which, viewed from the south, is as seen in Pl. 3 and in outline in text fig. 6.

The biotite-gneiss ($\frac{29}{376}$, 12294, Pl. 9, fig. 6) is of greyer tint than that at Dijio, with a finer foliation and much contorted or puckered on a small scale. It is invaded by striking veins of biotite-aplite which ramify and cut across the foliation of the gneiss in a very complicated way. Near the summit, and down the descending spurs,

Fig. 6.

occur numerous enclosed blocks of the overlying Delhi Quartzite with contact-minerals as at Dijio.

Several other little hills east of this, and surrounding a dry tank (reservoir)-bed, are similarly composed, the dip of foliation being east at about 60°, and containing included blocks of the Delhi Quartzite. On the east these exposures are connected in a disjointed way with the Delhi Quartzite masses of the main hill-range.

Microscopic details.

In the gneiss of the 858 ft. hill, No. $\frac{29}{376}$ (12294, Pl. 9, fig. 6), the quartz, andesine-labradorite and biotite are much the same as in the Dijio rock, but are arranged in smaller and more closely parallel layers. There is, however, in addition, a fair amount of irregularly bounded areas of highly refracting, colourless material, which appears to be all diopside. There is also some calcite and minute zircons. No. $\frac{29}{377}$ (12295), an included block of quartzite in the biotite-gneiss of the 858 ft. hill, is very similar to the included blocks of Dijio ($\frac{29}{372}$, 12290), the contact-minerals developed being garnet, diopside, wollastonite and granules of sphene, but there is not so much garnet. The undetermined pink mineral is also visible in the hand-specimen.

Outcrops near Medh.

The next and last outcrop of the biotite-gneiss of these eastern exposures is in the low 936 ft. group of hills, north of Medh. They are completely isolated by alluvium from all other rocks, but on the west the calc-gneiss is not far away. Here, as before, the dip of foliation is easterly at about 40° and the gneiss is penetrated by aplite veins, so that the whole exposure is suggestive of a non-calcareous variant of the calc-gneiss continuing in regular sequence above it. On its other side it is some distance away from the Delhi Quartzite outcrops. No. $\frac{25}{389}$ (12296) and $\frac{25}{390}$ (12297) are both specimens from the Medh area of little hills, the former being characterised by a quartz-felspar mosaic with brown biotite plates, such as we have already noticed in the previous example at Damavas, the andesine-labradorite being much less in quantity than the quartz. Some of the basal sections of the biotite show sagenite webs as three sets of black lines of (?) rutile needles crossing one another at an angle of 60°. They are probably secondary in origin, as they accompany a partial bleaching of the dark mica. Pinkish garnet is fairly common in this rock along certain lines in the thin section in ragged granular areas. There is a noticeable amount of short rods of apatite in the rock. The latter specimen ($\frac{25}{390}$, 12297) is very similar generally, but garnet is absent, and, intergrown with the quartz areas, is some pale green, faintly pleochroic, uralitic hornblende in large ragged plates.

Specimen No. $\frac{25}{392}$ (12298-9), from south of Wasan in one of the western areas, is remarkable for the large pink garnets (12298) and areas of quartz rendered dark by swarms of included minute grains of dark green (?) garnet and biotite flakes (12299).

(3) Aplite and Pegmatite Veins intrusive in the Calc-gneiss and Biotite-gneiss.

Constant association with the calc- and biotite-gneiss.

In order to complete the geological description of the Aravalli areas occupied by the calc-gneiss and biotite-gneiss, it will be desirable now to consider the veins of more or less acid aplite material that penetrate them in a very perfect and complicated manner, the penetration being sometimes so complete that the veins have become to all intents and purposes integral parts of these masses, and any description of the one without the other would be unsatisfactory. (See Pl. 1, fig. 1 and Pl. 3.) Furthermore, these aplite veins, though not absolutely restricted to the calc-gneiss and biotite-gneiss areas, still are but seldom found outside those areas among any of the other detached representatives of the Aravalli system. Nor do they as a rule penetrate up into the Delhi Quartzite, and certainly not into anything but its lower beds in the neighbourhood of the underlying biotite-gneiss. The fact, however, that they do penetrate though rarely, the Delhi Quartzite must not be lost sight of in considering their mode of origin and age.

No visible connection with large masses.

It is not at present known to me whether or not these generally acid hypabyssal vein rocks are now in any direct connection with large plutonic masses, with which they might be assumed to be genetically related and from whose magma they presumably may have been differentiated. From first impressions there was a disposition to associate most of them with the large masses and stocks of the granite that has already been referred to and which will later on be described under the name of the Idar granite; but, opposed to this are many and serious objections. For instance, these aplite veins in the calc-gneiss are considerably different from the Idar granite, not merely as regards the scanty ferro-magnesian minerals (which show striking differences and are more varied), but also as regards the felspathic constituent of the eutectic which is considerably different in colour, and especially so in the thicker and more massive examples of them which occasionally present themselves; secondly, their outcrop areas are nearly always distinct and separate from those of the Idar granite, and there is nothing to suggest the passage of the one rock into the other on the ground, whilst, thirdly, at those few places where the outcrops of the aplite and Idar granite do approximate, the massive Idar rock is found to cut across and truncate the veins and veinlets of the other. Lastly, these aplite veins seem to have had their inception among the calc-gneiss about the period when the latter was bent into its larger earth folds; whereas, from the evidence of the truncated calc-gneiss and from other evidence, there is reason to believe that the large irregular bosses and stocks of the Idar rock were altogether posterior to such diastrophism.

We are forced to conclude then that these aplites, so far as at present exposed at the surface of the country, have no visible plutonic stock into which we can trace them, though we may, if we wish assume one at present buried out of sight at some depth below its vein equivalents. Further remarks on the debatable question of their origin will be found later at the end of this section when summarising the origin of the veins and the intruded gneiss.

A network of veins.

Though occasionally appearing in rather thick elongated exposures—as already remarked, some 50 feet thick and upwards—their more usual rôle is that of a network of veins, frequently from a few inches to a few feet wide, ramifying among, and generally parallel to, the banding or bedding of the invaded series. They are very generally discontinuous when any one is followed along its outcrop very far, and not infrequently they appear at the surface merely as eye-shaped sections, 1 to 2 feet long. Hence the individual veins cannot be mapped, except diagrammatically. The rough parallelism of the veins certainly appears as if the result of injection along lines of least resistance, and there is evidence of vague banding or streakiness among the minerals of the veins, but not amounting to or resembling in any way the foliation of a real gneiss. Chiefly on these grounds, one is inclined to regard the period of inception of these veins as approximately coinciding with that of the folding and, doubtless, dislocation of the calc-gneiss. Here as in other countries, pegmatite appears to be "the universal healer of all wounds and dislocations in the various rocks of the area" (Adams and Barlow, *loc. cit.* p. 141).

Other characteristics of the veins.

The examples in the low hills 1 mile S.S.E. of Khed Brahma are very characteristic. The width of the exposure here taken at right angles to the strike of foliation of the calc-gneiss and also to that of the general run of the aplite veins is about ½ mile and within this width there are numerous very small veins from a few inches to a foot across, and as many as 8 or 12 larger veins, 3 to 5 feet across. The veins as already remarked, show no foliation, but a rough streakiness parallel to the walls of the veins. Being white in colour and weathering white, they stand out boldly against the darkly weathering calc-gneiss. In the railway cutting 1¼ mile S.S.W. of Khed Brahma the fresh surfaces of rock show veinlets, even smaller than a few inches across, and which in some cases seem to merge into the material of the calc-gneiss, though this is probably deceptive, not being borne out by ordinary sections in which the distinctiveness of the two rocks seems fairly established.

Mineral Composition.

The material of the veins differs in the relative amounts of the white and dark minerals and in the class of felspar present, as well as in the amount of quartz and the nature of the prevailing dark minerals. These latter are characteristically scanty, as in typical aplites, and the few patches that do appear are very vague and blurred to the eye, even in the freshest specimens obtainable—as if the ferro-magnesian magmatic material had been too complex in its composition to favour the formation of any simple mineral species. Thus, examined microscopically, the dark minerals, though generally green pyroxene and its uralitic derivatives, are often biotite or garnet or groups of these together; whilst in special cases, and less frequently, appear zoisite, epidote, sphene, tourmaline and allanite. Notwithstanding these differences, the veins being too small to map, are also too small to subdivide further on the ground, especially since their differences of composition are often merged in a general superficial likeness. Whether these differences vanish by local passages or not cannot be certified on the present data at my disposal. In the country south of Khed Brahma it is not unlikely that the pyroxene-aplite is in a measure distinct from the biotite-aplite which occasionally develops tourmaline at the edges, a difference that is paralleled by the varying bands of the calc-gneiss, some of which as we have seen, are characterised by green diopside and some by biotite being in the ascendancy.

Classification.

Without necessarily implying any important genetic distinctions between the different varieties of these vein aplites, they may be conveniently classified as granite aplites and syenite aplites (from the point of view of the white minerals) and as biotite aplites and pyroxene-hornblende aplites (from the point of view of the dark minerals). Even then a few varieties would remain over, such as those with garnet or with allanite as the sole dark minerals, and a few consisting of a coarse graphic intergrowth of quartz and felspar without any dark minerals at all.

A characteristic of all these differentiated hypabyssal rocks is the practical absence of all free iron-ores in their composition as has also been seen to be the case in the calc- and other gneisses. Another negative characteristic is that they never appear as very coarse-grained pegmatites (giant granites) with very large crystalline elements or, so far as at present detected, important occurrences of valuable minerals. The following examples, which are illustrative and not exhaustive, will sufficiently describe these veins.

Granite Aplites.

Certain of these aplite veins (which, as already remarked, could not be separately mapped on the scale of the present survey) are rich in potash felspar, quartz and biotite, and obviously must be classified with the granite aplites. Of these, No. $\frac{29}{379}$ (12315), intrusive in the calc-gneiss of the low hills S.S.E. of Khed Brahma, has the usual white or grey colour, medium grain, and the scales. of biotite arranged in streaky lines, and also in eyes or nests, following the direction of the veins. These nests, or glomero-porphyritic groups, are frequently associated with a reddish-orange garnet, (Pl. 10, fig. 1). The most prominent mineral is microcline, occurring in numerous, rather small, roughly euhedral shapes, the almost square basal sections showing the characteristic coarse "grating" structure and giving extinction angles of about 15°. See (12315) second slide, Pl. 10, fig. 2. There are also many rather large porphyritic crystals, also of microcline, with roughly idiomorphic, but not very sharp, outline. Soda-lime plagioclase is practically absent from this rock. Quartz is in large and small grains and interlocking areas, fairly full of minute fluid inclusions. Micropegmatite, in small curved or elliptical areas, wanders about the microcline like a disease (in one slide). The biotite, giving pale greenish-yellow and dark brown pleochroism, occurs as scattered plates of moderate size, which are aggregated into nests and streaks. It is associated with and often surrounds a garnet grain, the mica plates being arranged parallel to the edge of the garnet. Apatite occasionally appears as an accessory, and there is practically no iron ore. There is a little dark-blue tourmaline (indicolite).

Another specimen which I select for description, as being of a different type, is from the hills ½ mile east of Damavas, No. $\frac{29}{380}$ (12316), and is intrusive in the biotite-gneiss. It is of rather an exceptionally fine grain, darker grey colour, and differs from the majority of the veins in the same neighbourhood which are of the ordinary aplite type. Perhaps the specimen is more of a fine-grained granite than an aplite. Besides biotite, there is a fair amount of silvery-white mica and some zircon. The potash felspar, though generally showing the repeated twinning of microcline, appears also to include some orthoclase. There is also a little plagioclase giving extinction angles of 16° to 20°, and which therefore is probably andesine. There is much quartz with abundant minute fluid cavities and some red-brown garnet here and there. No iron ores.

The specimen from Asai hill, S.W. of Vadali No. $\frac{26}{486}$ (12317), is a very typical example of the granite-aplite of these parts, both in its general appearance and in its composition. It is rather fine-grained, grey in colour and sparsely speckled with dark green. It penetrates the calc-gneiss in veins usually parallel to the foliation of the latter, both veins and foliated gneiss being obliquely truncated by the Idar granite of the centre of the hill. Microcline is the dominant felspar and shows very generally Carlsbad twins superposed on the ordinary microcline twinning. There is a little plagioclase, the albite twinning lamellæ extinguishing at angles of 11° to 13°, and being therefore probably albite-oligoclase. Quartz is in fair abundance. The dark minerals are green-yellow hornblende, a little iron ore and zircon.

Specimen no. $\frac{25}{506}$ (12318), from 1¼ mile west of Babsar, also a vein in the calc-gneiss, is again very characteristic of these grey, mottled, medium-grained granite-aplites. The thin section shows microcline with Carlsbad twins predominant, quartz, and a great deal of what appears to have been bleached biotite in nests, altered now to a crypto-crystalline aggregate of chlorite. There is a very little iron ore, and garnet appears here and there in the hand-specimen, but there is none in the slide.

Specimen $\frac{25}{496}$ (12319, Pl. 10, fig. 3), occurring in veins in the calc-gneiss on the west side of Dharol hill, is another rock generally similar to $\frac{25}{506}$ just described, the dark minerals being almost entirely garnet, and even this is very sparingly developed. There is abundance of quartz and the felspar, much kaolinised, appears to have been chiefly microcline and plagioclase. There is no iron ore. Specimens $\frac{25}{297}$ and $\frac{25}{498}$ (12320), also from the west side of Dharol hill, are similar examples with biotite arranged in nests and streaky lines, the quartz-felspar being much as in $\frac{25}{496}$. The biotite is very scanty and is in ragged plates and irregular aggregates of plates with pale yellow and dark brown pleochroism, intimately intergrown parallel with the uralitic hornblende. There is a very little iron ore associated with the biotite, and some apatite.

The last three examples from Dharol hill constitute an instructive series as regards the ferro-magnesian minerals, which always appearing in blurred and indeterminate patches in the hand-specimens, are observed under the microscope to be composed of garnet, biotite, and biotite intergrown with uralitic hornblende in varying mixed proportions.

Specimen $\frac{25}{481}$ (12321), from the boss on the ridge 2 miles N.N.E. of Vadali, and $\frac{25}{482}$ (12322), from the south end of Dharol hill, both being intrusive in the calc-gneiss, are also typical medium-grained grey rocks with abundant quartz and microcline, and very scarce little nests of vague ferro-magnesian minerals, probably mainly biotite and hornblende in intimately parallel intergrowths. No iron ore. There is a very little of a mineral appearing in highly dichroic elongated sections with parallel extinctions and moderate double refraction. The direction of least elasticity is at right angles to the elongation, and vibrating in this direction the transmitted light is a deep indigo-blue, whilst it is colourless in the other direction at right angles to this. The mineral is referred to tourmaline (indicolite).

Specimen $\frac{25}{486}$ (12323, Pl. 10, fig. 4), from 1 mile N.W. by N. of Medh, is a coarsely graphic pegmatite composed chiefly of microcline and quartz, but with patches of small, zoned tourmaline needles and prisms, giving pleochroism which is colourless for vibrations parallel to the elongation and yellowish and bluish-green at right angles to this. There are a few colourless garnets and some matted bundles of slender prisms of sillimanite running through the quartz. A little plagioclase—albite-oligoclase (?)—and no iron ores. Specimens $\frac{29}{387}$ and $\frac{29}{388}$ from the hills south-east of Khed Brahma are coarse graphic pegmatites with much garnet and black tourmaline.

Syenite Aplites.

The vein aplites that are grouped under this heading, without being sharply distinguished from the granite-aplites, nevertheless, as a whole, contain less potash felspar and quartz and more plagioclase, whilst the dark minerals are more consistently represented by diopside, or diopside in addition to uralitic hornblende and other alteration products, and a certain amount of biotite. Sphene also becomes a far more common accessory.

The following specimens may be taken as typical of this class of aplite intrusive in the calc-gneiss: Nos. $\frac{29}{381}$ (12324) and $\frac{29}{382}$ (12325), from localities respectively 2 miles N. by E. and hills S. of Khed Brahma, appear almost identical in the hand-specimen, but the question of the class of felspar is not clear in the former; microcline is quite certainly the dominant mineral, basal sections showing the 'grating' structure with extinctions of 15° with the lamellæ, whilst in sections giving nearly rectangular cleavage and which must be at right angles to (001) and (010), and in which also only one set of twin lamellæ appear, the extinction angle with the trace of the lamellæ and cleavage is about 19°, which is all characteristic of microcline. There appears to be no plagioclase in $\frac{29}{381}$ but in $\frac{29}{382}$ which otherwise is very similar, there is a considerable amount of—probably—andesine, the twin lamellæ extinguishing at 20° and 15° respectively on each side of the twinning line. Most of the other felspar in $\frac{29}{382}$ is too much kaolinised to be certain whether it is microcline or plagioclase of the albite-anorthite class. The quartz present is rather small in quantity. In $\frac{29}{381}$ the dark mineral is amphibole, which from the pleochroism scheme, Z = dark bluish green, Y = sap green and X = greenish yellow, appears to be common hornblende. Sphene is also present. In $\frac{29}{382}$ however, the prevailing dark mineral to the eye shows dark bluish-grey when perfectly fresh, and when altered, external zones of bluish-greenish-grey with rusty-coloured internal zones and kernels. This, under the microscope, appears mostly as pyroxene with extinction angles up to 45°, changing to uralitic hornblende in patches and marginally, with also, in one slide, a contact border of zoisite and epidote next the kaolinised felspar. There is also a little blue tourmaline (indicolite). There is much sphene, and apatite in rather large stumpy prisms. No iron ores in either of these specimens. Specimens $\frac{29}{383}$ and $\frac{29}{384}$ from the railway cutting 2 miles S.S.W. of Khed Brahma, are very similar to the above.

Specimen No. $\frac{25}{484}$ (12326), from the hills north of Gada, a pale grey medium-grained rock, also intrusive in the calc-gneiss, is superficially very like $\frac{25}{481}$ and $\frac{25}{482}$ already grouped with the granite aplites, and has the same vague ferro-magnesian mineral, showing as small dark greenish-black irregular blotches with rusty-coloured centres. There is, however not much quartz in this specimen, and the more definite presence of pyroxene and uralitic hornblende, revealed by the microscope, suggest the classifying of this as a syenite-aplite rather than a granite-aplite, or it may be a passage form connecting the two.

Specimen No. $\frac{26}{484}$ (12327), intrusive in the calc-gneiss at Vadali, is a similar grey, mottled rock, of medium grain, that must come either as a granite or syenite-aplite. Here the nests of ferro-magnesian minerals show green uralitic hornblende intergrown with biotite. The nests are arranged in streaky layers.

Specimen No. $\frac{26}{499}$ (12328), from 1 mile S.E. of Matora, is from a coarse band in vein aplite, about 6 feet thick, intrusive in the calc-gneiss. It is a particularly coarse variety with dark green pyroxene, diopside, especially well preserved ($\frac{|}{c} \wedge Z =$ over 31°). This pyroxene in the hand-specimen is of a dark greenish-grey, with submetallic lustre on the cleavage surfaces. In thin section this appears as a pale greyish-green, the central parts being sometimes a more pinkish- and greenish-grey mixed. The central parts can also be seen to be more finely cleaved along the length of the section which gives parallel extinction, being near $\frac{|}{c}$ and at right angles to the clinopinacoid (010). The rock contains some large porphyritic microclines (not seen in the microscope slide, but easily determined in the hand-specimen by cleavage flakes), a fair amount of quartz and some lime-soda plagioclase, which has mostly been converted into scapolite (probably meionite) which is prominently visible in one slide of this rock. There is also some calcite and zoisite-epidote (in one slide).

This rather peculiar, coarse-grained aplite is not improbably a rock which at contact with the calc-gneiss, into which it is intruded, has itself suffered some contact change or hybridism. Except where the large masses of microcline occupy the rock, the rest of the finer-grained material has quite a large percentage of quartz in it. There is no iron ore.

Diorite Aplite.

Specimen no. $\frac{25}{492}$ (12329, Pl. 10, fig. 5 and fig. 6 nicols crossed), from Proia, N.E. of Khed Brahma, forms a prominent cliff in the stream-bed and is intrusive in the calc-gneiss. It is a rather coarse-grained, grey and green speckled rock with a small or moderate amount of quartz. There is no microcline and the presence of orthoclase is doubtful. There is much plagioclase in long lath-shaped sections (albite-oligoclase and (?) also andesine) with albite, pericline, and also Carlsbad, twinning. Diopside, changing to uralitic hornblende, is characteristic and there is much sphene with accessory apatite. Besides the diopside and slight marginal uralite there is also a further border of zoisite, passing into epidote, lying outside the hornblende and coming next the felspar, as was noticed in the calc-gneiss of the same locality ($\frac{25}{385}$) and also in the Khed Brahma vein rock (see sp. $\frac{29}{382}$, 12325). In these cases it seems suggested that the zoisite is a contact effect on the felspars of the uralitisation of the diopside.

Allanite Aplite.

With Allanite.

Two miles N. by E. of Khed Brahma, and forming a long straggling tongue of scarcely exposed rock, running out into the plain southward from the main hill-mass behind, is an exceptional variety of the vein granite permeating the calc-gneiss, $\frac{26}{490}$ (12330). It is remarkable for the fact that the only dark minerals represented in it are allanite and sphene. The allanite largely predominates in rather small elongated grains $\frac{1}{4}$ to $\frac{1}{2}$ inch long by one-sixteenth inch wide. The grains are roughly aligned more or less parallel to the edge of the vein, making a rough streakiness not amounting to banding. They are sometimes of good crystal outline, sometimes ill-defined grains constituting a centre for some other decomposed mineral (? diopside or uralite). The allanite is of pitchy lustre and fracture, black colour (greenish by transmitted light, when it has the appearance of bottle glass). Under the microscope it is of pale bluish-green colour, centrally, with an outer yellowish-brown or orange-coloured border, which sometimes extends into the other minerals of the rock, staining them. It is not pleochroic, being generally also abnormally isotropic, except for a few patches which show double-refraction tints. It has no regular cleavage, but a set of more or less parallel cracks traverse the crystal. Radiating cracks also traverse the mineral surrounding the allanite in neighbouring specimens ($\frac{26}{490}$, 12331, Pl. 11, fig. 1 and $\frac{26}{492}$, 12332). Before the blowpipe it swells up slightly and glows a little, yielding a greyish slag-like mass. It dissolves in hydrochloric acid, but not after heating. I hesitated to choose between allanite and gadolinite for the mineral until a chemical examination of it, made for me by Mr. Tipper in the Geological Survey laboratory, gave the following results:—specific gravity 3·12 (which is much too low for gadolinite); it contains much water, and gelatinises at once with strong hydrochloric acid; it contains silica, iron, alumina, cerium earths with traces of yttrium and erbium, calcium and the alkalies, but no beryllium. From this analysis the mineral is clearly not gadolinite. It is associated in the rock with a fair amount of sphene, some zircon, besides much microcline, plagioclase with bent lamellæ, and quartz. In specimen $\frac{26}{492}$ (12332), a variety found near $\frac{26}{490}$ there is also present uralitic hornblende in ragged plates and long section. Other specimens are $\frac{26}{491}$ and $\frac{26}{493}$ numbered in order according to their proximity to $\frac{26}{490}$. The bands of the granite with allanite prominent, are about 6 inches to 1 foot thick, following a rough parallelism in the veins.

$\frac{26}{322}$ (12147), is the calc-gneiss associated with the above. Allanite has been discovered before in coarse pegmatites in India* (see specimens found by Sir Thomas Holland and myself near Andiguppanur, Salem district, Madras Presidency (see General Report, Geological Survey of India, 1897—1898. p. 19), and analysed later by Mr. F. R. Mallet, but only as isolated lumps). This is the first instance, so far as I know, of it constituting almost the sole ferro-magnesian mineral in a rock of medium grain, and not as a mere accessory, with the exception perhaps of the Nellore pegmatite described by Mr. Tipper,[1] which also contains samarskite. It is of interest to note, however, that gadolinite, which often accompanies allanite and other minerals of the rare earths in pegmatites, has been recorded by Babu Baidyanath Saha in the neighbouring state of Palanpur in a tourmaline pegmatite, together with distinct, large crystals of cassiterite.[2]

It will have been noticed in the preceding descriptions of these various aplites that micropegmatite and also coarse graphic structure in the quartz-felspar have seldom been referred to. Such structure is more common where the accompanying dark minerals disappear nearly or altogether, although even then it is not universal. At the following places, these more purely quartz-felspar varieties have been observed, but the list is not exhaustive: the 858 ft. hill near Damavas ($\frac{25}{488}$) near Medh ($\frac{25}{487}$) and ($\frac{25}{485}$) being the same locality as $\frac{25}{486}$ already described, p. 37, south of Vivau and 3 miles N. by E. of Vadali ($\frac{25}{483}$) and from near Khedwa ($\frac{29}{389}$) the last being a beautiful, coarsely graphic granite with no dark minerals.

Other analogous vein granites.

There does not seem to be much analogy between the aplites of Idar State and the granites and pegmatites of Chhindwara lately described by L. L. Fermor in connection with his description of the calc-gneiss and other associated rocks in the Central Provinces (see footnote, p. 21). In Ceylon, however, the granites and pegmatites of the Balangoda group described by A. K. Coomara-

* It also occurs in large quantity in a coarse pegmatite associated with megnetite, at Karadikuttam Pattiambodikutru in Madras District.

[1] *Rec., Geol. Surv. India*, Vol. XLI, pt. 2, p.

[2] Misc. Note by T. H. Holland, in *Rec., G. S. I.*, Vol., XXXI, pt. 1, p. 43 (1904).

swamy (*Geol. Mag.*, August 1904), have some similarities, especially in their mode of occurrence as narrow and often lenticular masses cutting disordantly across the foliation of the charnockite series and in the diverse nature of the dark minerals present. The occurrence of allanite granite as one member of this series is noteworthy, and in particular the reference (*loc. cit.* p. 421) to the allanite as "forming a centre for radiating cracks in the rock giving it a rather conspicuous appearance"—which agrees with my own observations of the allanite in $\frac{26}{490}$ (12331) and $\frac{26}{492}$ (12332) (see p 40).

(4) Origin of the Calc-gneiss, Biotite-gneiss and their Plexus of Aplite Veins.

Before proceeding to the description of the neighbouring Kherod series of metamorphic limestone and amphibolite, and before passing to the other more distant and disconnected members of the great Aravalli complex, it will be well to clarify our conception of the series so far described by considering the question of their genesis, in so far as this is in any way involved with, or inspired by, the foregoing descriptions of them.

No evidence of a sedimentary Origin.

From some of the leading features already alluded to in the preliminary remarks on the Aravallis as a whole, and from the facts of structure and composition of the calc-gneiss already presented in some detail in a previous section, it is clear that the latter in its present highly crystalline, foliated state reveals no indisputable evidence of a sedimentary or clastic origin; exposes no lithological sequence that might be regarded as dimly corresponding to a varying set of beds formed like modern calcareous, argillaceous and arenaceous deposits. We cannot point to any conglomerate, any waterworn or water-distributed material, any bedded, false-bedded or interbedded arrangement of such material and of course no trace of organic remains. If, therefore, the calc-gneiss series in its ultimate and original state was deposited by any process akin to present-day sedimentation, we must acknowledge that all signs of such a process have been obliterated, and the whole of the material rearranged molecularly into fresh and often new mineral forms.

It must of course be conceded that the large amount of general evidence bearing on the metamorphism of known sedimentary calcareous rocks (on a relatively small scale) makes it verbally intelligible that such an all-round metamorphic transformation of great thicknesses might conceivably have taken place. In support of this it is only necessary to allude in passing to such well-known instances as those of the Coniston limestone and Mountain limestone in contact with the Shap granite and the Whin Sill respectively, so carefully worked out by Harker and Marr[1] to establish the fact that very similar sets of highly altered calcareous rocks with identical contact minerals may locally, and on a small scale, be produced from what is elsewhere a sedimentary series among the historical rocks. Unfortunately in India, wherever calc-gneisses (including crystalline marble beds) of the character of those above described in Idar, have been found, they never, so far as I know, have been traced across the country into any unmetamorphosed and easily recognisable calcareous sedimentary series; and the converse of this is equally true in those areas of (for instance) Vindhyan and Cuddapah rocks, where, over enormous areas to be reckoned in hundreds of miles, definitely stratified sedimentary series embracing calcareous, shaly and arenaceous deposits, in clean and well-defined horizons (notwithstanding their containing no fossils) equally never show any local passage into rocks in any way resembling those here defined as calc-gneiss. Whether, then, we contemplate these calc-gneisses of the Aravalli region, those of Coimbatore and Salem in Madras, those of the Central Provinces described by Fermor and Burton, or those of Vizagapatam or Burma, we are obliged to admit that so far there has appeared no particular proof, adequately linking each of them with any clearly avowed sedimentary series. Hence, in the past, attempts have been made[2] to explain much of the crystalline limestone and calciphyre content of such calc-series by referring them to alteration effects of lime-bearing silicates of an original pyroxenic orthogneiss, whose nature is necessarily assumed to have been deep-seated and magmatic. Such views, however, are not much in favour at present, so that I propose at once to examine the question from the more conservative standpoint of the Idar calc-gneiss being a metamorphic sedimentary series—a supposition that will also receive important support later on when the Mundeti series of allied calcareous rocks is described (see p. 53).

[1] *Q. J. G. S.*, xlvii (1891), p. 266.
[2] Judd and Barrington Brown, Phil Trans. Roy. Soc. Vol. 187 A, p. 205.

Suggested contact effect of the aplite veins.

With this end in view, it is obviously necessary to turn to one factor in the problem that manifestly might seem more or less possibly accountable for the specially mineralised condition of the calc-gneiss, namely, the plexus of aplite veins, or possibly the intrusive masses of the Idar granite. Neglecting the letter for the moment, does the calc-gneiss throughout its great thickness and great development of calc-silicate minerals, owe its present condition to thermal and contact effects of the aplite veins on lime-bearing sediments? Here the great doubt that obtrudes itself is the small volume of the vein material compared with that of the rock intruded by it. Notwithstanding the wide dissemination of these veins and their striking, white appearance, the total mass of them appearing at the surface is not very considerable. At p. 33 I have defined a characteristic section across half a mile of calc-gneiss country. There, at most, 12 veins of 5 feet thickness each can be allowed. That is to say a thickness of 60 feet of the aplite must be accountable for thermal contact effects extending through an apparent thickness of more than 2,500 feet; or, distributing the 12 veins equally across the section, the gaps would be 220 feet in width across which the contact action of 5 feet of igneous rock would have to be imagined as operative.

These conditions certainly seem to imply an insufficiency of igneous rock to account altogether or primarily for the highly mineralised condition of the gneiss, though at the same time we cannot disregard the circumstance of their ever-present ramification through the calc-gneiss in a very intricate way, and also the possibility that they may connote the presence of more extensive parent granites situated possibly not far below the present surface.

Suggested influence of the Idar granite.

Turning now to the masses of the Idar granite, it may be remarked that the addition of idocrase to the calc-gneiss, developed in considerable quantity quite close to the granite and nowhere else (see p. 20) seems to mark one narrow aureole of this contact influence, a conclusion borne out by a very similar development of idocrase quite close (within a few feet of) the same granite where it is intrusive in the possibly related Mundeti series presently to be described.

The question whether we can admit the Idar granite masses as also responsible for the general crystalline condition of the main body of the calc-gneiss—imagining the latter as an outer and very wide aureole of more moderate metamorphism—is however considerably uncertain. As in the case of the aplite veins, there may be vast unseen developments of this granite hidden from view by alluvium and other surface rocks.

This exhausts all the available contact thermal action of well-defined igneous bodies that we can appeal to in this area to account for the mineralisation of the calc-gneiss; and there only remains, as possibly coming under suspicion, the biotite-gneiss.

Possible action of the biotite-gneiss.

The question whether the biotite-gneiss might be regarded as an ancient orthogneiss that induced this metamorphism at the same time that it stoped and assimilated xenoliths of the Delhi quartzite, may well be given a short consideration. One difficulty here is that the biotite-gneiss is not an ordinary granite gneiss. The felspar, which is in small proportion, is a lime-soda plagioclase, whilst the enormous percentage of quartz is much above that of any ordinary igneous rock. But even here again it should be noted that on Daly's eclectic theory of igneous rocks[1] (whereby granites and other acid and intermediate plutonics are regarded as mixtures of an underlying fluid basic shell, reacting on and absorbing its acid and sedimentary crust rock-cover, the resulting "syntectic" subsequently crystallising out into various magmatic differentiates) one might regard a rock such as my biotite-gneiss as being a granodiorite unduly acidified by absorption of the material of the Delhi quartzite, as indicated by its stoped contact with the latter.

One cannot, then, dismiss this explanation as being entirely inadequate, although there is no positive field evidence that would in any way support the idea of the biotite-gneiss being a foreign eruptive rock among the calc-gneiss, with which, on the contrary, it shows a parallelism of foliation and of general aspect, as if it had arisen in some similar way.

Regional metamorphism.

There still remains the explanation that the calc-gneiss and the biotite-gneiss have both alike been derived from a pre-existing sedimentary series by sustained and perhaps periodic regional metamorphism (dynamo-metamorphism). It seems to me quite admissible that dynamo-metamorphism, resulting in rock deformation so intense as to produce rock-flow, might have brought about all the mineral

[1] "Igneous Rocks and their Origin" by R. A. Daly, New York, 1914.

and structural reconstitution necessary to provide, not only the calc-gneiss of to-day in all its slightly varying forms, but also the biotite-gneiss and the peculiar stoped contacts with inclusions in it of the Delhi quartzite.

If this be granted, we might even go further and regard the subsequently intruded plexus of aplite veins as also explained on some such hypothesis as Lane's "selective solution" or differential fusion theory (quoted in Daly's "Igneous Rocks and their Origin," p. 370), which is as follows :—

"During intense regional metamorphism, especially of the dynamic kind, deep-seated rocks, charged with much interstitial water, may reach the relatively low temperature at which minerals corresponding to the quartz-felspar eutectic go into solution with the water and other volatile fluxes. Such small locally generated pockets, lenses or tongues of fluid may be driven through the solid country rock for an indefinite distance; subsequently to crystallise with the composition and habit of the true batholithic derivatives. It is thus quite possible that these particular rocks, though truly magmatic, have had no direct connection with abyssal injections."

The same hypothesis would also help to explain the appearance of partial interchange of material between the aplites and the intruded calc-gneiss.

Details of the problem still lacking.

In the few remarks above I have confined myself to what may be regarded as plausible, general hypotheses to account for the chief features of the local problem, on the basis of the rocks being essentially, and at first hand a sedimentary series. In describing in a later section (see p. 53) the Mundeti series, distant some 8 miles away from the nearest outcrops of the calc-gneiss, it will be shown that they offer pertinent evidence making this fundamental assumption highly probable. At the same time it should be noted that none of the problems regarding the detailed history and order of development of the calc-gneiss minerals from such a sedimentary series have yet been directly touched upon.

Views of Fermor and Burton.

It will be well for a moment to see how these local results compare with others recently expressed. The larger and more general problem of the calc-gneisses as a whole is one that has recently attracted much attention, not only in India, where my colleague Dr. Fermor has gone very systematically into the question,[1] but elsewhere, as

[1] *Rec., Geol. Surv. India*, Vol. XXXIII, pt. 3, pp. 168-171, (1906); also *Mem., G.S.I.*, Vol. XXXVII, p. 299, (1909), and *Genl. Rep., G.S.I.*, for 1914, *Rec., G.S.I.*, Vol. XLV, p. 2.

at the 12th International Geological Congress at Toronto, where the subject was discussed. The most recent pronouncement of opinion of this Department (one may say) is that of Dr. Fermor and the late Mr. R. C. Burton, as expressed in the annual report referred to above which was based on progress reports for the year 1912-1913. Quoting from this :—

Mr. Burton regards the crystalline limestones as derived from sedimentary limestones of various degrees of purity, and accepts the formation of mica, pyroxene, amphiboles, and chondrodite, as due to the recrystallisation of the original impurities in the limestone, with pneumatolitic addition of fluorine; but the felspar in the quartz-pyroxene gneisses he regards as in part of pneumatolitic origin. He thus favours in the main the recrystallisation hypothesis. During the past season's work (1913-14) Mr. Burton had the opportunity of devoting further attention to these calcareous rocks as developed in the Balaghat district. This led to an interesting development of ideas, so that whilst Mr. Burton still supposes that the calc-silicate minerals of the calc-gneisses (calc-granulites) were in part derived from original impurities in the calcareous sediments, he lays stress on the fact that the predominant felspar is microcline with varying amounts of orthoclase, plagioclase being present only in small amount or altogether absent. He deduces that this microcline was derived from the associated ortho-gneisses during folding, when the latter became re-fused and attained the condition of an igneous magma containing gases and pneumatolitic agents. The felspars both of the calc-gneiss and of the ortho-gneiss show quartz inclusions (*quartz de corrosion*), and this, Mr. Burton thinks, indicates that the calc-gneiss and the ortho-gneiss must have crystallised under the same conditions of pressure, indicating that the calc-gneisses are really mixed gneisses which have recrystallised under plutonic conditions.

A footnote to the above quotation states that "during the present field-season (1914-15) Dr. Fermor has accepted Mr. Burton's idea that these rocks are mixed gneisses and both he (in Chhindwara) and Mr. Burton (in Balaghat) have arrived at the conclusion that the hybridism has, at least in part, been effected by the *lit-par-lit* intrusion of the calcareous rocks by an acid magma."

Trend of modern opinion.

It is of considerable importance to the subject of petrogenesis generally to note that an acceptance of explanations on the above lines for the origin of the calc- and associated gneisses, and perhaps for the vein rocks too, commits one to the view that the distinction between para- and ortho-gneiss, and, by implication, that between sedimentaries and igneous rocks (owing to mutual assimilation or hybridism), can no longer be regarded as a hard-and-fast distinction : that the barrier breaks down, in fact, under sufficiently intense conditions. The more conservative view, that magmatic differentiation from more or less separate or connected magma reservoirs at unknowable depths is responsible for all the varieties of igneous rocks, does not seem to stand the strain of modern arguments as exemplified in recent petrological and geophysical writings, such as Daly's elaborate treatise (*loc. cit.*) and the concise but extreme form of the same ideas by Stanislas Meunier.[1] The researches of H. Jeffreys[2] on the viscosity of the earth, which have led him to conclude that the earth as a whole is plastic and that the lithosphere has the hydrostatic form to a high degree of accuracy, must also seriously influence our conceptions of the physical conditions underground at great depths, and of the amount of molar and molecular readjustments (deformations) that must be continuously at work with their accompanying dynamic metamorphism.

Mylonitisation and plastic deformation.

Before closing this account of the calc-gneisses and other associated rocks, it is necessary to remark on the crushed examples, Nos. $\frac{29}{337}$—$\frac{29}{340}$ (12142-12146), from certain narrow and straight bands in the railway cutting near Khed Brahma (see p. 18). These show a series of stages in the progress of mylonitisation of the calcite ground-mass. Effects of this kind have frequently been noticed in crystalline limestones, and were long ago adduced as evidence of dynamic stresses acting on the rock since solidification.[3] Such destructive cataclastic effects, however, are now generally interpreted as belonging to a comparatively recent crushing which has taken effect locally near the present surface of the ground in the 'zone of fracture,' as contrasted with the more general deep-seated phenomena we have been considering in the 'zone of flow'[3] where plastic deformation, embodying crushing with recrystallisation and foliation (constructive dynamic action) has resulted in a widely different order of effects. The former are rare in the crystalline rocks of this part of India, the latter are universal in the Archæan, and, though showing no crystal fracture now, may none the less imply a far intenser phase of dynamic metamorphism.

Here we must leave the problem for the present until other facts in neighbouring areas of what may be related rocks, have received due attention.

[1] *Proc. Acad. Nat. Sc.*, Philadelphia, Vol. LXVII, pt. 2, p. 351, (1915).

[2] *Mem., Roy Astr. Soc.*, Vols. LX, LXXV and LXXVI (1915) as reviewed in the Geological Magazine for March, 1916, by A. Holmes.

[3] Geological Structure of the N. W. Highlands, 1907, p. 598.

(5) Amphibolite Limestones of Kherod.

This series of partly calcareous rocks, although it has some features in common with the neighbouring calc-gneiss, is nevertheless sufficiently different in many ways to require separate treatment, and to be coloured separately on the map.

Distribution and Surface Features.

If the rather uniformly elevated country, occupied by the calc-gneiss and lying to the north of Khed Brahma be followed northwards, it will be seen to come to an end along a somewhat sharply marked N.E.—S.W. line coinciding with a few low summits among which are the points marked 1137 and 1123. Here, in fact, the level drops suddenly, over a low "ghât" or scarp, down to the alluvium of the Sabarmati valley, where are situated the villages of Dan Mauri, Nau and Kherod. This valley, however, is not entirely occupied by alluvium. Rising out of it there are a few disconnected, strongly accentuated, low and narrow, strike ridges, which follow a N.E.—S.W. direction parallel to the scarped edge of the calc-gneiss. Several of these may be seen round about Nau, Kherod and Timri, and similar, but more connected, little ridges may also be discerned on the other side of the river in Danta State, and away again to the north-east in the direction of Posina.

Their aspect is in many ways distinct from that of the calc-gneiss country, and their peculiarities of contour are fairly well reflected in the hill-shading of the 1″=1 mile sheets. This sudden drop in altitude, and the change of aspect in the country-side, presage the incoming of this somewhat different set of rocks—the amphibolite limestones of the Kherod neighbourhood—of which a short and rather imperfect account will now be given. Owing to local conditions I was unable to complete the examination of them in their most northern continuation as far as Posina, and I was also not allowed to do more than make a short excursion across the river into Danta State.

Sharp junction with the Calc-gneiss.

The rocks are fairly well exposed near Khered in the stream-beds and in the Sabarmati river-bed, as well as in the little ridges before alluded to. The sections are not, however, continuous right up to the calc-gneiss owing to alluvium; so that one could not be certain as to the nature of the junction. It appears to be rather definite and sudden, at least so far as the absence of any interbanding of one with the other is concerned.

Field relations of the Amphibolites.

The rocks, as here exposed, and as also beautifully seen in the gorge of the Sai River about $1\frac{1}{2}$ miles above where it joins the Sabarmati, are a dark grey, rather fine to medium-grained crystalline limestone, as a basis, in which are developed very closely packed, thin, parallel layers of basic hornblende-bearing rocks of a very fine grain, the origin of which is not very clear. They have not the typical aspect of epidiorites, but closely resemble in many particulars the amphibolites described by Adams and Barlow[1] in Canada. The amphibolite layers are frequently very thin, from $\frac{1}{4}$ inch to 1 or 2 inches across, and these again are banded in still finer parallel layers of varying tints of greenish-grey and black, arranged parallel with the banding or bedding of the limestone, so that in a single hand-specimen of the rock one may have a number of these bands present. In the main river-bed at Kherod and in the gorge in the Sai river, they are practically vertical as regards this banding or bedding, but nearer towards the calc-gneiss they appear to underlie the latter with a dip of about 60° S.E. They sometimes have a contorted or gnarled aspect. As regards their typical dark colour and compact structure, as well as the general absence from them of the white aplite veins, they contrast very noticeably with the paler and more coarsely crystalline calc-gneiss. In the Sai gorge there are exposures of vertical cliffs of bare rock, 50 to 60 feet high, with the regular and close interbanding of the amphibolite with the limestone as shown in the sketches (see text figs. 7 and 8).

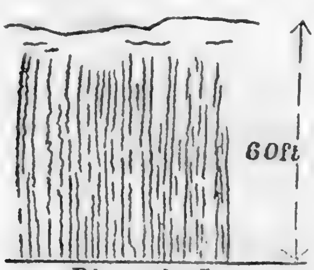


Fig. 7.

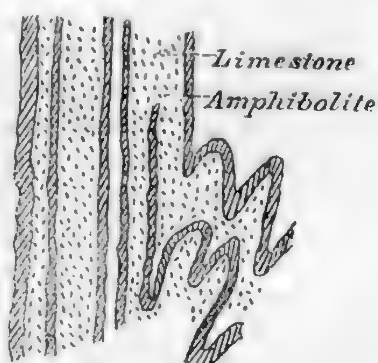


Fig. 8.

[1] Geology of Haliburton and Bancroft areas, Ontario; *Dep. of Mines, Geol. Sur. Branch, Mem.* No. 6, 1910, p. 157.

Microscopical Characters: the Limestone.

The limestone basis of this Kherod series, as represented by specimen No. $\frac{26}{341}$ (12333), from the hill 1 mile north of Kherod, is a rather dark grey moderate to fine-grained crystalline marble.

There is a little iron-ore in opaque small grains, and likewise a trace of some other doubly refracting mineral that has not been determined.

The Amphibolite.

The highly complex bands of amphibolite vary somewhat among themselves, but all contain a ground-mass of scarcely resolvable, finely granular quartz felspar mosaic, in which, nevertheless, occasional short stumpy crystal plates of plagioclase can be distinguished as in $\frac{26}{332}$ (12335), from just east of Kherod in the stream-bed. Sphene in irregular, rather small granules, but sometimes with rough crystal outlines is universal. There is also a fair amount of very minute plates of colourless to pale greenish-brown biotite, a very little scapolite and some iron ores. All these make up a microcrystalline ground-mass, and among this appear large, more or less regularly aligned, ragged, hornblende blades. According as these latter are present, (1) more or less sparingly scattered, or (2), thickly aggregated into a matted mass, the differently coloured layers within the bands of amphibolite are recognisable in most of the hand-specimens, and are even comprised in a single thin microscopic preparation.

The Amphibole.

In many cases where these bands are paler than usual, it is seen that the amphibole as in $\frac{26}{331}$ (12334), quoted above is often one large, elongated, ophitic plate developed around the other constituents of the ground-mass. It is crowded with lacunæ filled with grains of the ground-mass, and is bordered by such an irregular, tattered outline that one can only refer the mineral to amphibole by its general colour, refractive index and extinction angles, and by analogy with other cases, as in $\frac{26}{332}$ and $\frac{26}{333}$ (12335 and 12336), where the blades are more distinct in outline and give a pleochroism, Z, yellowish-green, X and Y, pale yellow, and an occasional basal section with the characteristic amphibole prismatic cleavage. In some cases the iron-ore is seen to be pyrite, especially in $\frac{26}{334}$ (12337, Pl. 11, fig. 2), from $\frac{3}{4}$ mile east of the junction of the Sai river with the Sabarmati, above Kherod.

'Feather' Amphibolite.

Where the darker bands become coarser in grain and the blades of amphibole more pronounced, the latter still have the 'filigree' appearance so well marked that their resemblance to the variety named 'feather amphibolite' by Adams and Barlow (*loc. cit.* p. 158 and plates XXXVII and XXXVIII) is very striking indeed, except that I have not seen in my area any specimens so coarsely crystalline as those of the Haliburton and Bancroft area. In nearly all other respects, the identity in the habit of the amphibole and its associations with the ground-mass, and finally the closely set, banded arrangement of the amphibolite with the crystalline limestone, is almost an exact counterpart of those described and figured by Adams and Barlow. The only principal mineral not found by me in these rocks, and recorded by the authors above, is pyroxene.

Chiefly owing to this absence, and to the suddenness of the change to the calc-gneiss with abundant diopside, has it been impossible to link the one rock (amphibolite) with the calc-gneiss. It is possible, of course, that the junction may not be a natural, but a faulted, one; in which case any transition layers might have disappeared in the break.

The rocks as exposed in the more continuous little ridges a short distance across the Sabarmati river in Danta State were only glanced at hurriedly by me. So far as they were seen, they suggested dark grey marbles weathering a yellowish-grey colour, with a little phyllite containing small garnet grains.

In the bed of the Sabarmati river one solitary band of fine-grained biotite-granite, six feet in width, No. $\frac{26}{512}$ (12339), was observed as the sole intrusive rock in the area. It cuts discordantly across the edges of the amphibole limestone, but was more of the nature of a fine-grained variety of the Idar granite than of the aplites so characteristic of the calc-gneiss.

Uncertain origin of the Amphibolite Limestones.

In the area covered by this description (partly perhaps owing to the limited exploration which I was able to effect owing to the season, lack of water and other reasons) I was unable to come to any conclusions, from the local evidence, as to the origin of these rocks, especially with reference to the question whether *lit-par-lit* intrusion, or metamorphism of impure calcareous sediment, was the method of their inception. Their similarity to the series described by Adams and Barlow is, however, of so striking a nature that it may be allowable to apply the explanations offered by the above authors as being at least probable in this case.

They consider (*loc. cit.*, p. 157) that the amphibolites of the Haliburton and Bancroft districts "include rocks of very diverse origin, but which, under the intense action of the metamorphic processes to which they have been subjected, have acquired a certain and often striking community of character and composition."

That some of them are intrusive in their nature is considered proved by their cutting across the edges of the beds of crystalline limestone. On the other hand the authors say, p. 166 :—

"It is, for instance, quite possible that the amphibolite may be derived in part from the recrystallisation of volcanic ashes thrown out from volcanic vents. . . ."

The sedimentary origin of the 'feather' amphibolite is said (p. 169) to be most clearly shown by passages into areas of much less altered limestones which in many cases are blue in colour.

On the whole I should imagine that Adams and Barlow would have interpreted such rocks as these at Kherod as having had a metamorphic origin. Consider the following remarks, p. 158 :—

"The several bands are sharp and well-defined, but differ in colour, owing to the darker constituents being relatively more abundant in certain of them. In certain cases there is also a difference in size of the grains of the several bands. This parallelism gives to the minerals in the rock the appearance of a bedded deposit which it probably is in many cases, especially when it is interbedded with thin layers of limestone. . . . . . . "

(6) Mundeti Series.

Isolated from other Aravallis.

Between the group of more or less connected members of the Aravalli system so far described (namely the calc-gneiss, biotite-gneiss and amphibolite-limestone, together with the aplite veins intrusive in the two former) and the Mundeti series whose description will now follow, there exists a gap, 8 or 9 miles wide, where only alluvium with no solid rock is met with. Hence the Mundeti series is not linked up by actual exposures with any member of the previously described Aravallis.

Comparisons with the Calc-gneiss and Kherod series.

Furthermore, this series is, at least superficially, different in character,—sufficiently different in fact to bear the new and local name of the Mundeti series; and, as in the case of the Kherod series, it is entirely destitute of any plexus of aplite veins. Nevertheless, as we proceed with the detailed statement of this new series of rock types, we shall find that there are not wanting features connecting certain of them, as regards their mineral composition, with the calc-gneiss and possibly with the Kherod amphibolite series—a point that, if it can be accepted as established, will be of the utmost importance in elucidating the origin of the two latter.

General features and position.

In geographical position this series will be seen to constitute one rather conspicuous hill 2 to 3 miles north of Mundeti, and a number of smaller ridges dotted about in the plain near Dhechania, Sisasan, Malasa and Kasangod, with very occasional stream-bed outcrops and exposures in wells—making up altogether only a very small, scattered area of more or less disconnected outcrops. As a whole these Mundeti rocks are generally dark, but sometimes pale-coloured, compact and generally only moderately metamorphosed, calcareous, arenaceous and even slaty rocks, so that their originally sedimentary nature seems beyond question. Chiefly on this account, but also because of their strange position interrupting the strike of two neighbouring Delhi Quartzite masses, it was naturally, at first, doubtful whether they were more related to the Delhi Quartzite than to the Aravallis, or whether they even represented some lower series of the former corresponding for instance to the Raialo limestone of N.E. Rajputana. As however, I have been unable to establish any relation, other than one of a discordant nature, between them and the Delhi Quartzite, and as they cannot very well be imagined as younger in age, it follows that they must be considerably older, and so come, at least provisionally, among the Aravallis as at present defined.

Dip and strike: lithological varieties.

The largest hill-mass of this series lies between 1 and 3 miles north of Mundeti, presenting a steep, rugged and jungle-clad surface, and comprising three summits marked on the 1 inch = 1 mile maps as 1333, 1263 and 1153, respectively. The greatest width across the strike is one mile. The direction of strike throughout these exposures and also those in the smaller outcrops, remains steadily N.E. by N. and S.W. by S. and the dip S.E. by E. at angles varying from 45° to verticality, but generally being between 50° and 30°. The bedding appears distinct and sharp, being accentuated by a continuous interbedding of two or three varieties of rock, one of which is a more or less compact or finely crystalline, dark grey limestone, another a compact, hornstone-like rock, of from white to grey and dark greenish-grey colours, and a third a black slaty rock, particularly well seen, interbedded with the preceding types, 1 mile S.W. of Sisasan and also in the little ridge N.E. of Dhechania. There is one more type of sandy rock, that is worked and exported for making hones, found near Malasa.

Calcareous variety.

Taking for descriptive purposes these varieties in order, the more calcareous kind such as $\frac{29}{392}$ (12341), from S.S.W. of hill 1153, three miles north of Mundeti, is a dark, banded, grey rock, fairly compact, looking rather like the limestone that constitutes the basis of the Kherod series, but not so crystalline. In thin section under the microscope it is seen to be a very finely equidimensional, granular rock, composed of what appears to be equal amounts of minute granules of diopside and calcite, a small percentage of quartz or (?) quartz-felspar mosaic, and a few minute plates of biotite and aggregates of iron-ore (pyrite).

The grains of calcite are seldom large enough to show typical rhombic cleavage and twinning, as is universal in the calc-gneiss and amphibolite-limestone, but these can occasionally be distinctly made out with high powers near the edge of the thin section. The very high order interference tints and moderate relief are everywhere sufficiently characteristic of calcite grains, just as the behaviour of the rock itself in the field and its reaction with cold acid is also characteristic of limestone.

The very pale, bluish-green, highly refracting and moderately doubly refracting grains, that I consider to be very small diopside grains (coccolite), have all the appearance of minute grains of diopside as seen in the calc-gneiss of the Vadali neighbourhood, but no euhedral shapes or cleavages other than irregular cracks can be seen. Large interlocking "filigree" areas of these grains include within themselves granules of calcite and quartz and frequently behave as single ophitic or poikilitic crystalline units, extinguishing together and showing uniform interference colours, after the manner of the "filigree" amphibole crystals in the Kherod series. Wherever these areas show any tendency to elongation the extinction angle is wide, as would be characteristic of pyroxene rather than amphibole.

The plates of biotite are similarly ragged and frequently enclose grains of calcite, the pleochroism being very pale straw-colour at right angles to the basal cleavage, and slightly greenish-brown parallel with it. There is a very little sphene here and there discernible.

From the above description it will be seen that we appear to have (on a minutely crystalline scale) a replica of one of the commonest types of the calc-gneiss such as has already been described from the Vadali area, *e.g.* $\frac{25}{381}$ (12136), (see pp. 14 to 16), but without any microcline or other prominent felspar.

Specimen No. $\frac{26}{432}$ (12349), a compact, dark, blue-grey limestone with pyrites, from 1 mile N.E. of Malasa, is a more simple limestone belonging to this series and showing in thin section a very minutely crystalline granular aggregate of mainly calcite with a little quartz. The whole appears crushed or bedded along parallel lines.

Compact hornstone variety.

The soft, calcareous type of rock, as exemplified in the two specimens quoted above, is only developed in very thin layers, some few inches across, at uncertain intervals among the thicker beds of the second, more compact, hornstone-like varieties, which in their various shades of pale lilac, drab, greenish-grey, dark grey and black, make up the bulk of the larger hill-mass, 2 to 3 miles north of Mundeti, and are also well represented in the other little hill-groups. These compact, flint-like rocks are not only fairly hard, but also extremely tough and intractable to the hammer. Many that seem partially homogeneous to the eye, are differentiated under the influence of the weather into fine pastry-like layers $\frac{29}{391}$. In some cases the dark and pale grey layers show a semblance of false-bedding $\frac{25}{393}$ as regards each other.

Specimen No. $\frac{29}{391}$ (12340) is an example of the pale drab, compact and very tough variety, and is taken from the west end of the 1,153 feet peak of the larger hill-mass. Under the microscope it shows a minutely granular structure as a ground-mass, consisting of quartz and a filigree or very delicate skeleton-fretwork of some highly refracting, moderately doubly-refracting granules, more or less connected together and that extinguish together in groups between crossed nicols. These are utterly shapeless and indistinct, but by analogy with other specimens, they too are probably pyroxene. Among this also are larger granules of quartz, often irregularly angular in outline and which are entirely separate and not in interlocking areas, and which give the impression of clastic grains, and, by their alignment in parallel layers, suggest a definite bedding in a sedimentary rock. There is also a little sphene and (?) some zircon. No calcite or other rhombic carbonate is detected in this specimen. The attempts at crystallising, on a relatively large scale, of what are here interpreted as skeleton plates of pyroxene, doubtless account for the extreme toughness of the rock under the hammer.

The following similar examples of this variety of the Mundeti series are taken from various localities. No. $\frac{25}{393}$ (12350), from 2 miles north of Mundeti, is almost identical with the one last described. No. $\frac{29}{401}$ (12346), from the eastern edge of the 1333 feet hill, is dark and variously banded and with much iron ore (pyrite) in filigree areas. No. $\frac{29}{397}$ (12347), from the western edge of the hill $1\frac{1}{4}$ miles north of Mundeti, and rather near the granite intrusion, is a pronounced greenish-grey in colour, extremely tough, and has the filigree plates of pyroxene much larger and better developed than in previous specimens. An occasional cleavage direction is seen in poikilitic plates giving extinctions of about 40°. The general effect in the thin section of this rock is as of a number of these pyroxene plates extinguishing alternately in the field of the microscope.

Brecciated forms of hornstone variety.

Certain brecciated forms of the hornstone-like variety are represented by Nos. $\frac{29}{395}$ (12344) and $\frac{29}{896}$ (12345), from the northern edge of the main hill-mass near some small intrusive bosses of the Idar granite or granite-porphyry, and also near where the sharp line of division between them and the Delhi Quartzite lies, just to the south of a small "tank" or reservoir. In these specimens examples of the darker variety, brecciated in its own dark tints, and including coarse-grained, lighter-coloured fragments, are most common ($\frac{29}{396}$); but the lighter variety also occurs with angular brecciated lumps of the dark blue-grey kind contained in it $\frac{29}{395}$. The northern slopes of the 1,153 feet spur, south of the tank, are fairly well plastered with this brecciated variety, which does not, however, seem to extend along the line of strike, but to be confined to this one line across the strike of the beds. It is therefore probably a fault breccia.

Variety with idocrase and wollastonite as contact effects of Idar granite.

Specimens $\frac{29}{394}$ (12343), collected from S.S.W. of 1,153 feet hill, 3 miles north of Mundeti, and $\frac{29}{398}$ (12348, Pl. 11, fig. 3), from $1\frac{1}{2}$ miles north of Mundeti, lie close to the Idar granite intrusions. The groundmass of these rocks is a pale grey in colour, somewhat like the last-described, but with slightly more crystalline structure. It contains much pyroxene, which, though usually present in irregular grains poikilitic over large areas as in many of the other compact varieties, occurs also sparingly in roughly idiomorphic shapes, giving basal sections with characteristic cleavage, and other elongated sections with extinction angles $Z \wedge c = 42^\circ$, which is characteristic of diopside. The rest of the ground-mass shows many elongated laths of wollastonite, with pearly lustre, parallel fibration, positive elongation, etc., exactly as has been described in the calc-gneiss from Golwara, $\frac{25}{388}$ (12141), (see p. 17). There is a considerable quantity of sphene in groups of small roughly crystalline grains. Thus the matrix of the whole rock will be seen to be practically identical with that of the Golwara rock except that it is finer grained. Scattered about the ground-mass either in rough layers or in detached individuals lie large prisms or roundish grains of idocrase of a bright brown colour. They are as much as an inch in length and $\frac{1}{4}$-inch diameter in the first specimen and more rounded in the second. In thin section they can be seen to enclose poikilitically a great number of pyroxene grains, and are in all their optical characteristics identical with the idocrase described in specimen $\frac{26}{325}$ (12152) from near Nadri. In addition to the above-determined minerals in the rock, there are also some dusty amorphous areas representing some altered mineral which cannot be determined. It may partly be leucoxene passing into sphene, with which it appears to be associated in the thin section. There is a patch of calcite in one slide of the second example.

Special contact metamorphism indicated.

It seems certain that the development of large idocrase crystals in this rock, its generally coarser grain than the average Mundeti rock, the presence of pyroxene and wollastonite and the absence of quartz and calcite (except one patch of the latter in one place) indicate special contact metamorphism induced by the proximity of the intrusive Idar granite along this N.W. end of the hill-mass; so that there has been produced what is practically a calc-gneiss closely resembling the Golwara rock $\frac{25}{388}$ and with idocrase in it as in the Nadri rock, $\frac{26}{325}$. It appears to be a valuable link connecting the Mundeti series with the calc-gneiss series.

Other obviously altered sedimentaries.

Finally we have in other parts of the series at some distance from the Idar granite occurrences, specimens, such as $\frac{26}{431}$ and $\frac{25}{400}$ from near Malasa, which are obviously but little altered grits or quartzites, the latter being used and exported as a hone: likewise slaty rocks, such as $\frac{29}{399}$ and $\frac{29}{400}$, which as a whole are in no ways different from ordinary slightly metamorphic members of any sedimentary series.

Calc-gneiss aspect in the Mundeti Series.

If we admit that the coarser examples of these Mundeti rocks, especially those with idocrase, diopside, wollastonite and sphene, are sufficiently like some of the calc-gneiss varieties (and I think the resemblance is exceedingly strong), it follows that rocks of a calc-gneiss aspect have been produced, here in the Mundeti area, from a series that contains abundant traces of a sedimentary origin, not only by the presence of clastic quartz grains, with distinct bedding in some cases, but also by the fact that ordinary grits and little-altered slaty rocks and limestones (Nos. $\frac{25}{400}$, $\frac{29}{400}$ and $\frac{26}{432}$, respectively) take a part in the series and are interbedded with the more metamorphosed varieties.

Theoretical significance of this.

The Mundeti series, in fact, seems to illustrate the actual transition from a sedimentary type of deposit to a thoroughly crystalline rock indistinguishable from certain varieties of the calc-gneiss; and, therefore, notwithstanding its detached position, separated by some miles from the calc-gneiss area, it may be regarded as strong evidence in support of the theory of the ultimate sedimentary origin of the calc-gneiss.

Absence of aplite veins.

A point of some theoretical importance, illustrated both by the Mundeti series and the Kherod amphibolite-limestones, is the total absence of microcline, in particular, and of felspar, generally, in them. It seems reasonable to connect this absence with the total absence of any plexus of aplite veins in them, such as, on the other hand, is so marked a feature of the highly altered calc-gneiss and of the biotite-gneiss.

Feather forms of pyroxene and amphibole.

Another point that tends to link up the three calciferous series into a variously metamorphosed chain of calcareous sediments, is the peculiar filigree or feather forms taken by the pyroxene in the Mundeti, and by the amphibole in the Kherod series, which may perhaps be regarded as constituting a certain parallelism between the two, sufficient at least to argue an analogous mode of origin.

It is possible that these Mundeti and Kherod series, not only afford striking evidence of this metamorphic process from sedimentary material, but also may indicate something of the early steps of that process. For it would seem that the first additions to the sedimentary quartz and calcareous material, consequent on regional or other metamorphism, was the differentiation of granules of pyroxene in the Mundeti area, and of hornblende in the Kherod area, which in the more pronounced forms of the same rocks became more or less united into irregular poikilitic plates or into long blades. To these also were added grains of sphene and small plates of biotite. The addition of other minerals, such as wollastonite and idocrase, seems to coincide in the Mundeti area with the additional thermal action engendered by the adjacent masses of Idar granite, whilst at the same time the quartz and calcite disappear as separate minerals.

A possible order of metamorphism indicated.

This is as far as the direct evidence takes us in these two areas; but, if we may reason from this that the more intense form of metamorphism shown by the calc-gneiss of the typical areas must be due to other superinduced causes, then it might be permissible to speculate whether the introduction of felspar in large amount, and especially microcline, into their composition, may have been due to pneumatolitic effects of the aplite veins, or by means of the aplite veins—consequent on dynamo-matamorphism, which thus ultimately must be held responsible for the granulitic condition, and also the hybrid constitution, of the main mass of the more typical calc-gneiss, a conclusion that would seem to be in harmony with those arrived at by Fermor and Burton in the Central Provinces.

Other speculations.

Before leaving the subject of the Mundeti series altogether, a few details must be given to illustrate its rather peculiar position as regards the surrounding Delhi Quartzite. If it is realised that the strike and dip is everywhere very steady throughout the dozen or so little hill-groups of these rocks, and that the strike, if continued beyond the outcrops in either direction, would run directly into that of the two Delhi Quartzite hill areas lying N.N.E. and S.S.W. of it, it will naturally be asked: do the former rocks really thus come suddenly to an end, and, if so, by what means?

Irregular junction with the Delhi Quartzite.

In answer to the first question it may be said that I have followed round the Delhi Quartzite exposures on both sides and that they show a continuous series of quartzite of the usual Delhi facies with dips and strike directly continuous with those of the Mundeti series, but without revealing any traces of the latter infolded with them. The point of nearest approach that the Delhi Quartzite makes to the Mundeti series is in the little hill (almost hillock) north of the tank 1 mile E.byN. of the 1,153 feet hill before referred to. Here the Delhi Quartzite is only separated by less than $\frac{1}{4}$-mile of surface alluvium from the brecciated hornstone variety of the Mundeti series, and just here the strike of the Delhi Quartzite is considerably twisted from normal, being E.byN. with dip of 60° S.byE. Both in this hill and in the succeeding little hill to the east and in the main spur of the 1,633 feet hill, the quartzite is very platy with veinlets of quartz, the platiness evidently being due to shearing. On the S.W. side the Delhi Quartzite of the little ridges N.E. and S.W. of Mundeti town, as well as the larger mass of the same with the intrusive quartz-porphyry lying south of Malasa, prove the prevailing dip to be the same, and the absence of infolded Mundeti beds is equally certain. The above facts undoubtedly point to faults or irregular junctions of some sort, and are not explicable by any simple unconformity of the Delhi Quartzite above the lower series. Such junctions between the two formations, we shall see later on, are of common occurrence at many other places.

(7) Other areas of Aravalli rocks.

Scattered and insignificant exposures only.

The remaining outcrops of Aravalli rocks are of a very scattered description. When laid down on the map they may be recognised as constituting the ground-work of a few more or less connected and wide-open peneplains covered with alluvium. The rock elements, themselves, make little or no show in the orography of the region : it is very seldom that they rise above the base-level of denudation for this part of India, and then only in the form of very gently rising, low, mounds. Their more constant mode of occurrence is as river- and stream-bed exposures, where they are just discernible under the banks of gravel and clay, or as little cliffs bordering the deeper pools. Nowhere do they build any dominating hilly or rolling country after the manner of the calc-gneiss, biotite-gneiss, Kherod series or Mundeti series.

Localities.

These scattered areas are located chiefly in the eastern half of sheet 146 of the Bombay survey, and more especially along the drainage areas of the Meshva river and its tributaries, as for instance near Bodi and over the large peneplain stretching from south of Bamanvada to near Jesangpur, which contains the greatest number of these scattered exposures.

Throughout this wide region these small outcrops are sufficient by their general occurrence and lie to enable one to conclude that these Aravalli rocks are constant in their underlie of the whole of the peneplain of this flat area, but they are insufficient to enable one to supply a properly coordinated petrological account of them. Hence the descriptions which follow will of necessity suffer from being imperfect and will be suitably brief.

(*a*) *The Bodi area.*

What I have here called the Bodi area is a peneplain of this character, lying south of Raighad, and generally having its Aravalli representatives concealed by alluvium. At one place, however, on and below the hill-spur to N. and E. of Bodi village, these Aravalli rocks are still preserved in the form of an undercliff and hill-spur, lying beneath (or so near as to have once been juxtaposed beneath) the overlying horizontal capping of Ahmednagar Sandstone. The latter has undoubtedly acted as a cover, protecting the Aravalli schists, etc., from complete reduction down to the base-level of erosion. In other places where this has not occurred the only outcrops are stream exposures, seen fairly connectedly in both arms of the stream which unite just below Paliarpar.

Schists and pegmatites.

In all the exposures of the Bodi area are to be seen biotite- and hornblende-gneiss with plagioclase, iron-ore and apatite, ($\frac{26}{415}$—12357), impregnated by numerous coarse granite-pegmatite veins $\frac{26}{522}$, $\frac{26}{526}$ (12358), and one instance of an (?) olivine-dolerite dyke, much altered ($\frac{26}{549}$, $\frac{26}{550}$) and with chilled edges ($\frac{26}{551}$; see p. 133). Traces of similar schists and pegmatites are also seen at Raighad and Vagdi, and even at Navalpur, N.W. of Vagdi, and within the area of Delhi Quartzite outcrops.

The position at Bodi is best illustrated in the section (see text fig. 9).

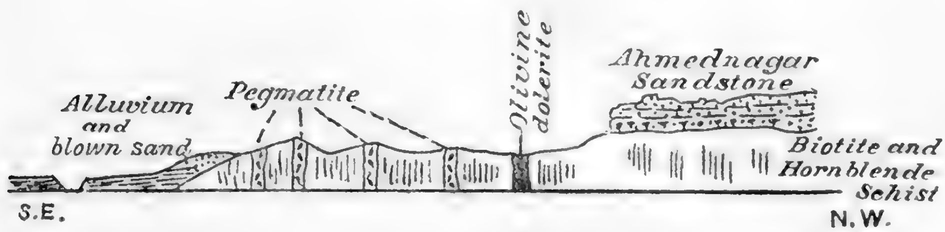


Fig. 9.

The pegmatite dykes ($\frac{26}{522}$) are from 3 feet to 6 feet in width, imperfectly exposed, and consist of quartz, pink and white microcline, $\frac{26}{527}$, $\frac{26}{528}$ muscovite and a little black tourmaline ($\frac{26}{524}$). They are arranged vertically, with strike parallel to that of the invaded schists, which is about E.byN.—W.byS. The muscovite plates ($\frac{26}{523}$) are numerous, and appear generally among the quartz, $\frac{1}{2}$ inch to 1 inch or $1\frac{1}{2}$ inch plates being most common, and very occasionally a little larger, but any plates as much as 6 inches across are unknown. Besides being found among the quartz, when differentiated into a separate layer, the mica plates are also found in what is simply a coarse mixture of the three minerals.

Elsewhere, beyond the hill-spur, the bands of pegmatite, as shown in the section and also those which occur further north, are generally invisible beneath the 10 to 50 feet of alluvium, but in the actual stream-beds sufficient outcrop is seen to allow one to deduce their position within a certain limited area.

Prospecting pits for mica.

Numerous small trial excavations for mica have been made along the crests of the little ridges which cross plagioclinally the general run of the hill-spur E. of Bodi. It does not seem that anything more useful than small mica has ever been extracted, or is likely to be obtained from this area.

(*b*) *Bamanvada—Jesangpur area.*

This area is undoubtedly the most continuous in its discontinuity. It is a nearly flat plain, some 12 miles long by 4 broad, entirely ringed round, with the exception of the opening of the Meshva river at Bakrol, by the winding and irregular hills of Delhi Quartzite. The rocks exposed embrace mica-schist, hornblende and chlorite-schist, gneiss or gneissose granite, grey crystalline limestone, coarse pegmatite, ancient trap dykes, and a peculiar band of coarse white pyroxene rock with tremolite and other minerals.

Mica and other schists.

The mica-schist is thinly foliated and soft owing to the large amount of mica. This is sometimes muscovite and biotite, as in the Meshva river near Bamanvada, where the schists are intercalated every yard or so with very prominent translucent quartz bands which are as much as 2 to 3 feet thick. At other places the only mica is muscovite (sericite) developed richly or more sparingly in the well-foliated rock, as in specimen No. $\frac{26}{420}$ (12354, Pl. 11, fig. 4), near Samalpar, 1$\frac{3}{4}$ miles S.W. of Samlaji. This specimen also contains a little chlorite and rather large grains of tourmaline and iron-ore (magnetite), a very little apatite, quartz with many minute fluid inclusions, and no felspar. Muscovite and biotite-schists are also seen at other scattered places such as Abharpur, Pala (Palo), ($\frac{29}{404}$), Gadadar, ($\frac{26}{426}$, 12373), and at many points along the tributary of the Meshva between Meru and Bamanvada,—as $\frac{29}{418}$ from Sunak. At many places, however, this rock is intercalated with veins of more felspathic gneissic material in varying proportion till it passes into the gneiss or well-foliated granite seen typically at Vandiol and Jesangpur. This will be described presently. These scattered outcrops of schist and gneiss indicate very extensive, and doubtless very thick, rock-masses totalling many hundreds and possibly thousands of feet. Chlorite and sericite-schist ($\frac{29}{405}$ 12355) is found close up against the Delhi Quartzite at Khercha (Kherancha).

Other schists are the hornblende-schist of Vijapar ($\frac{29}{406}$, 12356), a finely foliated rock containing minute blades of green hornblende and numerous irregular grains of epidote or (?) clinozoisite in a vague crushed ground-mass of quartz or quartz-felspar. It is probably an epidiorite. Another complex crystalline schist, found near the latter up the small tributary stream, is banded with flesh-red quartzo-felspathic (with microcline) layers so as to constitute a mixed gneiss, of which the dark green layers contain chlorite, white mica, epidote, some calcite and a little sphene ($\frac{29}{407}$, 12362). The rock is also penetrated by much altered ancient dyke-like masses ($\frac{29}{408}$, 12363), composed like the dark bands above together with some green-yellow amphibole. Large extensions or thicknesses of these rocks seem indicated. One mile S.S.E. of Bhetali near Karanpur small patches of a rather hard schist protrude through the alluvium ($\frac{29}{409}$, 12364). It possesses a quartz-felspar mosaic in which the lamellar twinning of plagioclase is visible in what appear to be crushed grains. Among this are large irregular areas and groups of grains, more or less connected together, of pyroxene, and, with and among this, long and sometimes large blades of pale green amphibole. There is a considerable amount of sphene and no iron ores. It is probably an epidiorite or amphibolite in origin. A schistose epidote-rock occurs 1¾ miles S.W. of Samlaji, specimen No. $\frac{26}{419}$, (12365), and contains minute grains of sphene. It only occurs as a narrow band, probably along the line of junction (discordant) between the mica-schists and the Delhi Quartzite series.

Gneiss or gneissose granite.

The gneiss, or gneissose granite, exposures are best seen in the Meshva river-bed near Vandiol and also at Jesangpur. At the former place there are large outcrops in the river-bed, with a rolling foliation dipping generally to the N.E., very distinct and marked out by eye-structure and lenticular bands, and also at intervals by thin parallel quartz veins. The rock—$\frac{26}{427}$ and $\frac{26}{423}$; 12366 and 12367—, contains both muscovite and biotite in relatively small plates, biotite predominating, and disposed at random through the other minerals. It has brownish-green and pale yellow pleochroism. There is much quartz, crowded with minute fluid inclusions, also orthoclase, the large irregular eyes of which occasionally show Carlsbad twins; no microcline. Under the microscope these felspar areas are not well-defined and show strain shadows and crushing at the borders. There is a considerable amount of plagioclase in small irregular grains and a few minute zircons. The very regular character of this massive rock suggests a foliated granite of some ancient type. A very similar rock from Jesangpur ($\frac{26}{417}$, 12368) has the felspar eyes of a faint pink colour and the lenticular structure very distinct. It stands up in massive little crags reaching 20 feet in height.

Quartz-tourmaline rock.

Quartz veins, with abundant tourmaline, become especially prominent up the Meshva river at Bamanvada, above Vandiol and near Kavadia, at a position where the gneissose granite adjoins the schist.

The tourmaline becomes massive in places and with a radiating columnar structure [$\frac{26}{530}$, $\frac{26}{533}$, $\frac{26}{534}$—(12369), $\frac{26}{537}$].

Here also at Kavadia occurs a very fissile, lenticularly foliated, muscovite-biotite-schist or gneiss ($\frac{29}{410}$—12370). It contains veins, veinlets and eyes of more gneissic material. It may represent a more crushed and foliated edge of the Vandiol gneissose granite.

The same rock with many quartz veins and pegmatites of quartz-schorl rock is well marked at intervals on the surface between Sodpur and the Delhi Quartzite hill above Kavadia. At the foot of the latter hill these rocks appear roughly *in situ*, in rising ground above the alluvium, the strike of the foliation and interbanding of the gneiss and quartz-tourmaline veins being N.W.—S.E., that is, at right angles to the strike of the Delhi Quartzite of the ridge which dips down against them, thus establishing a complete discordance.

Other pegmatite occurrences, very coarse and with tourmaline in addition to muscovite, are found at many places too numerous to mention, especially in the Meshva river and its main N.—S. tributary (just as was described at Bodi). All these pegmatites (*e.g.*, $\frac{29}{417}$) from Sunak, appear to be entirely subsequent to, and probably much younger than, the schists with their gneissic veins and the gneiss or gneissose granite of Vandiol and Jesangpur.

Fluorspar.

In a deep reddish pegmatite vein $\frac{29}{416}$ (12395), just below Vajapar on the Meshva River, and which is intrusive as several parallel dykes in augen gneiss, there were found small particles of a violet-blue mineral in small patches along certain lines. Its specific gravity is between 3·0 and 3·1 refractive index about 1·44, chemically it contains Ca and F, and it etched a watch-glass on the application of sulphuric acid. It is isotropic. It is therefore fluorspar. The above determinations were made by Dr. Christie, and are of interest in view of the great rarity of fluorspar in India.

Grey crystalline limestone.

At Jesangpur there must be a considerable extent of grey crystalline limestone ($\frac{26}{363}$, 12371), indicated by the scattered outcrops that are visible within 1 or 2 miles radius of that place, and by the material exposed in wells. It makes a good building-stone, a temple at Bhetali being built of this rock in cut stone. Owing to the exposures being entirely surrounded by alluvium and detached from other outcrops, it is impossible to suggest how this calcareous rock is related to the other Aravallis of this area. $\frac{29}{411}$, from $\frac{1}{2}$ mile N.W. of Jesangpur, has much tremolite developed in it and it suggests a comparison with the similar rocks associated with the white pyroxene rocks of Bamanvada (see p. 69).

White pyroxene and associated rocks.

A striking and interesting feature of this Bamanvada-Jesangpur area is the occurrence of a peculiar and well-marked band of white pyroxene-rock, prominently seen on the right bank of the Meshva river about 1 to $1\frac{1}{2}$ miles S.S.W. of Bamanvada. Here it is exposed continuously for $\frac{3}{4}$ mile in an outcrop striking N.byW., that is, parallel to the river at this place. It appears interbedded with some calcite and pale amphibole-rock and also with some quartz-schists, through a thickness of about 60 feet or more. In the direction of the river-bed it is underlaid by muscovite-biotite schists with translucent quartz layers as already described, and it is overlain by more schists with a profusion of white quartz veins, the latter, with the white pyroxene band at its base, forming a low mound or strip of rising ground lying parallel to the river bank. The dip of the beds is W.byS. at about 50°.

The section (text fig. 10) will illustrate the above general facts,

Fig. 10.

and further details will appear presently. Other exposures of the same set of rocks are seen at the following places : $\frac{1}{4}$ mile higher up stream, just above the entrance of the tributary stream which joins the Meshva $\frac{3}{4}$ mile W.S.W. of Bamanvada, again near Sunak and near Kheradi in the stream-bed ($\frac{29}{415}$), and also about 2 miles north of Jesangpur—the last exposure being only poorly seen in the shallow stream-beds of that part. These several widely separated partial outcrops roughly follow a line stretching N.—S. between Bolundra and Abharpur, a distance of about 10 miles. Owing to alluvium it is not certain whether all represent the same or different beds.

White pyroxene : diopside.

In the better exposures, as seen W.S.W. and S.S.W. of Bamanvada, the prominent white pyroxene occurrences indicate beds of the mineral of from 2 to 3 feet thick, totalling 8 feet in one section and 30 feet in another, associated with two or three beds of about an equal amount of calcite and calcite-tremolite rock, etc. The pyroxene beds are very coarse to medium-grained, and consist of almost pure pyroxene—specimens Nos. $\frac{26}{342}$—$\frac{26}{346}$ (12374—12379, Pl. 11, fig. 5). Its white, creamy white, or pale whitey-grey colour at first suggests a coarse felspathic pegmatite. Its true nature as a pyroxene, however, became evident on examination of the more or less complete crystals and cleavage fragments broken out of the rock. The specific gravity of these was determined as 3·10, the hardness as 5—6, and the mineral was practically infusible except on the edges of thin chips. Chemically examined in the Geological Survey laboratory by my colleague Mr. Tipper, it was found to be slightly aluminous with a little iron, and with calcium and magnesium in very fair quantities. The mineral, therefore, must be principally a calcium-magnesium silicate. From thin sections cut in typical directions it shows the single and double refraction of pyroxene, an interrupted prismatic cleavage angle of 86°, a more perfect orthopinacoidal cleavage, and distinct basal cleavage or parting, the two latter making an angle of 74° with each other. The extinction angle $Z \wedge \acute{c}$ is 38°—39; it is optically positive. All these data plainly indicate a pyroxene of the diopside group. Along with the large crystalline grains there is a very little interstitial quartz and calcite, the latter also appearing along cracks as a decomposition product, and being sufficient to give a fugitive effervescence with acid on freshly broken surfaces ($\frac{26}{347}$, 12380). There is also a very little sphene.

Change to amphibole.

The purer bands of this diopside rock show nothing but this one mineral, except the change in a few places of the pyroxene to tremolite or pale greenish actinolite. In specimen No. $\frac{26}{349}$ (12381) the process of the replacement of the pyroxene by tufted aggregates of tremolite can be studied in some detail.

Some of the more compact bands of the pyroxene-rock when cut up into $\frac{1}{8}$ inch slabs, become slightly translucent in creamy, pale green and occasional pinkish tints ($\frac{26}{344}$), so that the rock might be useful as an ornamental stone and for small carved objects. Its hardness, 5—6, is such that it is just able to be worked with file or other steel tool, a polished surface being difficult to scratch.

Tremolite-rock.

At one place, an isolated exposure of a few yards wide, in the shingle of the river-bed just below the junction of the Meshva with the tributary-stream almost exactly S.W. of Bamanvada, shows the change to amphibole to be completely established, with the production of a layer, 1 to 2 inches thick, which in thin section shows matted tufts of fibres and delicate prisms of colourless or very pale green tremolite or actinolite—specimen No. $\frac{26}{349}$ (12381 ; see Pl. 11, fig. 6)—giving extinction angles up to 19° and typical basal sections of amphibole. Its specific gravity is 2·96, hardness over 6, and it is infusible, but becomes white and opaque before the blowpipe. The 1- to 2-inch layer is bordered on one side by the white pyroxene and on the other by a gradual passage into calcite. Its colour in the hand-specimen is a rather pretty translucent green, and the rock when polished has a handsome appearance. Its extremely tough, somewhat compact and translucent condition kept one on the lookout for any jade-like variety. Nothing, however, sufficiently compact, or sufficiently translucent, to merit the name of true jade (nephrite) was found, although the associations, and the purity of the white pyroxene and pale green amphibole, are very suggestive for a further search in the neighbourhood for an occurrence of jade of the true nephrite variety, such as the well-known jade from Karakash in Khotan (M. 1374—12389). In certain places in the thin section of $\frac{26}{349}$ (12381) the basal cleavage of the pyroxene continues into the neighbouring amphibole, the fibres of the latter being developed at right angles to this cleavage (see text fig. 11). Calcite films are of common occurrence in this tremolite along cleavage cracks.

Calcite-tremolite rock.

Specimen No. $\frac{26}{351}$ (12382), from the right bank of the Meshva river 1 mile S.S.W. of Bamanvada, is a much more calcareous rock, composed of calcite and tremolite ; the latter being present in a number of bunches and sheaves or tufts. There is no quartz or other mineral. The extinction

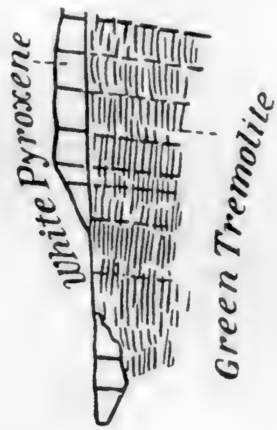


Fig. 11.

angle of the tremolite, $Z \wedge c$ is 15° to 17°. Very similar specimens, $\frac{26}{365}$—$\frac{26}{366}$ are from $\frac{1}{2}$ to 1 mile west of Abharpur, and $\frac{26}{364}$ from the same locality with white pyroxene also. Specimen No. $\frac{26}{353}$ (12383) from the right bank of the Meshva river S.S.W. of Bamanvada, appears in the hand-specimen as a white tremolite-rock, exactly reproducing the pale green rock, $\frac{26}{349}$, in the criss-cross and tufted arrangement of the fibres. There is, however, a considerable amount of calcite in places, as also in parts of $\frac{26}{349}$.

Crystalline limestone bands.

The more purely calcareous layers of this series are intercalated as shown in the section (see fig. 10). No. $\frac{26}{354}$ (12384) is an example of these. It is medium-grained, well crystalised, saccharoidal marble, and is not so commonly found in this Bamanvada area as the calcite rock containing a considerable amount of tremolite or actinolite.

Quartz- and white pyroxene-schist.

The base of the white pyroxene (diopside) section, where it overlies the thinly foliated muscovite-biotite schists, and generally also the uppermost layer, can be seen in one or two places in the Bamanvada locality. This is found to vary, sometimes being quartzose, when it becomes a quartz-pyroxene schist without any felspar, as in specimen $\frac{26}{358}$ (12386, Pl. 12, fig. 1), a small crag in the Meshva river-bed 1 mile S.S.W. of Bamanvada, and having the prevailing dip and strike. Also $\frac{26}{359}$ from the southern end of the little ridge, a quartz-actinolite—or diopside-rock, and $\frac{26}{360}$, from a little to the north of the latitude of Sunak, in the stream-bed, a quartzose pyroxene-schist on the N.W. (upper) side of the white pyroxene bed.

Rock with microcline.

At the exposure in the side stream just above its junction with the Meshva, at a horizon immediately above the basal layer and between it and the lowest pyroxene bed, is a thin layer of calcite which passes laterally into a finely granular microcline-rock with a little sphene and with large idiomorphic, very pale green pyroxene crystals[1] $\frac{26}{424}$ (12387, Pl. 12, fig. 2).

Bowenite.

At one locality in the chief exposure of these rocks near Bamanvada, some of the calcite bands near the top of the section show patches of a compact, transparent, dark and light green, hard, serpentine, which I refer to bowenite ($\frac{26}{357}$—12388). Its hardness is 5—6. The patches are only very small, an inch or so across, and mixed with calcite; but in all their physical and optical characters they accurately reproduce the mineral, *sang-i-yashm*, mined in the Safed Koh and brought down to Bhera where it is cut for sale (as soft jade) into paper knives and other similar ornamental objects.[2] Similar material is said to be found in Khotan and brought down from there along with true jade (nephrite) to Kashmir where the two are sold together in the Srinagar bazars.

Basic dykes and pegmatite.

Both the white pyroxene bands and the surrounding thick layers of mica-schist are here and there penetrated by much decomposed fine-grained, dark, basic dykes of (?) olivine-dolerite (which will be described later on under the heading of "basic dykes"), whilst in the neighbourhood there are many pegmatite dykes as already described (see p. 66). The former are comparatively scanty and do not seem to have had any causal connection with the white pyroxene.

Origin of the white pyroxene bands and associated rocks.

The occurrence of such thick and continuous beds of almost pure white pyroxene, as above described in this area, is, so far as is known at present, peculiar to this part of India, and is pro-

[1] Not seen in the slide
[2] See McMahon, *Min. Mag.*, Vol. IX, p. 187.

bably a rare occurrence anywhere, as distinguished from igneous pyroxenite masses which usually are of higher specific gravity, contain more iron, and are darker coloured. The regular and banded appearance of this white pyroxene, its association with beds of crystalline limestone and with quartzose varieties—the whole series being sandwiched between thick beds of sericite-biotite schists—is certainly suggestive of a metamorphic origin for it. Its pale colour, low specific gravity, and other characters dependent on its small percentage of iron, are also in favour of the same view. Also it shows no passage into any gabbro-like or other igneous rock such as commonly happens with pyroxenite masses—felspar being entirely absent from all its occurrences. The above considerations seem to be very strongly in favour of a thermo-dynamical origin for these beds, by the metamorphism of impure limestone or dolomitic limestone, an explanation which, apart from the massiveness and purity of the diopside layers, is natural enough, since diopside crystals are frequently and typically found in a similar association.

Massive white pyroxene-rock S.E. of Bhetali.

Before, however, closing the description of the white pyroxene rocks of Bamanvada, it is necessary to mention a somewhat similar occurrence of what appears to be a massive and quite unbedded, coarse- to medium-grained rock with exactly similar white pyroxene in its composition, together with other minerals as detailed below. It is found in a few very isolated lumps, about 20 yards across, protruding above the alluvium (and with crystalline limestone a little further on) 1¼ miles S.S.E. of Bhetali (specimen No. $\frac{26}{361}$—$\frac{26}{362}$—12390, 12391, Pl. 12, fig. 3). It is thus out of all actual connection with the ordinary bedded white pyroxene rocks near Bamanvada although in the same neighbourhood and line of strike. Besides much white pyroxene and a little tremolite in this rock, there is also a small amount of quartz and a little microcline ophitically surrounded by the pyroxene, and a considerable amount of manganese ore, probably pyrolusite, between and surrounding the white pyroxene and as coatings round the edges of the pyroxene crystals and along veins and cleavage cracks. There is also some iron ore and sphene. The manganese ore is in sufficient quantity to give the rock a mottled or grey appearance. The massive habit of this rock and the presence of microcline, quartz-iron ores and sphene certainly differentiates it from the ordinary white pyroxene rocks of this area. On the other hand, the presence of a considerable amount of this mineral in the Bhetali rock, and the fact that the latter is found along a line of country marked by several outcrops of the ordinary white pyroxene-rock as well as crystalline limestone with tremolite, $\frac{29}{411}$, is likewise an argument of some force disposing one to regard the two rocks as somehow related to one another in origin. Perhaps the safest conclusion to come to is that this rock represents an extreme stage of metamorphism of the same series as gave rise to the bedded pyroxene rock—the whole being complicated by hybrid effects caused by (perhaps) concealed pegmatites in the vicinity.

Pyroxene-rock of Reda and Wasan.

Although belonging to another part of Idar State, it may be advisable to mention here another rock that has a great resemblance to the white pyroxene rock of Bamanvada, except that it is pale grey or greenish-grey in colour. It occurs $\frac{1}{2}$ mile south of Wasan ($\frac{26}{375}$—12392) and $\frac{1}{2}$ mile west of Reda ($\frac{26}{377}$—$\frac{26}{378}$—12393, 12394). The neighbouring rocks are calc-gneiss, pegmatite and quartz veins and a basic dyke-rock. The occurrence at Reda is as a dyke or vein in the vein quartz of the 720 feet hill, $\frac{1}{2}$ mile west of Reda. On its N.E. face and close to it, occurs some pale rose quartz. The low 720 feet ridge of vein quartz (white or clear) protrudes through the alluvium (see sketch text fig. 12), the pyroxene

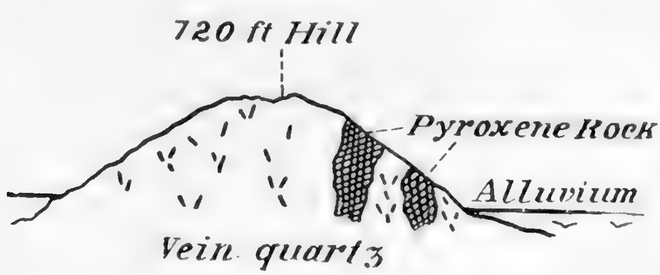


Fig. 12.

rock is quite unbanded and there is no association with it of beds of calcite, etc., after the manner of the Bamanvada rock, nor is there any microcline or other association as in the Bhetali rock. Specimen No. $\frac{26}{377}$—$\frac{26}{378}$ is a pure pyroxene-rock, coarse-grained, and with only a few interspaces filled with a very finely granular substance (? leucoxene) and a little sphene.

It cannot be said that this occurrence of a nearly pure diopside-rock surrounded by vein-quartz simplifies the matter by throwing any light on the question of the origin of these curious pyroxene-bearing rocks.

Structural features.

It is not possible to coordinate the widely separated outcrops (and their strikes) of the Aravalli rocks generally over the whole of this Bamanvada-Jesangpur area, or to say more than can be seen by an inspection of the map. Wherever prominent master-strikes are indicated, they are sometimes more or less parallel with the run of the neighbouring Delhi Quartzite ridges; but at two notable places, namely, (1) the Meshva river near Kavadia and Vajapar, and (2) the neighbourhood of Meru, the discordance is so striking as to be remarkable, and—as will be pointed out later when describing the Delhi Quartzite—this is of the very greatest importance in discussing the relation of these two great rock systems to each other.

DELHI QUARTZITE SERIES.

(1) Preliminary Remarks.

Nomenclature.

The above name, taken from Hacket's terminology, seems fairly appropriate as applied here to the very massive set of quartzite rocks which form an important, and generally the lowest visible, member of a second great system which overlies the first-described Aravalli. There is no doubt that Hacket used the term for these very rocks and mapped them down to as far south as latitude 24°, that is to say, touching the northern part of the present described area. Moreover the strike continuity of this characteristic and massive formation can be recognised right through the area mapped by Hacket in Rajputana (and recently revised by Heron) until, after coinciding with the Alwar quartzite, its last and most northern portion finally tails out in the Ridge at Delhi itself, preparatory to disappearing under the Gangetic alluvium.

A high-lying contrasting formation.

If we exclude all the smaller inequalities of the surface and the flat plains in Idar State, wherein are developed the Aravallis as already described, together with the distinctive, isolated, rugged peaks of the Idar intrusive acid rocks, whose description will follow (see p. 115), there remains principally a set of steep, fairly elevated and connected ridges lying generally to the north and east of the State. They show up prominently against the horizon, as seen from the south and south-west, and appear to form chains of hill-ranges whose mean elevation lies at a higher level than that of most of the Aravallis. The Delhi Quartzite constitutes these ridges. Its sudden appearance at its western margin of outcrop, where it overlooks the plains and the undulating country of Aravalli rocks, gives the immediate impression of a formation sharply contrasting with anything that the Aravallis present, and implying a discordance of some sort on a grand scale.

Its simple appearance at variance with detailed structure.

Although simplicity in the details of its lie and structure (as will presently be explained) is very far from characterising these elevated ranges, they appear at first as though they might consist of capping outliers of a younger more massive formation succeeding unconformably upon the lower-placed Aravalli. This impression is so strong that when afterwards one finds no sign of long, winding scarps of nearly horizontal strata, such as are typical of formations like the Upper Vindhyan, the Cuddapah and the Deccan Trap; and when at the same time one is confronted with a chaos of quartzite rock showing either no bedding at all or one that seems often to plunge irregularly among the Aravalli "setting" with steeply inclined dips, it would certainly be a relief to be able to accept some theory by which a once nearly horizontal mass of these coarse overlying sedimentaries had been reduced to a condition of partial disruption and engulfment of great descending portions of it among a semi-plastic basement of Aravalli rocks, rather than that the strata forming them had been folded, packed and piled up on a solid Aravalli floor in normal, inverted or recumbent folds after the pattern of the younger mountain systems—such as for instance the younger Himalayan zones. We shall return to this point later.

Junction exposures generally hidden.

One of the most striking and tantalising features of Idar State is the fact that the Delhi Quartzite is seldom found in actual exposures lying on, or in direct contact with, any well-developed sequence of the Aravalli system—the stoped contacts with the biotite-gneiss as described on p. 26 being exceptional. In this respect it differs markedly from the similar quartzites of Alwar, where distinct unconformity, with a basal conglomerate, is plainly seen. Almost everywhere in Idar the self-contained Delhi Quartzite builds connected or isolated ranges, or in some cases isolated and small undulations and hillocks, bathed all round at their bases by a sea of alluvium; although this is not by any means everywhere a thick deposit. The Aravalli rocks on the other hand have been already described by me as composing either low, undulating country, surrounded also by alluvium, or as detached and restricted outcrops in the beds of streams, likewise surrounded and covered by Recent deposits. The Delhi Quartzite itself never appears at very low levels exposed in the beds of the larger streams, and only very occasionally in minor gorges which cut through, and directly across, a prominent strike-ridge of quartzite. Thus the secret of its direct and detailed relationship to the Aravallis is usually veiled from actual view, and such conclusions as we arrive at concerning it must be more or less reasoned conclusions drawn from scanty data.

Not altogether due to alluvium.

In some cases no doubt the cause of this is the fair thickness to which the alluvium and wind-borne sand attain, but this is not everywhere the case; and frequently there is no apparent reason why, over so large a range of country, chance should have afforded so few actual contacts, either by portions of the Aravalli rocks having been left protected in hilly form under cover of some quartzite hill or spur, or by the same thing happening in one or other of the river-bed sections and the quartzite being left in superposed contact with the Aravallis.

Quartzite outcrops and their actual distribution.

Another preliminary matter that requires mentioning is the following: if we look at the map and note the irresponsible way in which the outcrops of the Delhi Quartzite very frequently wander, we feel the necessity of asking whether the surface area coloured as Delhi Quartzite substantially coincides with what the outcrops of it would be were the region stripped of its mantle of alluvium. In other words, is the alluvium in any effective degree responsible for these great irregularities? I believe, myself, that the apparent and real areas of quartzite do practically coincide. I believe that when a quartzite ridge comes to a sudden end against alluvium, or when it twists about in sinuous curves, the apparent boundaries of the quartzite are very closely identical with the actual boundaries that would be laid bare under the alluvium. There is no reason to think that the subaërial agents of denudation (weathering, erosion, etc.) have to any serious extent planed down a quartzite mass here, and hollowed it out there, whilst leaving it elevated and continuous elsewhere. And the chief evidence for this opinion is necessarily the fact that no Delhi quartzite at all is found in the plain areas of Idar State, whereas there should be at least some vestiges of it round the present margins were it really continuous for any distance below the alluvium, but with its edges truncated and ground down to the same base-level of erosion as the Aravalli rocks themselves have been reduced to. Such an instance is very distinctly seen in the area south of Delhi town but not in this area.

I conclude then that so far as this region is concerned, the apparent outcrop areas are for all practical purposes the real areas of the quartzite, and that we may therefore now study the lie and trend of these masses in all confidence that they truly expose practically all the rocks of this nature that are left standing in relief among the softer or more easily weathered masses of the Aravalli schists, gneisses and pegmatites, on the one hand, and of the similarly unresisting phyllites on the other.

(2) Descriptive Details.

Lack of variety.

Compared with the great variety of petrological type found among the Aravalli rocks, the Delhi quartzite series is monotonous in its uniformity. In saying that it is a quartzite, one has said nearly all there is to be said, and it is merely necessary to mention a few lithological generalities as to the grain, colour and superinduced structures, before going on to a detailed description of the special areas where the quartzite is developed. We may sum up these as follows:

Lithology.

The rock with the exception of some doubtful layers near Khercha that will be referred to later is generally of from moderate to coarse grain, the micro-structure being generally that of a completely altered and recrystallised quartz mosaic in which none of the outlines of the original sedimentary material appear to have been preserved. (Pl. 12. fig. 4 nat. light, fig. 5 crossed nicols.) It might sometimes be called a quartz-schist owing to secondary crushing along parallel planes. It is generally a rough, "harsh" rock, of pale grey or pink, sometimes purple and white, colours. It is occasionally ferruginous, and also occasionally penetrated by quartz veins, but not by granite veins, like the calc-gneiss except very locally. The bedding is generally obscure, and so cannot be detected in hand specimens or ordinary rock exposures, though in rare instances examples occur of distinct bedding or of vague banding. Sometimes a scarp or dip-slope is plainly indicated. Examples of the latter are more plentiful near the top of the series where it is passing up into the Phyllite series. Otherwise the rock is vague in all these respects, the obscurity being frequently heightened by a rough, platy structure developed as a coarse cleavage or along lines of shear. No clearly defined base to the series has as yet been discovered. Its upper limits, on the contrary, are in many instances plainly exposed. The thickness probably varies greatly as we go from west to east; but in any case, owing to the obscurity of the dip and to unknown amounts of displacement, it can only be roughly estimated as possibly between 5,000 and 10,000 feet.

Accessory minerals.

With the exception of the Delhi Quartzite blocks included in the biotite-gneiss, and the lowest beds of the quartzite seen in contact with the latter, whose special mineralization, with development of garnet, diopside, wollastonite and calcite, has already been described along with the enclosing Aravalli biotite-gneiss (see p. 27), thin sections under the microscope merely reveal among the irregularly interlocking quartz areas, varying amounts of minute plates of muscovite and some also of biotite, together with a few small inclusions of plagioclase. There is also a little iron ore and minute zircons. The plates of mica where best developed are arranged in lines cutting indiscriminately through the recrystallised quartz areas. There are in addition occasionally other minute undetermined minerals. In the occasional phyllite layers, sericitic mica is common, and very seldom garnet and sillimanite.

Delhi Quartzite areas.

The chief interest in the Delhi quartzite formation is provided by its puzzling behaviour towards the underlying Aravallis. The nature of this has already been partially suggested, but it is now necessary to advance evidence in support of this obtained from the large number of exposures of the formation in our area. We shall investigate this we proceed with the ordinary description of the Delhi quartzite areas.

Two categories.

Taken as a whole the areas may be divided into two categories, namely: (1) a region of broad outcrop areas, which in a S.W. direction end among the Aravallis in a set of blunt processes arranged one behind the other *en echelon*, and which in the other direction coalesce, or apparently coalesce, into still wider hill-masses across the border, outside Idar State; (2) a region of narrow outcrop areas, which twist about in a complicated way that can only be appreciated by reference to the map. The former, or broad outcrop areas, lie more to the north-west, and the latter, or narrow outcrop areas, to the south-east as a whole; and it seems likely, on *a priori* grounds, that the former are connected with a more expanded free surface of them exposed to view by denudation, whilst the narrower areas depend for their limited breadth on the fact that the superposed phyllite series just there has not yet been sufficiently removed by denudation. A very similar arrangement into broad and narrow areas appears to be reflected in the disposition of the Alwar quartzite in the region recently described by Mr. Heron.

Harnav R. to Chorivad.

At the northern end of our area, in the neighbourhood of the Harnav river and as far south as Chorivad the Delhi quartzite builds the usual prominent ridge, generally speaking, though somewhat dissected by side streams in its more northerly part. Actual observations of the rock were made at the following localities: (1) the 1,150 feet hill-spur and neighbourhood, $1\frac{1}{2}$ miles E.N.E. of Walren, (2) in the Harnav river-bed, (3) south of Kaĺol, and (4) along the straight ridge north of Chorivad. The exposures at locality (1), near Walren and at Derol, where the remarkable stoped contacts with the biotite-gneiss occur, have been described when treating of the latter (see p. 25). It is only necessary to add that there are occasional thinner-bedded schists intercalated among the ordinary quartzites of the 1,150 feet hill and neighbourhood. Near Talao and at a point about north of hill 1150 a small road-cutting exposes a few white aplite veins with tourmaline, which are intrusive in the quartzite. There are also white quartz veins. No good dips are visible, excepting at the summit where dips of 30° and 40° E.N.E. are illustrated by a good banding of vein quartz and a tendency to split, until 3 or

4 miles E. of Dijio where strike continuations of the Harnav river sections show a good dip of 35° S.E. by means of interbedded mica schists and more fissile quartzite. Here too occurs another solitary example of vein quartz and biotite-aplite intrusive in the Delhi Quartzite.

Harnav river-bed.

At locality (2), in the Harnav river-bed, three strike-spurs come down and touch the actual river-bed on its right bank. Of these the western spur, situated about 2¼ miles east of Derol, is poorly exposed and shows no structure. The middle spur, about 1 mile further on, a rocky spur truncated at its tip by the river, is remarkable as exhibiting a very distinct and unmistakable dip, of 40° to 50°, towards E.byS. or E.S.E., in massive 2-feet beds of a rock of slightly varying composition, but much crushed and crumbled along joint-planes (see Pl. 4, fig. 2). The rock of the third and easternmost spur is manifestly continuous across the narrow gorge and there is plenty of clearly exposed rock, both in the river-bed and in the continuation spur to the south. Notwithstanding this, and although a definite strike is well seen, one cannot be sure of anything more than a rolling irregular dip, generally steep to the east at an average angle of 40°. At locality (3) south of Kalol, the exposures are poor and irregular, as at Walren, and there is most probably much shattering near the small outcrop of biotite-gneiss at that locality. The usual N.N.E.—S.S.W. strike is generally indicated but there is no dip.

Ridge north of Chorivad.

At locality (4), N.N.E. of Chorivad, the high ridge of Delhi quartzite is much more regular and straight, and the same characteristics seem to follow its strike-continuation towards N.N.E. and across the border into Vajenagar State. This ridge, north of Chorivad, attains an elevation of over 1,900 feet reaching even to 2,200 feet in one place; it is steeper than usual, and, as seen from the distance, its W.S.W. face suggests a banded or bedded structure which gives it the appearance of a scarp (see Pl. 5, fig. 2). The rock is a white, grey and pale pink, generally coarse, quartzite, and it is to variations of coarseness and colour that I attribute the aspect of bedding as seen from a distance. Unfortunately the steep, jungle-clad slopes are so much occupied by huge dislocated masses of débris that clear exposures were generally impossible to find, and where such were found they were indecisive as to dip, though the strike was plainly indicated as being N.N.E.—S.S.W. along the ridge and also along the foot-hills. A climb, over the main ridge from the west and then down the steep spurs to Chorivad, revealed the impossibility of gauging the dip, though the outcrops continued down in that direction as if the bedding were steep, which is very likely to be the case.

Outlying patches.

In connection with these exposures should be mentioned the outlying patches of Delhi quartzite at the 876 feet knoll, $1\frac{1}{2}$ miles east of Medh, and the 842 feet knoll, at $2\frac{3}{7}$ miles S.E. of Vadali. They reveal no structure.

Plagioclinal range: four strike masses.

A noticeable feature about the four localities referred to in the area N. of Chorivad, is the slightly plagioclinal nature of the hill-range from north of the Harnav R. to Chorivad, whereby one can recognise as composing it four slightly differently-behaving strike-masses (A, B, C, and D of the diagram text fig. 13) which traverse obliquely

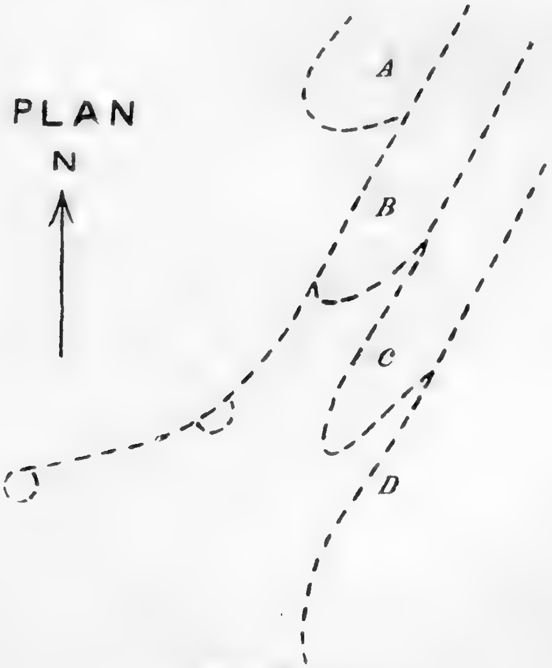


Fig. 13.

across the range. There is the mass east of Walren (A), there is that composing the western and middle spurs in the Harnav river-bed, which is apparently continued into the strike-masses of the low hills south of Kalol and at Damavas (B), there is that of the eastern spur in the Harnav river, which manifestly continues into the spur between Chhapra and Anthra and into those forming the foot-hills of the main ridge 2¾ miles east of Medh (C), and there is lastly the strongly marked and very lofty ridge north of Chorivad itself (D). These plagioclinal elements of the range as a whole are grouped *en echelon*, and each disappears towards the south-west, where it enters the plain. Of these zones, A is characterised by its irregularity of dip and stoped junctions with the biotite-gneiss, B is remarkable for a clear bedding-dip in places, C for its obscure dip and ferruginous character at its south-western end, and D for its paler tints, coarser grain and more massive character with perhaps steeper bedding.

Relation of quartzite masses to Aravalli rocks uncertain.

Owing largely to the alluvium in this case, it is manifest that the Delhi Quartzite of the above area is not self-explanatory. The four zones, A, B, C, D, show differences of colour, grain, texture and bedding, which suggest a stratigraphical sequence. On the other hand, the superinduced structures and more especially the areas of rock chaos and absence of dip might well be held to indicate an abnormality far removed from what is characteristic of a normal sequence. As regards their relationship to the Aravalli rocks, which, with the exception of the Walren and Damavas localities, are some miles apart as to their outcrops, a flat, unconformable overlie of the Delhi quartzite seems absolutely out of the question. But as to what the steep straight A, B, C, D, elements of the ridge connote, together with their disappearance from view to the south-west in the alluvial plain, no formal answer can be attempted here just yet. It is only necessary now to keep in mind the few known irregular stoped junctions, which have already suggested a somewhat unusual explanation that will be elaborated later after other areas have been described.

Region between the Hathmati and Ghuvai rivers.

The next, somewhat expanded area of the Delhi Quartzite, that can be conveniently described together, is that which, with some local interruptions, sweeps south-west from a few miles N.E. of Mundeti town *viâ* Vasai, Munai, Mau, Chhapra, Khed (or Khedgal), Sabli and Jamla, and lies between the alluvial plain south and east of Idar town and the course of the Hathmati river.

North of Mundeti.

North of Mundeti, and separated by about a mile of alluvium from the Mundeti series (already described p. 53) the more lofty, northern ranges of the Delhi Quartzite are largely outside the boundary of Idar State. Their southern prolongations, however, forming the 1,150 feet peak at Kathroti, the 1,633 feet peak and the 1,667 feet peak, together with the bays between them, have revealed the steady, steep dips to E.S.E. and the line of discordance between the Delhi Quartzite and the Mundeti beds as described in the section devoted to the Mundeti series (see p. 60), and have elicited the important fact that none of the Mundeti series of calcareous and other rocks (so well developed in the 1,333 feet hill, 2 miles north of Mundeti and in the group of straggling outcrops near Sisasan) are continued into these hills, although their strike (if there were no discontinuity) would carry them directly in that direction. The outcrops of Delhi Quartzite in these northern spurs are in fact sharply separated from the more or less uniform, and somewhat less elevated, range of Delhi Quartzite at Vasai and Jhumsar by a plain of alluvium and Mundeti outcrops, some 4 miles in extent, that completely interrupts them except for two minor, very broken extensions, as indicated by two little sets of knolls and low ridges, all being of quartzite. The first of these comprises the ridge N. E. of Mundeti and that between Mundeti and Vasai (which appear to form a synclinal trough with marked platy structure), whilst the other is much less well-marked and embraces the 980 feet knoll S.E. of Kasangad and the 799 feet hillock north of Ghanti.

Vasai.

At Vasai fine-grained, pink or purple and white, splintery (fissile or cleaved) quartzites or quartz-schists are exposed in the little south-westerly terminations of the spurs given off from the 1,127 feet peak, and seen dipping at 30° to 40° E.S.E., which is the same in direction and amount as that in the Mundeti series.

West of Mau.

The expanded, and somewhat elevated hill-mass of Delhi Quartzite lying to the south of this and to the west of Mau, is a curious tract of country, composed of pink and white quartzite of the usual kind. It keeps a low elevation, and consists of round-backed undulatory ridgelets. The evidence of dip, derived from beds of varying degrees of massiveness, is fairly satisfactory across the main area from Kuvava *viâ* Munai to Mau, where it appears to be E.S.E. or S.E.

at rather low angles of 30° to 40°, thus agreeing with that at Mau itself where the edge of the hills is a dip-plane (see Pl. 4, fig. 1). The hills are jungle-covered, with no villages, except in the narrow intermediate valleys where alluvium has accumulated, and they are very rough going for the pedestrian. The quartzite is frequently sheared, with production of platy structure and of quartz-schist, and there is much vein quartz. As was remarked towards the north, so here, there is no trace along with them of any limestones or slates of the Mundeti series the beds of which however, have an identical strike.

The intrusive rocks of quartz-porphyry and Idar granite of the neighbourhood will be described below (p. 126). It is not certain whether the three bosses near Vagesari and the one at Lilchha, together with the string of little bosses S.S.W. of Mundeti and reaching to Posina and Chhapra are actually intrusive in the Delhi Quartzite or whether they indicate the presence of Aravalli rocks in the vicinity. That at Posina is certainly in contact with Delhi Quartzite and the same is certainly true of the quartz-porphyry of Malasa. But the Vagdi and other sections must be considered in relation to this question.

Possible intrusion.

The E.S.E. dip seen at Mau is also noticeable along the south-eastern edge of the hills stretching to the south-west, whilst the cross-valley from Chhapra to Kapreta, in the vicinity of Nankhi, has laid bare in the hills to the south-west an apparently continuous section of fairly steeply-dipping Delhi Quartzite inclined in the same direction. At least this was the impression received from a view of the truncated edges of the strata as seen from the opposite side of the valley in the distance; but the remaining hilly mass to the south-west has not been searched in detail.

Chhapra and Kapretta.

At Khed or Khedgal, at the south-west extremity of the Mau hill mass, the Delhi Quartzite is split up into platy layers, which are obviously not original bedding-planes, as is shown by a rough slab taken at the surface near Khed. This is a good example of the very complete way in which all original trace of bedding may become obliterated in the Delhi Quartzite by superinduced coarse platy cleavage or shear planes.

Platy cleavage near Khed.

Coming to the final portion of this area, namely the Jamla hills, and the connecting winding strips of Delhi Quartzite near Sabli between it and the area

Jamla hills.

just described, we find the hill masses further reduced in height and characterised by still more intrusive masses of quartz-porphyry and possibly granite. Here I first examined the two little isolated knolls of Delhi Quartzite surrounded by alluvium 1½ miles due south of Jamla town. Their outlines are of no particular shape as indicating any structure. The rock is pale, slightly reddish in colour, of fine grain and not very massive. There is a fair amount of vein quartz among the quartzite. The main mass of the Jamla hills N.N.E. of the town, the 757 feet hill and its continuation through the town, and also the ridge next to the east of that, are composed of hard and glassy quartzite with obscure bedding. Neither in the shape of the hills, nor from evidence of any scarps or dip-slopes, could I see any sign of bedding and also no coarser or finer bands. It seems that all stratification has been masked by subsequent pressure-cleavage or rock-flow or something similar. The hill-side ½ mile to the north of Jamla shows a similar absence of bedding. At the crest of the same spur a pale blue-grey quartzite is entremely hard and harsh causing very rough walking. The spur is rounded and hog-backed with just a faint suggestion of dipping away from the porphyry. This is especially most noticeable at the south-western end of the 846 feet spur about 2 miles E.N.E. of Jamla, the strike being N.E.—S.W. In sections 1 mile S. E. of Jamla the rock is the same as in the other places described, with uncertainty of dip.

Bhadardi, Surpur and Likhi.

At the north-eastern end of the Jamla mass of Delhi Quartzite at Bhadardi, Surpur and Likhi the quartzite forms long, low, N.E.—S.W. spurs diminishing in height down to the alluvium. It is of rather coarser grain than at the south-western end of this hill-mass. There is no good bedding except locally. One can see that there is some sort of folding of the hill-mass, but as there is no interbedding of coarse and fine, or of any other thin-bedded rock, one cannot solve the kind and amount of the folding. We may perhaps deduce a general N.E.—S.W. strike from the run of the range and a considerable amount of folding. The highest points of these hills marked 961 and 969 feet respectively are about 450 feet above the general level of the surrounding plain.

Kesarpur.

The detached, winding, very low, flat, ridge of quartzite at Kesarpur, between Kaniol and Khanusa revealed nothing except its abrupt junction with the granite south of Kesarpur, which argues intrusion.

Sabli and Ruvach.

Six miles to the north-east of Jamla, at Sabli and Ruvach, there is evidence of a distinct dip of 10° S. in the quartzite.

Summary.

The above briefly described area of Delhi Quartzite taken as a whole, certainly presents much regularity of strike (N.N.E.—S.S.W.) and an apparently dominating dip of about 30° to 40°, and even steeper angles, in a generally E.S.E. direction. The quartzite is nowhere discovered to lie upon Aravalli or any other rocks, the latter when they do appear, as near Mundeti, indicating a discordance that yet awaits explanation. Whether the sequence is entirely a normal ascending one in an east-south-east direction, as seems clearly indicated at the north end of the area, where these rocks are followed by the younger phyllites in the higher reaches of the Hathmati river, and as more vaguely indicated by sericite-schists and very prominent quartz-veins near Tembana Math lower down in the same river valley; or whether it conceals repetition by isoclinal folding, or whether it is cut through by strike-faults causing an equivalent repetition, is the merest guess at present.

Hathmati river sections.

Let us now examine the south-eastern aspect of this quartzite area as it appears along the general direction of the Hathmati river.

Ridge west of Chithoda to Bhiloda.

Beginning at the northern edge of the State in the Hathmati river, at a point 2 miles west of Chithoda, the Delhi Quartzite is well exposed on the right bank of one of the affluents. Here its passage by gradual interbedding up into the Phyllite Series is observed. Bedding in both series is absolutely vertical, in all clear sections reasonably free from surface bias. Cross, or false, bedding is noticeable in some quartzites, but ripple-marks, which are a feature of some of the Alwar exposures, I have never been able to detect in any rocks in Idar.

Below this point southwards the Delhi Quartzite ridge, down to near Bhiloda, continues with much the same strike and dip though with some curving of the former, as near Bhiloda itself; but there are no more visible occurrences of the Phyllite Series, except as narrow straight ridges following parallel to, and at a short distance from, the quartzite.

The Mau hills have already been referred to as showing a steady south-easterly dip. From Mau there is some sharp recurving of the strike and irregularity as indicated by the zigzag bending of the strike as displayed in the isolated hills near Thuravas.

Bamna-Punasan hill.

The still larger hill-mass at whose south-eastern foot lie Bamna and Punasan, shows a remarkable, curved semicircular strike. The south-eastern edge appears generally, but probably deceptively, to be a scarp. with dip towards the hill as just north of Punasan,—but vertical again to the S.W. and N.E. of this village. In the latter direction beyond Bamna, where the strike begins to curve more rapidly, the dip appears to be 50° due east, from which point the strike carries the outcrop following round the northern and north-western edge of the hill-mass, the dip continuing outwards.

Colour-banding in the quartzite.

Near Punasan, what appears to be bedding is somewhat strongly indicated by alternate layers of white and grey quartzite of different degrees of massiveness.

The same aspect is even more markedly noticeable behind the village of Bamna in the little gorge running into the hills. (See section text fig. 14.) Here, great ribs of white, grey, and other

Fig. 14.

coloured quartzite, of varying grain, appear, as seen in perspective, to be inclined in towards the hill, *i.e.*, N.W., but that the real inclination is not far from vertical is shown by the rocks exposed immediately behind the village.

Brachy-anticline or syncline.

Taken in connection with the northern end of this hill-mass, where the strike curves round so definitely the total impression is as of a much restricted brachy-anticline.

Junction with Phyllites.

In this Hathmati river area just described, a point of great significance is the actual junction of the Delhi Quartzite with the Phyllite Series along a $1\frac{1}{2}$-mile stretch at the boundary of the State; and that this line of junction continues beneath the alluvium to a few miles north of Bhiloda is quite probable from the presence of the phyllites in the form of an extended narrow ridge running parallel to, and within less than a mile of, the quartzite. Inasmuch as a duplicate of this arrangement in opposite order is present on the other side of the Hathmati valley one may be reasonably certain that a long syncline in the phyllites follows down the valley; and so we should be prepared to find the phyllites continuing to the east and south-east of the three hills near Thuravas and Bamna and that the uppermost beds of the Delhi Quartzite also follow round somewhere here. So far as the scanty evidence at Thuravas and Tembana Math goes, the sericite-schists and white quartz-veins there seen may reasonably represent the Phyllite Series. The same three hills, however, on their other, south-western, flanks, present a ragged broken aspect, surrounded by alluvium, and with no trace of the Aravallis; so that it is impossible to guess at the detailed relationship between the quartzite and the Aravallis, except that there is great irregularity and discordance of some sort.

Hill-mass south of Dhuleta and Sathrol.

The next of the fairly expanded areas of Delhi Quartzite lies south and south-east of the Bamna-Punasan hill. It is a lofty and well-marked feature, with a somewhat flat or gently undulating upper surface at a level of about 1,000 feet. This expanded area coalesces on the east into a single, prominent ridge following parallel to the river and bounding the Hathmati valley on this side. Leaving the latter for the moment, the expanded portion, like the hills just described presents numerous fine examples of dip-slopes of 40° to 50° to N.N.W. and N.N.E., etc., along the plateau edge from Hunj (and the little ridge 1 mile N.W. of Hunj) *viâ* Dhuleta, Vantadi, Sathrol and the edge of the "bay" *viâ* Bebar Nani to Janali. These dip-slopes (see sketches, text figs. 15 and 16), from the occasional presence of thinner bedded phyllites and one considerable bed of mica-schist among the quartzites, and also from lithological variations in the quartzite particularly well seen in the low ridge to the north-west of Hunj, which accentuate and prove the actuality of the dip, cannot fail to suggest the upper surface limits of the Delhi Quartzite along this winding line of country. The

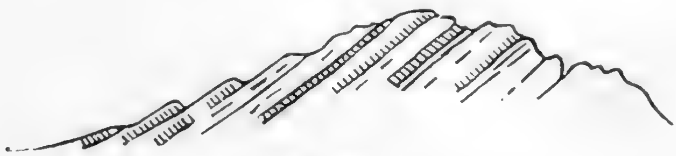


Fig. 15.

Fig. 16.

tilted, stair-like appearance of the outcropping dip slopes, one behind the other, through a vertical distance of 500 feet, is very marked south of Dhuleta. The marked schist bed, whose continuation runs a little S.E. of Hunj is a muscovite-quartz-schist in which the quartz grains are interpenetrated by sillimanite fibres, and in which are garnets and ferruginous layers. This is very like Khondalite. All these facts seem to indicate an ascending series in the Delhi Quartzite towards the Hathmati valley with its scattered suggestions of the Phyllite Series.

Relation to the Aravallis.

But, as before, the much broken-up mass of spurs which succeed to the south-west towards Hamirpur, Vagdi and Surajpura in one direction, and towards Raighad, Navalpur and Mahadevpura in another, have only a very obscure relation whatever to the representatives of the Aravallis that may be presumed to lie hidden beneath the alluvial screen at their bases, judging from the few exposures seen here and there. The only semblance of stratigraphical order in the quartzites here is furnished near Raighad and Vagdi, where a steady strike and apparent dips to the N.W. at about 60°, might be construed as indicating a base or local base of the quartzites near the foot of the scarp. For instance, here at Raighad in the ridge above the town there is a marked banding of the quartzite, striking N.E.—S.W., and at the dam outflow, ½ mile N.E. of Raighad, there are great ribs of very massive quartzite striking in the same direction and parallel to the length of the dam. Nevertheless, there is considerable local contortion visible in the outflow channel where occurs a perfectly freshly cut section, 10 yards long. Another of these marked ribs is found 1 mile N.W. of Raighad with the same direction of strike. Between Raighad and Bokhar all the hills are composed of the same crystalline quartzite[1] as that at 2 miles E.byS. of Wantra. Very occasionally there is evidence of strike, N.E.—S.W., with vague dip, locally high and varying, judging by certain more massive beds, and a rough banding. One band of mica-schist to the south-east of Bokhar is 10 feet thick. All along the hill foot from Raighad to Vagdi there are several prominent ribs of stout, white, pinkish or clear quartzite, which descend by side spurs to cross the line of the streams going to Phulpur and Paliapur. Examining them in detail, one sees that there is no real bedding in the sense of sedimentary planes of division. The whole rock has been completely recrystallised and is merely platy in certain directions. As to how far the extremely coarse colour banding may represent a former stratification it is not possible to say, but it seems quite possible that it does represent it.

Plateau surface.

The almost level, plateau-like summit in the more connected northern part of this hill-mass appears most likely to be due to a plane of denudation coincident with what elsewhere, and quite near, is overlaid by the nearly horizontal Ahmednagar Sandstone (see p. 138).

Local traces of Aravallis.

As has been noticed under the head of the Aravalli System, the minute traces of Aravallis among the quartzite fringe at Vagdi, Mahadevpura and other places, as well as the well authenticated presence of them in the wide plain some distance away from Raighad, make it certain that the puzzling junction between the quartzite and the Aravallis must be very nearly exposed in this locality, the only impediment being the alluvium and the scattered débris of the quartzite.

Other semi-detached areas.

In addition to the expanded area of Delhi Quartzite and its south-western fringe just referred to, there are a few more or less connected exposures of the same in a southerly direction that merit a passing remark. The little patch 2 miles E.byS. of Rupal is interesting because it and the Aravalli schists at Bodi (a little further east) have suffered a planing of their summits and a nearly horizontal capping of the Ahmednagar Sandstone that will be described later (see p. 138).

Sardoi Hills.

The much larger semi-detached mass of quartzite forming the hills surrounding Sardoi, about 900 feet high, displays few features of special interest. In a section across it from Vaghodar to Vanta all the quartzite exposed is of pale colours. There are good massive beds of pale or white tint, varying to grey, but without any definite banding. There is no vein quartz. The fine walls of rock W.S.W. of Vaghodar suggest a vertical dip. In spite of this, the intimate structure shows no trace of a sedimentary character, everything being completely recrystallised. There are some horizontal and some vertical divisional planes, but none which imply bedding. The strike of the distinctly coloured rock-masses is N.—S., and so is parallel to the general outcrop and to the general run also of the Aravalli schists in the Meshva river bed as found a little north of Bolundra.

Bhatkota : change of strike.

There is a noticeable change, however, at the extreme south of the mass near Bhatkota. The strike of the ridge-mass suddenly veers to N.E.—S.W., a strike which carries it in the direction of the little Dholia ridge, 5-6 miles away to the W.S.W. All the quartzite here is much impregnated with white vein-quartz. In the opposite direction towards Titoi there is a small hillock of quartzite which seems to carry on the same line of strike.

Some lithological differences in the quartzite.

Before passing on to the long, contracted ridges of the Delhi Quartzite in the rest of the area left over, it may be remarked that in spite of the confusion apparent in the behaviour and constitution of the quartzite of this expanded area and its semi-detached masses, one general truth seems to emerge, namely that the nearer the quartzite outcrops are to the Phyllite Series the more normal and distinct appears the evidence of bedding and interstratification, whereas in the outcrop of the same rock in the vicinity of the Aravallis, though banding in various tints with occasional coarse ribbing may be prominent, the quartzite shows less trace of a sedimentary origin, appears more glassy and is cut through by superinduced planes of platy structure, which are not evidently coincident with anything that could be construed as original planes of sedimentation.

Narrow outcrops on east bank of Hathmati R.

We now leave the broader areas of the Delhi Quartzite. The first of the narrower areas taken here for description starts at the north-eastern end of the expanded area just described near Bebar and Sobheda, and proceeds along the left or east side of the Hathmati valley. The change is sufficiently abrupt and noticeable to arrest the attention, but I shall defer any conclusions that may be drawn as to the meaning of it for the present. One remark, however, may be made advantageously here. The long, narrow ridge of 900 to 1,000 feet elevation, stretching from Bebar and Sobheda as far as Meru, is flanked on the east by a wide, open plain, among which have already been described (pp. 63—74) numerous examples of the Aravalli rocks— the nearest points being those round about Jesangpur although well-sections in Bhetali village, close up under the quartzite, also expose the same. On the other side it is flanked by the unbroken alluvium of the Hathmati river. There is good reason, however, for supposing that the Phyllite Series, which is strongly represented a few miles further up the Hathmati valley at Jalia and Kanadara, must continue below the alluvium of this part. A confirmation of this is found in well-sections at Bhutavada, where phyllites are seen. There is, therefore, not room in the cross-section near Bhetali for any very great increase in the width of the Delhi Quartzite outcrop beyond and above that exposed in the narrow ridge. This tends to confirm the conviction expressed at the beginning of this section (p. 77) that the Delhi Quartzite ridges correspond roughly to the actual outcrops of such rock beneath the alluvium.

Sobheda and Bhetali.

The quartzite of this ridge at the gap near Sobheda is in the form of a great wall-like mass, striking N.E. byN. and with what appears to be a vertical dip. This is rendered the more probable from the excellent sections exposed further on at Modhri and Bhetali, where (in the latter case) an elaborate road cutting has laid bare the quartzite in an exposure the like of which is rare in Idar away from the railway. Although the bulk of the rock is quartzite, there are numerous bands of interbedded phyllites giving a plainly seen dip of 70° E.S.E. at the west side of the cutting. Some of these interbedded phyllites are 20 feet and less in thickness. In agreement with the dip shewn by these more fissile rocks, the quartzite itself also shows the same in excellently exposed walls of rock.

Meru and Abhapur.

From Bhetali the quartzite ridge continues steadily N.N.E. to Meru. There, the innermost quartzite strata (that is those nearest to the Aravallis) bend very sharply round into an arc of outcrop to Abhapur. The next higher beds in sequence are probably more sharply bent, until finally their outcrops proceed parallel in a more or less continuous set of steep narrow ridges, with some zigzagging and interruption by alluvium, to near Pal, high up the Hathmati valley. At Abhapur the apparent base of the Delhi Quartzite is almost in contact with some soft mica-schists to the south. In the absence of evidence to the contrary, these have been supposed to be Aravallis. But the foliation of the schists follows in strike and dip that of the Delhi Quartzite, and so the question is not beyond discussion whether these might not more appropriately be grouped with the quartzite and so constitute a lowermost layer of the latter. Similar soft mica schists are known among the Aravallis in the Meshva river near Samalpur and at Bamanvada and other places.

Ridge east of Bhutavada.

Returning to the quartzite, the ridge east of Bhutavada, of about 1,200 feet elevation, is composed of a very compact quartzite with vertical dip and with traces of phyllites in the gap one mile south-east of Madhupara, which may be regarded as a wrench in the strike of the Delhi Quartzite. As a whole, all the way down to Torda, the quartzite ridges are composed of massive vertical ribs striking N.N.E.—S.S.W. These dyke-like, vertical walls of massive quartzite protrude from the débris slopes and form a backbone to the hill-spurs all along the tract *viâ* Ubsal or Umarvada and the 1,500 feet ridge east of Chorimal and Raisangpur.

Northern end of the quartzite at Pal.

Near Pal, the most northerly exposure of this strike-mass of the Delhi Quartzite is seen. From that point its strike swings rapidly round, and its eastern edge in contact with the Phyllite Series apparently returns beyond the State boundary and ultimately joins up with that found 2½ miles to the east of Abhapur, near Bornala village.

Presence of Aravallis to the north of Meru doubtful.

Whilst it is very probable that the gap, between Torda and Ubsal or Umarvada, through which the Boroli river flows, has been cut through and across the Delhi Quartzite, I am unable to say what lies concealed beneath the alluvium of the rather wide plain, to the east of this, which I have not examined. It seems likely that the eastern edge of the quartzite lies betwen 1 and 2 miles east of Torda, and that there the Phyllite Series follows normally above it. At all events it is impossible to suggest that in that valley any of the underlying Aravalli rocks lie concealed. It is true that the strange bifurcation of the quartzite ridges just west of Torda, along the line of what must be the axis of the anticline in the quartzite, is suggestive of possible Aravalli or other rocks here and recalls a similar position in the quartzite hills between Dev Mori and Kundol and at Khercha (presently to be described), and the same may be said of the similar but more pronounced bifurcation of the ridge E. of Chorimal; but these areas are too much covered in with alluvium and scree material for any exposures of solid rock to have been preserved.

Evidence of intense Compression.

Considered as a whole, this, generally straight, but much locally twisted and narrow, set of outcrops of the Delhi Quartzite stretching from Bebar to Pal, all of which appear to be composed of nearly vertically dipping ribs of rock, seems to imply a very intense form of plication under probably enormous pressure, such that, though here and there the rock has preserved some traces of its original bedding-planes, especially in its higher horizons, it has as a whole, and more particularly in its lower parts in contact with the Aravallis, behaved much as a semiplastic mass and been stretched here and bulged there, with resultant deformation probably by differential shearing of platy layers one over the other, so as to have considerably mutilated whatever simple structural folds it originally may have possessed.

Long chain of quartzite outcrops S.E. of Abhapur.

The remaining areas of relatively narrow outcroppings of the Delhi Quartzite are nearly all connected together in a long and complicated chain, and also are a continuation of the outcrops last described near Abhapur. Their rational explanation on any ordinary system of folding presents extreme difficulties.

Their position as regards the Phyllite Series.

If it were only their lie with regard to the superincumbent and widely developed Phyllite Series that needed consideration, the matter would not be beyond fairly easy expression. For instance, the positions (1) near Od, (2) west of Navugam, (3) Dev Mori, and (4) Kundol, are all instances of a rapid passage from the quartzite series up into the phyllites. The regular interdigitations of the quartzite outcrops with the phyllites and the resulting deep sinuosities of outcrop, are just what would be expected in a much folded combination of two such widely differing lithological types that at the same time are conformable. In anticipation of the descriptions of the Phyllite Series that will be found further on, I must assume here its complete distinctiveness from all the Aravalli schists and gneisses: the uniformity of the one series and the great diversity of the other from point to point is by itself sufficiently conclusive. But, even apart from this, their position and interbeddings with the Delhi Quartzite, as seen for example west of Chitoda, all round the ridge of quartzite between Od and Navugam, on the eastern side of the ridges from between Dev Mori and Kundol down to the neighbourhood west and southwest of Sangal in the Majam valley, make their position sufficiently clear as coming in sequence above the Delhi Quartzite. Throughout all these areas, the upstanding outcrops of the phyllites, strengthened by their resistant quartz veins, give one plenty of solid hill-sections illustrating this position.

Their position as regards the Aravallis.

On the other hand, the position of the Delhi Quartzite to the Aravallis which latter have been described as occupying the great flat plain, almost wholly covered by alluvium, that stretches N.—S. from Jesangpur to below Bamanvada, and W.—E. from Kheradi to Khercha and Samalpur, is far from being as clear as could be desired, and must be carefully discussed. The mere outline of the quartzite series towards the plain containing the Aravallis tells one but little. It is hopelessly irregular, without any simple interdigitations corresponding to those shown by the quartzite towards the phyllites. Whilst some of this irregularity such as exists between Abhapur and Khercha (Kherancha) may be the result of a surface filling of alluvium in the plain, this cannot, I think, explain all or even most of this irregularity.

Abhapur to 1,085 feet hill.

Following round the outcrop from Abhapur south-east towards the portion of the quartzite hills between Abhapur and the hills enclosing the Meshva river gorge near Samlaji, presents no features of interest except the ordinary vague dip and strike, until we arrive at the 1,085 ft. hill to the north-east of Meravada or Kheravada.

Section in Meshva gorge.

Here, the western spur dips about W.N.W. fairly steeply, in strike continuation of the same dip in the 1,204 ft. hill to the south-east of Od. This turns over in an anticline along the centre of the 1,085 ft. hill so that the S.S.E. spur of that hill dips E.N.E at about 30°, and the same dip is continued into the next spur eastwards. No further clear dips are seen in the Meshva river-bed, as it makes its sharp curve through the range, until the gorge comes to an end south-east of Samlaji and the phyllites make their appearance. At that point dips of 60° E.S.E., or S.E., in the quartzite mark a long and very regular line of dip slope, extending from east of Venpui to Kuski, and representing the upper limits of the Delhi Quartzite. The western part of the hill-mass south of the gorge and between Rudadi and Rampur gives no clear sections, and is heavily wooded, and one is puzzled to understand what becomes of the two limbs of the anticline in the 1,085 ft. hill near Meravada. Their strike would carry them to the south and S.S.E., into the Aravalli area of Meravada and Samalpur, which lie very near to the Delhi Quartzite outcrops.

Khercha hill.

The isolated hill, S.S.W. of Khercha (Kherancha), is also an interesting puzzle, though fortunately it affords at the same time some useful clues and a few new facts of some importance. It is elongated along a N.E.—S.W. axis, and its N.W. face shows a distinct strike in the same direction, as evinced by a banding noticeable from a distance, though the angle of inclination is not so easily apparent. An exhaustive examination of the whole hill leads to the conclusion that it is the south-western half of another brachyanticline which pitches to the S.W. under the Phyllites of the plains in that direction, the latter sweeping round from the east across its south-western termination up to near Vandioli, where they come in direct contact with Aravallis just north of the 689 ft. hill at a point ½ mile S.W. of Vandiol.

A special feature of the hill is a small bifurcation of the ridge at its north-eastern end which opens out towards the village, and in the direction of the similar and opposite bifurcation in the 1,085 ft. hill before referred to. The quartzite of the north-western arm of this bifurcation—specimen No. $\frac{29}{424}$ (12397)—descends to within ½-mile of the river-bed and then is represented among the shingle of the river by a rocky bed of quartzite identical lithologically with that of the spur ($\frac{29}{425}$—12398, Pl. 12, fig. 6). In the plan of the river section (text fig. 17) it will be seen that,

Ridge bifurcation near Khercha; new magnesian phase.

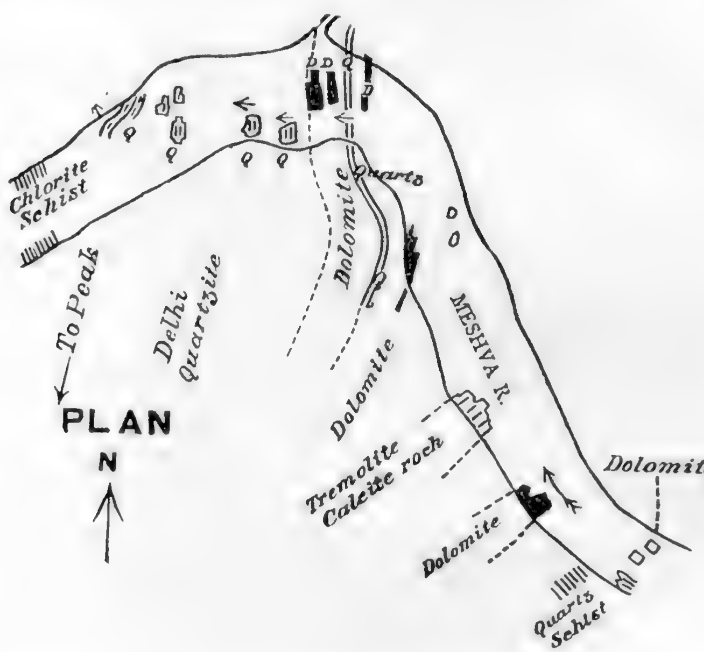


Fig. 17.

closely juxtaposed against the Aravalli chlorite-schists, the Delhi Quartzite, which is of a rather dark purplish grey colour and cut through by many wandering iron-stained divisional planes, dips at 60° N.W. There is about 500 feet in thickness of this represented, and it is followed downwards in the section by a set of magnesian rocks of a novel and specially interesting character.

(3) Magnesian Phase associated with the Delhi Quartzite.

These magnesian rocks have a bedded appearance that by itself would lead to no suspicion regarding the normal succession were it not for similar sections elsewhere that suggest questions on the lines of those with reference to the Bamanvada white pyroxene (diopside) series. There is, first, a dark-grey quartzose dolomite with quartz stringers—$\frac{26}{373}$ (12410) and $\frac{29}{430}$—the passage appearing to be a regular conformable one with interbedding—all plainly visible in the naked rocks of the river-bed. The dark dolomite is succeeded by a little white tremolite-calcite rock, $\frac{26}{374}$ and $\frac{29}{428}$ (12412), and that in turn is followed by pale dolomites with filmy layers of steatite,—$\frac{29}{429}$ (12413)—exactly reproducing a rock that will presently be described in more detail associated with the steatite of the Dev Mori-Kundol exposures. A detailed search above the village along the strike revealed none of the magnesian and calcareous rocks extending up into the ridge; but, inasmuch as the height of the latter is only about 400 feet above the plain at Khercha, the anticlinal structure of the hill would hardly be able to accommodate them together with 500 fit. of the Delhi Quartzite, unless the dip were very steep. A sketch view of the hill outline as seen from the river near Khercha is added (see text fig. 18) with

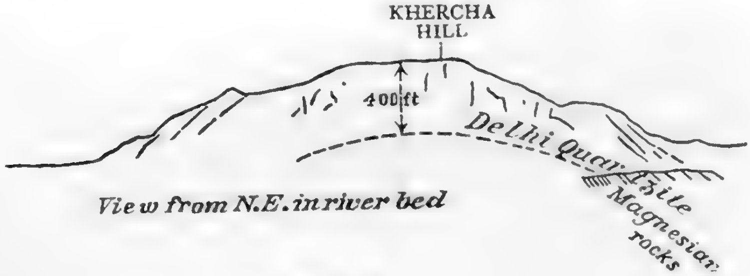


Fig. 18.

the suggested structure inserted to illustrate the above interpretation.

Disappearance of the centre of the brachyanticline.

If we join up the quartzite arms of the Khercha anticline northwards to meet the arms of the 1,085 ft. hill across the intervening alluvium we shall find that, except the river section as just described, the rest of the river-bed up to Samalpar gives no exposures, whereas on the analogy of the Dev Mori-Kundol section (see p. 99) we should expect dolomite or other magnesian rocks o underlie the surface here. The problem then is how does this ov l dolomitic and otherwise magnesian local phase of the Delhis, together with the overlying quartzite, become merged into the Aravallis round about Samalpar? It is clear that the arrangement must be most discordant and irregular, inasmuch as it presents the appearance of a distinct anticline in the Delhis with a core of magnesian rocks, planted down among or upon, and, as it were, melting into, the Aravallis? This is obviously not the same thing as finding a syncline in the Delhis in a similar position. We must leave the puzzle for the present in order to describe a number of other analogous sections where magnesian rocks again become visible along local anticlines in the Delhi Quartzite.

Other anticlines of magnesian rocks among the Delhi Quartzite.

The first of these that will be described is that of the hills between Dev Mori and Kundol a few miles further to the east, another is at Ghanta, a third in the big wrench of the Delhi Quartzite between Kokapur and Vartha, and a fourth to the south-west of Thuravas.

Magnesian rocks between Dev Mori and Kundol.

In a short note in the *Records* (Vol. XLII, pt. 1, p. 52) I have previously sketched the main features of the magnesian rocks of the Dev Mori-Kundol area, with special reference to the steatite content from an economic standpoint. The outcrop occurs along a little valley almost enclosed by low ridges of Delhi Quartzite. These coalesce round the head of the valley to the north into the 1,034 ft. and 948 ft. summits, which together form the blunt nose of the anticline in the Delhi Quartzite as it pitches under the Phyllites lying west, north and east of it. All the above statements are supported by ample exposures round about Dev Mori and in the hill-slopes to the north-west of Kundol. It is clearly a parallel case to the similar neighbouring positions at Venpui and Od.

Shape of outcrop: general composition.

The main outcrop of the magnesian series in the heart of this anticline has the surface shape of a narrow ellipse, about 1 mile long, and tailing off to the S.S.W. in a long narrow process. With the exception of the uppermost layers, where the magnesian rocks appear to pass up into the Delhi Quartzite, the rest of the exposures (which are not numerous and generally had to be dug out) yielded chiefly talc, in the compact form of steatite, $(\frac{26}{380}-\frac{26}{396})$ together with a little hornblende asbestos $(\frac{26}{402})$. The steatite is apparently bedded or banded practically vertically, forming a core to the anticline varying from 200 feet to 300 feet in width or thickness.

Steatite.

A few remarks on the large amount of steatite present and its quality, will be given in the section devoted to economic minerals (p. 148), it being only necessary to remark here that it varies from the softer, white, cream-coloured, purer kind, as exemplified by specimen No. $\frac{26}{390}$ (12418), to a slaty or greenish-coloured, firmer and less pure variety mixed with much chlorite, $\frac{26}{395}$ (12419). All the varieties are somewhat flaky and have a certain tendency to split parallel to the bedding—this tendency being less marked in the purer soft creamy-coloured kind.

Asbestos.

The asbestos, $\frac{26}{402}$ (12420), was found originally on the south of the little divide, 800 yards south of the hillpath from Dev Mori to Kundol. Other deposits were found in some shallow pits sunk across the wider part of the ellipse of outcrop. It appears to occur sparingly and irregularly among the steatite, but it has not yet been properly exposed by any prospecting operations. Examined in the Geological Survey laboratory by the late Mr. H. S. Bion, it gave the following analysis:

Ign (H_2O)	1·529
SiO_2	55·54
Fe_2O_3 } Al_2O_3	8·35
CaO	12·15
MgO	21·27
Loss	1·17
	100·00

The iron and alumina have not been separated and a little manganese is present.

The asbestos is remarkably pure, soft and of silky and long staple, without any hard residual fibres. By simply macerating it in water with a slight movement, and afterwards drying, the beautifully soft silky tresses are obtained together with a certain amount of fine down. In the matter of tensile strength, it of course cannot compare with serpentine asbestos, but this quality is not imperative in many of the modern uses to which asbestos is now put. (See also p. 148.)

Rocks and minerals associated with the steatite.

Although the central and main mass of the anticline is very uniformly steatite, or steatite with some asbestos, the margins, where it comes in contact with the Delhi Quartzite, show some interesting modifications. Exposures, owing to the habit of the Delhi Quartzite to break up into débris and cover the junctions, are not common: long grass at certain seasons of the year and much small forest likewise often hide the junctions. Instructive sections are, however, seen on the eastern margin of the ellipse, lying just a little north of the direct hill-path from Dev Mori to Kundol, and also round the northern end of the ellipse. At the former the section exposed in a little round hill gives, in descending order, (1) massive Delhi Quartzite dipping at about 40° or less down in the direction of Kundol. There are only some hundred feet or so of this exposed, but, from the position of the boundary with the Phyllites in the neighbourhood, there may be as much as 1,000 feet really present. Below this comes (2) interbedded quartzite and phyllites, together with vein-quartz, about 60 feet thick. Below this again (3) another 60 feet down to the valley bottom, consisting of calcite and pale amphibole rock, 20 feet thick, succeeded by 40 feet of dolomite and dolomite-talc-serpentine rock with a little interbedded quartzite.

This is the base of the section as exposed, but from the nature of the little plain which forms the valley bottom and from closely situated sections in a large square well and stream-bed, the thick mass of steatite probably succeeds immediately below the above-detailed section.

The calcite-amphibole, dolomite, and dolomite-talc-serpentine rocks are very conspicuously visible at the base of the section and also as boulders strewn about the path going to Kundol. Of these the dolomite-serpentine-talc rock, $\frac{26}{397}$ (12414, Pl. 13, fig. 1), is a massive, rather brilliant, dark-green rock, tough under the hammer, and weathered at the surface into holes. In thin section it shows the dolomite in great ophitic plates crystallised round a confused mass of the other minerals. It would probably polish into a rather handsome rock. The dolomite in this rock is exactly similar to that of the neighbouring bed above, namely No. $\frac{26}{399}$, which is wholly composed of the same mineral. The latter was analysed in the Geological Survey laboratory, giving a small unweighed quantity of silica, together with—

Fe_2O_3 etc.	4·80
$CaCO_3$	51·84
$MgCO_3$	43·31
	99·85

It is of a pale creamy-brown colour and is also fairly massive. There is a very minute amount of a canary yellow mineral in $\frac{26}{399}$ which has not been determined.

The calcite-tremolite rock, $\frac{26}{404}$ (12416), at the top of the lowest 60 feet in the section, is a coarse crystalline limestone with pale to dark-green, elongated blades of actinolite, in radiating and felted groups. No. $\frac{26}{406}$ (12417) is a similar, paler rock from the northern end of the hollow, the tremolite being in radiating tufts.

Veinlets of the green amphibole.

This uppermost bed, with some modification, can be traced round the northern end of the ellipse at intervals, where it appears as dark green crags just above the cup-shaped hollow in the hills. The tremolite or actinolite, besides being found with calcite as a definite layer, also (it is important to note) wanders away and pervades the quartzite above in irregular veins giving it a distinctly green tinge (specimen No. $\frac{29}{431}$, 12421).

Other junction sections.

At other places round the steatite ellipse local, imperfect exposures show the creamy, coarsely crystalline dolomite, and (as at the low gap about ½ mile south of the path from Dev Mori to Kundol) the bright green amphibole and amphibole-quartz rock—$\frac{26}{409}$ (12422) and $\frac{26}{408}$ (12423, Pl. 13, fig. 2)—forming a junction rock with the quartzite series on each side of the steatite outcrops.

Magnesian rocks thinning away to the south.

The southern end of the exposures of this magnesian series narrows down to a very small thickness, and it cuts the cross-stream going to Odha at a point which looks as if it were about to leave the Delhi Quartzite hill-mass altogether.

Irregular horizon of the magnesian rocks.

Before describing the other occurrences of magnesian rocks, it may be as well to draw attention to the fact that the sections just described, as well as that at Khercha, seem to indicate that if this magnesian series, brought to view in what appear to be local anticlines among the Delhi Quartzites, is really a sedimentary deposit, it must be located at a horizon not more than 1,000 feet below the top of the Delhi Quartzite where it passes up into the Phyllite Series, and probably at a much less depth in the case of the Khercha occurrence.

Adventitious vein origin.

This hardly accords with ordinary sections in the Delhi Quartzite, and one must therefore be prepared to conceive of the magnesian series either as a locally developed sedimentary deposit only, or (what may seem more probable) as being adventitious in some way, *e.g.*, vein-filling along a fissure or gaping in the Delhi Quartzite, where the anticline pitches strongly and must have suffered a violent wrench. The observation that the green amphibole actually passes up in the form of small veinlets ramifying among the substance of the quartzite at the northern end of the steatite ellipse makes this supposition additionally probable, whilst we shall see later that other facts from localities yet to be described strongly support this idea. Finally, it is in agreement with observations, made on a similar magnesian series of rocks in Dungarpur district (adjoining the Idar area on east and north) by my colleague the late Mr. N. D. Daru, which tend to show that the magnesian minerals occupy narrow bands cutting indiscriminately into Delhi Quartzite and Phyllite Series. Their constant association in Idar, however, with the former, in apparently bedded or banded masses and layers, has made it convenient to describe them here along with their (albeit perhaps abnormal) host, the Delhi Quartzite.

(2) Ghanta outcrop.

The second occurrence of similar magnesian rocks at Ghanta is of very small area. Ghanta is a deserted village, really lying in Sadra State, about $1\frac{1}{2}$ miles east of Kundel and 3 miles E.byS. of Titoi (Tintoi). It lies in an alluvial inbaying among the same ridge of Delhi Quartzite as that which carries the outcrops of steatite, etc., last described but on its western flank, and it is separated from the latter by some miles of quartzite hill barren of any such deposits, so far as is visible.

It is exposed in the dry stream-bed just $1\frac{1}{4}$ miles N.W. of the village site, and consists of steatite in some 3 or 4 beds of 10 feet thickness, $\frac{26}{391}$ interbedded with more greenish chloritic rock ($\frac{26}{393}$—$\frac{26}{394}$) through a distance of some 20 or 30 yards. Specimens taken from here indicate a very fair quality of steatite. There is no visible extension of the band or deposit into the quartzite of the neighbouring Delhi Quartzite ridges.

(3) The Kokapur-Vartha outcrop.

The third occurrence covers a rather extensive tract which has the form of a knee-shaped bend, some 4 or 5 miles long, in a hollow in the Delhi Quartzite hill-mass between Kokapur and Vartha, this occurrence being likewise connected up by more or less continuous ridges of Delhi Quartzite along the line of strike with the Ghanta and Dev Mori-Kundol outcrops already described. In addition to magnesian rocks, including pure serpentine rock, steatite, dolomite and some few magnesite veins, there is also associated with them a considerable amount of siliceous material as secondary quartz and chalcedony (gangue), ramifying as drusy structure through the quartzite in a plexus of veins, and which, together with some poorly exposed compact ores of iron and manganese, constitute a definitely mineralised band. Although the tract here exposed is of larger extent than that between Dev Mori and Kundol, it is equally imperfectly exposed owing to alluvium and quartzite débris, and has not as yet (1916) been opened up by any digging. It starts about 1¼ miles due south of Dedhalia town, as a narrow band between quartzite ridges. This expands to a wider area, some ¾ mile across in the actual angle of the knee-bend, whence it follows, with a moderate width of ¼ mile, to Vartha.

Magnesite, steatite and green amphibole.

About due west of Kokapur, at a locality reached from the latter village through a gap in the bordering quartzite ridge, the magnesian rocks, imperfectly exposed amongst alluvium and kankar, are chiefly impure magnesite, $\frac{29}{432}$, dolomite, $\frac{29}{433}$ (12424), talc, $\frac{29}{434}$, and the green amphibole rock, $\frac{29}{435}$ (12425, Pl. 13, fig. 3) next the quartzite as near Kundol.

Serpentine.

In the wider part of the actual knee-bend I found on the northern and south-eastern edges, (almost hidden by alluvium quartzite débris, and siliceous and dolomitic rock) isolated but *in situ*, masses of very tough, dark, serpentine rock, $\frac{29}{436}$—$\frac{29}{437}$ (12426, 12427, Pl. 13, fig. 4) having a very dyke-like ultrabasic igneous aspect. This, however, under the microscope, shows simply pure serpentine and iron-ores (chromite ?), the latter in small veins and aggregates, and without any trace of any original olivine or other mineral from which the serpentine might have been derived. An irregular net-structure is all that suggests olivine. It polishes to a dark-green, handsome rock.

It seems quite a plausible theory that these outcrops indicate a peridotite mass, situated somewhere in this area, and originally intrusive along the "gape" of the quartzite rocks at the angle of the knee-bend, and from which all the other siliceous, dolomitic and magnesitic material originated by secondary changes such as are common to ultrabasic peridotite rocks.

Siliceous, ferruginous and manganiferous veins.

Another interesting phase of this band of rocks becomes manifest in the moderately wide arm going towards Vartha from the direction of the knee-bend. This constitutes a fairly marked intermediate ridge between the two flanking Delhi Quartzite ridges, which have a steady dip of about 50° S.W. (text fig. 19). The width of this intermediate

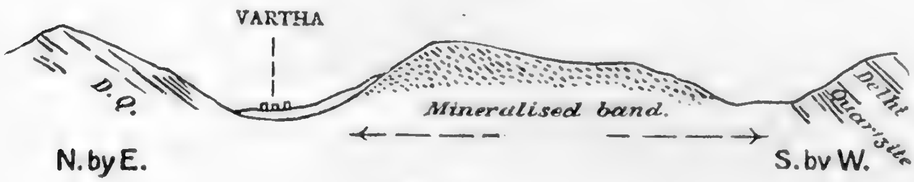


Fig. 19.

ridge is $\frac{1}{4}$ mile; and the whole of it, as exposed immediately south and south-east of Vartha, has the quartzite altered and permeated by drusy cavities which give it a vesicular, slag-like appearance. Exposures are numerous enough, but the hill is simply a heap of disintegrated blocks and fragments thrown about at random, though approximately *in situ.* Whilst most of these are highly siliceous and gangue-like, such as specimens Nos. $\frac{29}{438}$—$\frac{29}{439}$, others are ferruginous and manganiferous, such as $\frac{29}{440}$, $\frac{29}{441}$ (12428), and become dark in colour, and contain within the druses minute crystals of (?) braunite and dusty pyrolusite, as in $\frac{29}{441}$. Others, again, still more rarely found in solitary lumps here and there appear considerably impregnated by black manganese ore which shows in the thin section as opaque dots, blots and irregular areas. The better specimens of this richer rock, however, $\frac{29}{442}$ (12429, Pl. 13, fig. 5), did not yield more than about 7 per cent. of Mn when analysed by my colleague Mr. H. Walker, in the Geological Survey laboratory. The appearance under the microscope suggests a metasomatic replacement of the quartz of the quartzite by the manganese-bearing solutions, and the concomitant deposition of an intimate plexus of veins and veinlets of secondary quartz and chalcedony. In some cases large veins and rounded hollows, an inch across, are filled with soft, sooty pyrolusite which lies loose or falls out on breaking the rock, like a nut from its shell, as in specimen No. $\frac{29}{443}$. Other specimens of vein rock, generally silicious and ferruginous are $\frac{29}{444}$—$\frac{29}{446}$, of these, $\frac{29}{446}$ shows in a quartzite matrix long lath-shaped crystals, much altered, of (?) a variety of amphibole. At the Vartha end of the band no thick beds of steatite or dolomite are visible, but minute flakes can frequently be seen in the microscopic preparations. A little further to the south-east, however, about $1\frac{1}{4}$ miles S.E. of Vartha, steatite with chlorite beds, is present in considerable beds (specimens Nos. $\frac{29}{447}$—$\frac{29}{448}$), the occurrence being similar to that at Ghanta.

Probably adventitious nature of the magnesian rocks.

It will be seen that the evidence now accumulating concerning these various occurrences of magnesian rocks, with their other associated minerals, seems to a large degree to discount their first appearance of being original sedimentary deposits interbedded with the Delhi Quartzite. The apparent horizon of the rocks is too near the uppermost limit of the Delhi Quartzite for them to belong to some different and basal phase of the Delhi Quartzite, such as the Raialo Limestone of N.E. Rajputana, recently re-described by Mr. A. M. Heron (*Mem., Geol. Surv. India, Vol. XLV, pt. 1*), and it is equally unlikely that they belong to some rapidly thinning, local, sedimentary deposit at any higher horizon. These magnesian rocks from many points of view, seem to be really adventitious in some way; to have become inserted among the quartzites, and, either bulged them up into local anticlines, or wedged apart neighbouring quartzite layers. We might imagine them as injected or deposited as veins or forced up along gapes among the quartzite strata by some strong deformatory movements such as elsewhere have resulted in stoping away the Delhi Quartzite in blocks. Or on the other hand it may be that the whole phenomenon is more of the nature of a normal peridotite intrusion, accompanied by the usual secondary changes of such rocks to serpentine, talc, magnesite and dolomite, and later still affected metasomatically by mineralizing solutions carrying manganese,

G. Merrill's views.

The occurrence of actinolite rock, hornblende asbestos and talc in these localities seems to present some analogies with that described by G. Merrill.[1] This author states that at Alberton, Maryland the fibrous anthophyllite occurs along the slickensided zone between a schistose actinolite rock and a more massive serpentinous or talcose rock which is also presumably an eruptive peridotite or pyroxenite. The fibration, it is also stated, runs parallel with the direction of movement as indicated.

Other views.

However, there are other views; Heinrich Ries in *Economic Geology* (1910), in describing the Virginia deposits, which occur in beds of 30 to 165 feet thick, in much the same terms as regards the colour qualities and hardness as are applicable to the Idar rock, is of the opinion that steatite in some cases has no doubt been derived from an altered eruptive rock, but in others probably from magnesian sediments, by metamorphism. In the New York deposits there are schistose layers from a few feet to 50 feet thick in Pre-Cambrian gneisses with belts of crystalline limestone. The schistose layers contain tremolite and enstatite as the chief constituents and it is considered that it is their alteration that has produced the talc by means of water charged with carbonic acid. An interesting occurrence is described from New Jersey, where talc occurs with serpentine in dolomite, and near pegmatitic intrusions. The latter, by contact metamorphism, developed tremolite, white pyroxene and phlogopite in the limestone. Later, during break-thrust faulting accompanying minor folding, squeezing and faulting in this area, the magnesian silicates were altered by water to talc and other products.

These quotations seem to show that the particular way in which steatite beds may be formed are many and various.

(4) S. W. of Thuravas.

The fourth occurrence of magnesian rocks, with their accessory minerals, stretches south-west of Thuravas for about $1\frac{1}{2}$ miles to a point in the Hathmati river due east of Fatepur. It is a rather narrow band, probably nowhere more than 300 feet thick, though lack of clean-cut sections prevents any more accurate estimate. The outcrop rises and sinks gently over the lower ends of the hill-spurs and is easily noticeable

[1] "The non-metallic Minerals," 1st Edn. p. 183, New York, Wiley and Sons, Chapman Hall and Co.

by its dark-brown colour. It begins in a little valley in the Delhi Quartzite just behind the village and along the axis of a faulted anticline, in the Delhi Quartzite, running N.E.—S.W. (text fig. 20).

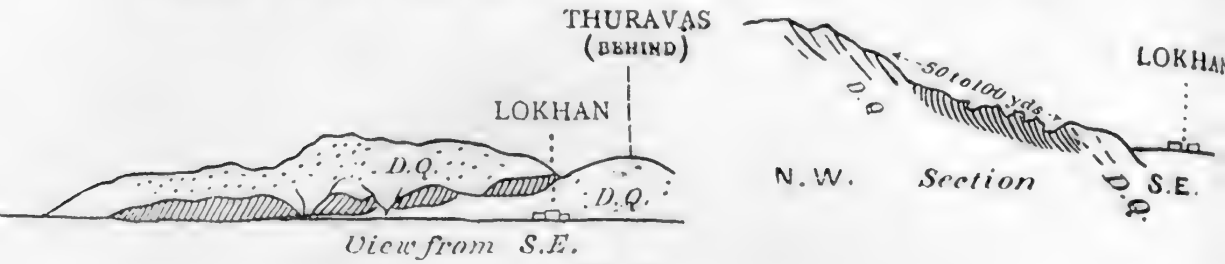


Fig. 20.

Serpentine.

The first rock here found is a serpentine of pale yellow and greenish tints, mottled or veined with lilac (specimens Nos. $\frac{29}{449}$—$\frac{29}{450}$ 12430, 12431). Judging from the irregular net-work structure visible in the thin section under the microscope as outlined by the minute grains of black oxide, which is chromite, the serpentine was probably formed from olivine. These two specimens are of rather soft but tough rocks that give a very pretty effect when polished and would probably make a pleasing ornamental stone. Only 10 to 20 feet of it is actually exposed on the footpath before reaching the little divide between Thuravas and Lokhan. It appears to end in an upward direction rather suddenly against the quartzite with just a thin layer of transition rock.

Ferruginous and siliceous gangue stuff; chromite.

Associated with it, judging by fragments scattered about, is a little of the dark brown, ferruginous chalcedonic, rotten, gangue rock, with minute particles of dolomite and other soft magnesian minerals scattered through it,—specimen No. $\frac{29}{451}$ (12432),—after the manner of that which is so prominent a feature in the Vartha area. Just above Lokhan the hill-sides are littered with the fragments of this brown siliceous and ferruginous rock only more or less *in situ* ($\frac{29}{452}$). In some cases this gangue rock is rather rich in small patches the size of a pea or less, of chromite, ($\frac{29}{451}$, 12432).

Steatite: actinolite rock

A fairly thick bed of steatite is found in the path round the last spur before reaching the river, but owing to the débris of quartzite fragments and of the rotten vein-stuff, it is impossible to estimate its thickness accurately, but it may be between 40 and 60 feet. It resembles the Dev Mori-Kundol steatite. Actinolite rock, ($\frac{29}{453}$ 12433), amphibole rock changing to calcite ($\frac{26}{370}$ k. 12434), and calcite and brown opal rock ($\frac{26}{367}$ 12436), are also associated with the steatite.

Origin.

The presence of chromite in this band of altered rock is additionally suggestive of some ultrabasic rock as the parent of the various modifications referred to above, but the thoroughly serpentinized condition of whatever the rock was makes it impossible to specify it more particularly. Hence in this case, as in that of the other similar occurrences, I have, though with some hesitation, included these magnesian rocks in the section on the Delhi Quartzite, rather than put them into a special class of ultrabasic intrusions, as to which there is no positive evidence.

Economics.

The possibly fair thickness of this band of derived magnesian and other minerals, which I estimate as something under 300 feet from the width of the outcrop of surface rock, renders this locality also worth the attention of the mineral prospector.

Other possible localities.

The above four localities for these rocks are all I have discovered in Idar State, but owing to the tendency of the accompanying Delhi Quartzite to break up into long débris slopes, there may be others hidden from view through the wide areas coloured on the map as Delhi Quartzite, and a few perhaps that I have missed in my traverses.

(4) Tectonic Relationship between the Delhi and Aravalli.

Irregularities of juxtaposition.

Whilst the relationship of the Quartzite series to the younger Phyllite series in this region is everywhere comparatively easily understood on the simple supposition that the former formation passes conformably up into the latter by a rapid if gradual interbedding, this being recognisable at the surface in many places by the outcrops of intermediate passage layers following continuously round a clearly exposed sinuous line of junction, the same (as we have had abundant proof of) is not true as regards the indirectly deduced relationship between the quartzite and the

Aravalli rocks below. Here, whenever we study the possible terms of this relationship, as made evident from the preceding details, we are brought face to face with amazing irregularities of juxtaposition that at first sight appear irreconcilable on any simple hypothesis of folding, even allowing as much as possible for the fact that actual junctions are almost always obscured by the alluvium of the valleys, or by débris from the quartzite scarps. The most noticeable phenomenon in this connection is the puzzling way in which long or short ridge-masses (strike-masses) of the quartzite end in sudden, blunt, or even expanded processes directed towards the south-west or tail away in long slender ones among the basement of Aravalli rocks.

Not explicable by simple folding above the Aravallis.

On the theory that these quartzites have been simply or complicately folded superpositionally with regard to the Aravallis, these sudden endings ought to show concentric outcrops of sharply rising synclines of the quartzite to the Aravallis, the exact counterpart of their sharply pitching anticlines as regards the overlying phyllites. But all evidence whatever of this is entirely lacking, whilst not infrequently the evidence is the other way, and as we have seen in descriptions given above the separated arms of anticlines or of vertical strata (probably isoclines) of the quartzite splay out, or end in a fringe, against the Aravallis as though they had sunk down, been engulfed in, or become frayed away by some process. It is easily recognised as a startling but undoubted fact, that no single one of the many quartzite hill-masses that mapping has revealed, ever displays anything that could be construed as a regular synclinal trough upon the surface of the Aravallis, as do the phyllites above them. On the other hand an instance has been given near Samalpar of a brachy-anticline in the Delhis with its central portion missing as if it had mysteriously disappeared or been effaced by the Aravallis below.

It resembles an eruptive unconformity.

Were the underlying Aravallis consistently composed of igneous rock, we should recognise this anomaly now-a-days as due to dismemberment of the quartzite by the solution, stoping away, or under-cutting and sinking of the broken ends in the igneous magma. In other words we should admit it as a complicated eruptive unconformity. The stoped contacts near Walren and Dijio are especially instructive instances of such a supposititious process.

In the present case, on the theory adopted of the largely metamorphic character of the Aravallis, a certain modification of this process seems necessary to satisfy the facts. We must suppose that the Aravallis being in part of an igneous nature and at all events being much invaded by igneous material, under the consequent heating and intense compression, have behaved largely like a semi-solid or plastic mass. This might have allowed the quartzite (whilst here and there preserving traces of stratification) to be melted off, stoped away, or dissolved or pinched out down among the hot and plastic Aravallis, especially towards the deeper sections of the folds where their pitching axes became steepest. It may even have been that some of the quartzite masses, which now remain to view, were so cleaved, sheared, and finally rendered plastic themselves by rock flowage accompanied by more or less free molecular motion, as to account for the blurring and effacing of all traces of original bedding, such as has often been described by me as characterising them.

A modified explanation.

The case of the magnesian rocks just considered must stand by itself for the present as an additional problem; which, although as yet left imperfectly explained, may on any interpretation easily fit in with the general conception of the tectonic relations of the Delhi Quartzite to the Aravallis outlined above.

We may contrast this position of the Delhis here in Idar with the much simpler aspect of the Alwar quartzite, its presumed equivalent, as described by Mr. Heron, and which I can corroborate from personal experience. The latter is generally well bedded, and the aspect of unconformity on the Aravallis is dominant; whilst, as we have seen in Idar, the relationship of the Delhis to the Aravallis is more on the pattern of that of the Dharwars to the underlying Archæans of southern India.

Contrast with the position of the Alwar quartzite.

PHYLLITE SERIES.

On account of its conformity with, and its passage downwards into, the Delhi Quartzite, neither this series nor the Delhi Quartzite series has been elevated into a separate system, but each remains subordinate to the other with which it appears to be connected by many features in common. In development, the Phyllite

Not a separate system.

series as displayed in Idar State is small compared with the much wider areas occupied by it in the neighbouring state of Dungarpur.

Boundaries.

As regards its lowest beds, which are interstratified with the uppermost part of the Delhi Quartzite, much has already been said incidentally. For the same reason it is unnecessary to define their boundaries since the lowest beds of the Phyllites coincide with the upper layers of the Delhi Quartzite while the upper limits of the Phyllites are unknown.

General distribution.

In general terms their distribution may, however, be roughly indicated as occupying the following areas, (1) in the upper valley of the Hathmati river from near Pal to Kanadara, where they are well seen, and again near Thuravas, Tembana Math and Janali in very imperfect and scattered outcrops; (2) as developed in the gently hilly country to the east of the more striking Delhi Quartzite ridges which stretch from Bornali *viâ* Od, Navugam, Dev Mori, Kundol and Sangam to the neighbourhood of the Majam river near Modasa; and (3) as seen at Meghraj and east of it in the very vide area stretching away into Dungarpur.

Possibly in part contemporaneous with the Delhi Quartzite.

On account of the probable thinning of the Delhi Quartzite in an easterly and south-easterly direction, it may be that the connection between the phyllites and the Delhi Quartzite may even be more essential and significant. The latter may have thinned away eastwards and south-eastwards concomitantly with a thickening of the Phyllites, the two being in part contemporaneous and representing respectively the coarser and more arenaceous sediments on the one hand, and the finer and more argillaceous on the other of an—at least partially—uniform and connected set of deposits. However this may be, it is necessary to give a short description of the Phyllites as a separate unit in a petrological sense, though full justice cannot be done to the subject on account of their very restricted development in this State, and that only on its north-eastern and eastern fringes. No detailed account, therefore, will be attempted here.

Surface features.

The Phyllite Series builds as characteristic country as the Delhi Quartzite, but in a different sense. Instead of rugged and steep little hill-ranges, as afforded by the latter, it yields softer and more undulating country that has been worn down by denudation into a perfect labyrinth of small and low knolls, mounds and ridgelets, seldom more than 200 feet above the nearest alluvium and frequently much mixed up with the latter. The 1 inch=1 mile topographical maps show very distinctly by the highly complex and sinuous windings of the contour lines, the change from the one formation to the other. On the other hand it never, or very seldom, sinks to such low-level peneplains as has been the case with certain of the Aravalli rock complexes. It is essentially the home of the Bhil people, who invariably build their scattered and frail wattle dwellings dotted about in completely detached huts and homesteads in lieu of collecting together into large villages or towns. A so-called village as marked on the map, covering, it may be, several square miles, is simply a loose assemblage of single huts in each of which one family resides.

A thin-bedded argillaceous series with white quartz veins.

As the name "Phyllite" implies, the chief member of the series is a markedly thin-bedded rock of slightly metamorphosed argillaceous type, but it is freely interbedded with more arenaceous quartzitic strata though these never attain to the importance and pure simplicity of the characteristic massive Delhi Quartzite. The colours are generally pale or dark sombre tints of grey, *khaki*, yellowish, purple and green, and these are everywhere, so far as exposed in Idar, freely interspersed with the white tints of ramifying quartz veins. These latter are as typical as the phyllites themselves, inasmuch as many of the small mounds and ridges owe their preservation as elevations to a backbone of these quartz veins.

Minute mica scales sheathe the surfaces of all the finely divided layers of the rock which is also generally contorted or minutely wrinkled. Magnetite is fairly common in rather large crystalline grains in some varieties, as for instance $\frac{29}{456}$ (12443, Pl. 13, fig. 6) from $\frac{1}{2}$ mile south-west of Mori. Some of the scattered examples from the neighbourhood of Thuravas and Tembana Math are a trifle more mineralised, biotite being associated with the sericite and also some tourmaline, as in specimen $\frac{29}{402}$. Chlorite and magnetite-schists are seen feebly at Tembana Math and at Janali. There appears to be some slight discordance between the strike of the Tembana Math-Modhri outcrop, which runs N.E.—S.W. and the winding outcrop of the Delhi Quartzite ridge lying to the south and east. The surface alluvium, however, hides so much in this little bay among the Delhi Quartzite ridges that one can say nothing certain about it. At one time I was inclined to put these more mineralised schists with the Aravallis, but the difficulties in the way of such an interpretation are very great.

No other petrological facies.

Although there must be considerable variety in detail, it is necessary to add here that no marked beds of quartzite, no limestones and no trace of intrusive igneous rocks have been met with in the area traversed by me among the Phyllite Series.

Thickness.

There appear to be miles of thickness of these phyllites, without any trace of any break in their monotonous regularity. It is, however, utterly impossible to make any more definite estimate on account of the lack of any marked stratigraphical horizons that could be taken advantage of in mapping them. The bedding is frequently steeply inclined and even vertical, this being a real bedding as shown by interbedding of varieties of rock type. But, notwithstanding this, beyond the fact that they have evidently been folded and frequently loosely cleaved, it is impossible to arrange the folds into any intelligible series. The whole country is probably a plexus of brachy-anticlines and synclines, with unknown amounts of slipping along axes and pitching constantly and steeply to all degrees of steepness. The only thing remaining steady is the strike, which keeps fairly constant at about N.E. by N.

Divisional planes.

There is frequently seen to be a rough uneven cleavage in addition to the bedding-planes, and often making considerable angles with them. This cleavage is necessarily more uneven and irregular in the more quartzose bands, with the result that the rock sometimes splits up into lumps with the formation of what looks something like autoclastic conglomerate, as $\frac{29}{462}$, from near Pathipura (see text fig. 21). Thin

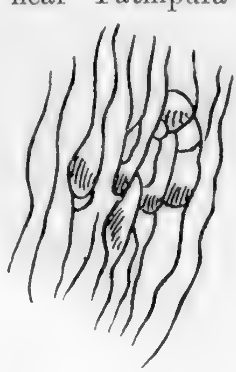


Fig. 21.

harder bands also sometimes become disrupted across their length and the severed portions curled up and twisted into irregular shapes, as in specimen $\frac{29}{457}$ from Nawagaon between Mori and Isri. The foliation planes can also be seen making considerable angles with the bedding, as in specimen $\frac{29}{458}$ from 3 miles N. of Samlaji, where wrinkled micaceous layers and sericite plates, set parallel in planes almost at right angles to the original bedding, become evident. Specimen $\frac{29}{461}$ from 1 mile south of Meghraj is quartzose and shows well-developed platy structure (see text fig. 22).

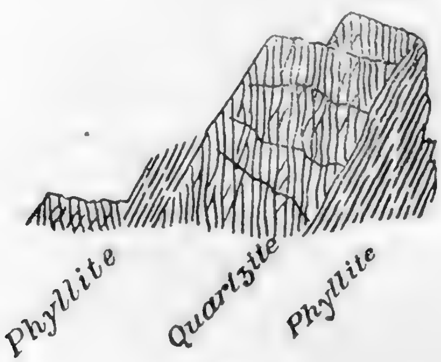


Fig. 22.

Manganese ore.

A little east of Dhanivada, 4 miles east of Meghraj, thin veinlets of pyrolusite occur in the Phyllites and interbedded quartzite (specimen No. $\frac{26}{454}$). By digging about in the alluvium and surface soil to a foot or so in depth, small pellets of pyrolusite were also found. A similar place 1 mile south or south-south-west of this was discovered with veinlets as thick as the finger. Fairly large lumps a few inches across, ($\frac{26}{456}$) of fairly pure, soft, radiating needles of pyrolusite were brought to me from between Naogaon and Chhapri. On visiting the place it was found to be a mere pocket in the quartzite.

IDAR GRANITE, GRANOPHYRE, ETC.

Classification.

In this section I treat together, as appertaining to one congruent intrusive body, certain prominent rocks of granitic, microgranitic and granophyric types. This is necessitated by the fact that so far it has been found impossible to separate them in the field, and it appears quite likely that all three types merge into one another without any decided boundaries. It seems very probable that all are of exactly the same age and belong to one order and time of intrusion. On the other hand it will be observed that I have relegated to a separate grouping the quartz-porphyries of the same area, although many authors consider this type to be no more hypabyssal than is granophyre. The reason for this is connected with the peculiarities of the appearance of the quartz-porphyry in this area and its easy distinction on the score of its black colour and uniform composition throughout large masses. The subject is further discussed under the description of the rocks themselves.

Striking appearance of the granite.

Whatever of vagueness may attach to the boundaries of the Aravalli schists and their injection by veins of aplite, etc., the very opposite is the case with the Idar granite. One of the most striking surface features of the central and western parts of Idar State is furnished by the massive granite and its allied varieties to which I have given the comprehensive name of Idar granite. It builds either fine little groups of rugged and pinnacled hills, often rising 500 to 600 feet above the plain, or scattered bosses and tors of smaller size. Some of the latter near the edge of the granite areas are frequently isolated and of grotesque outline, a result probably partly due to the original form taken by the intrusive material as it solidified and partly to unequal weathering by exfoliation in a torrid climate (see Pl. 6, fig. 1). Other scattered irregular outcrops appear like clusters of monoliths, some standing and some thrown down. A few of these are of extra large size, such as the cyclopean masses of Sapavada south of Idar town, which are without joint or flaw for lengths of 300 yards. The approaches to and surroundings of Idar town are marked by a picturesque array of many such fine examples, and as is natural, they are frequently surmounted by temples.

Remarkable weathering.

A peculiar manner of weathering into rounded undercut recesses is common to certain of the varieties. This results in caves, galleries and abrupt concavities on vertical surfaces which vary in size from a few inches across to such as would hold two or more persons comfortably sheltered from sun or rain (see Pl. 6, fig. 2).

Distribution.

The outcrops of this rock are of a very scattered nature. One of the largest of the groups is seen at Idar, where hilly masses several miles long and about one mile wide entirely encircle the town. In a southerly direction from Idar these split up into more and more detached rocky hillocks and isolated tors, until they are finally lost to view altogether at a distance of 3 to 4 miles away. In a northerly direction the Idar group splits up into more widely separated but larger masses, such as the notable one forming the Sabalvada hill, that of Dantroli, Vasna and Asai, and lastly that of Dharol hill, some 10 or 12 miles north of Idar. The members of this extended group of granite hills mostly rise straight out of the Recent alluvial deposits, and form the only hills in the neighbourhood. Their striking and picturesque outlines naturally contrast very much with the continuous and monotonous ridges of Delhi Quartzite seen further to the east and south-east.

Within a short distance of the Idar-Dharol group there are found to the west, near the banks of the Sabarmati river, one or two isolated granite hills near Mhor, some large and small groupings near Veherabar and Kawa, and from there to the south in the direction of Ora, Umedpura, Desotar, Manpara Chitrori, where the outcrops again become extremely split up into curious little isolated patches and weathered-out *quasi*-monolithic forms. Across the Sabarmati river, which is here the limit of Idar State, the same granite may be discerned building similar hill features in the Palanpur State. The Mhor and Veherabar groups are associated with hills of calc-gneiss, vein-quartz, dolerite and other rocks, so that here the country is not so simple as round about Idar. Nevertheless it is still true that the granite hills keep almost entirely to themselves, rising up from bases entirely surrounded by alluvium, and so absolutely detached from direct contact with any other formation.

South and south-east of the Idar group, to the N.E. of Ahmednagar in the neighbourhood of Jamla, Wantra and Mundeti, the outcrops of Idar granite are of smaller size and importance. They are here much associated with rather similar tors of black quartz-porphyry and also with ridges of Delhi Quartzite, which they only doubtfully penetrate. The most southerly occurrences, as at Berna and Wantra, are horizontally truncated and capped by outliers of the Ahmednagar sandstone series.

Throughout all this area it will be seen that the Idar granite occurrences are as a rule restricted to the lower-lying portions of the State. Granite has not been found to the north and east directly penetrating the more mountainous parts of the country where the Delhi Quartzite is in force. Although it is probable that the granite is younger than the Delhi series, only one or two doubtful contacts of it with the quartzite can be recorded near the margins of the latter. It is probable that lack of penetrative power in the granite is the main reason for this, whereas it had much less difficulty in forcing its way through the lower-lying parts where the more permeable calc-schists and other thinner-bedded, foliated rocks may be presumed to underlie the alluvium.

As already stated it is certain that the same rocks are continued far away beyond the limits of Idar State, westwards and northwards into the neighbouring States of Baroda and Palanpur, and probably beyond that to join up with the Siwana and Jalor granites of Rajputana. In a south-easterly direction, on the other hand, the plutonic acid igneous rocks come to an end some distance before the boundary of Idar State is reached.

Relation to surrounding rocks.

The exact defining of the relationship between the granite and the rocks through which it has been intruded suffers, like a great many of the geological questions in Idar, from the fact that the ever-present alluvium and the wind-borne deposits cover up all the low-lying lands and so bury the bases of these granite hill-masses, and for the most part hide their junctions with the older rocks through which they presumably penetrate.

Apart from special and rare accidental sections which do show such a relationship, there is every reason on general grounds to predicate an extremely discordant relationship. The actual outcrop areas and their general distribution entirely favour the conclusion that the intrusion of this igneous rock happened subsequently to, and quite independently of, the period of folding of the surrounding calc-gneiss and its injection by vein aplite, etc. The absence of any special orientation of the group outcrop areas and the shape of the individual areas (which are, as one might say, entirely irregular) warrant the above conclusion.

Asai-Vasna hill-masses.

Of the few clear sections illustrating this relationship of the granite to its surrounding rocks one is furnished by the little hill marked by the two villages Asai and Vasna, and lying 4 miles S.W. of Vadali. The hill stands up entirely isolated in the midst of the alluvial plain, but shows its N.W. and S.E. extremities composed of the older calc-gneiss series profusely penetrated as usual by thin bands of vein aplite whilst directly in the saddle between the two hill portions, and on the footpath joining the villages of Asai and Vasna, come a thick and a thin band of the coarse and fine Idar granite. The latter is of typical massive Idar granite weathered into its characteristic grotesque monolithic masses, some being as large as a house and one a gigantic ovoid body, perched on end in a very unstable condition (see Pl. 5, fig. 1). Its outcrop cuts directly across the strike of the calc-gneiss and the general run of its accompanying aplite veins with complete transgression, one actual junction section showing torn-off fragments of the aplite included in the Idar granite. In composition, grain, colour and habit the Idar granite and the vein aplite are entirely distinct.

Morad Hill, 3 miles N.W. of Vadali.

Another junction of the same sort is afforded by the tiny range just south of Morad village, 3 miles N.W. of Vadali. At that place a small tongue of Idar granite may be seen transgressing the edges of the calc-gneiss, but the exposure is on a small scale and is not very good.

Dharol Hill.

A third excellent example is furnished by the western edge of the Dharol hill-mass, about 5 miles N.W. of Vadali, where, on one of the spurs to the north of Dharol village, the calc-gneiss, distinctly banded and injected by the vein aplite with a N.W.—S.E. strike, comes into abrupt contact with a N.—S. outcrop of the massive Idar granite building the main body of the hill. This has already been referred to in the section devoted to the calc-gneiss (see p. 19) and the special contact reaction of the Idar granite on it with production of idocrase rock (p. 20).

These few examples are perhaps sufficient to prove the younger age of the Idar granite and its eruptive contacts towards the calc-gneiss with its plexus of vein aplite. They thus confirm the impression derived from a consideration of the distribution and general appearance of these granite masses.

Parallel case in S.E. and C. Highlands.

This relationship between the two sets of granitic rocks appears to find a close parallel in certain occurrences described by Barrow in the S.E. and C. Highlands (see Summary of Progress, Geological Survey, 1907, p. 111) where likewise the granites are broadly divisible into two, an older and a newer group. The newer occurs in large coherent masses, whilst the older is in comparatively small patches, in small sills permeating the intruded rocks (by *lit-par-lit* injection) or represented by veins of pegmatite.

No laccolites, no foliation or banding.

In all the occurrences of the Idar granite bosses described above there is no sign of any laccolitic habit. The junction exposures, no less than the general shape of the masses of this rock, suggest a below-the-surface condition much resembling what is visible above, that is simple boss-like or plug-like forms with more or less vertical boundaries. There is also an entire absence of any foliation, or banded structure or streakiness, in these acid igneous rocks.

To sum up, the field evidence points to a wide difference in age, appearance and composition between the granite, micro-granite, etc., of Idar type now being dealt with and those already treated of under the name of vein aplite, etc. I am now of opinion that thin veins and apophyses from the Idar granite masses are at least extremely rare and but seldom appear. Exactly under what conditions of intrusion these plug-like masses were formed it is difficult to say, but, whatever they were, they seem to have been unfavourable to the development of offshoots in the form of an interveined plexus. The petrographical details which I shall now enumerate will conclusively indicate the differences mentioned above between the two granites.

Colour, texture and general appearance.

The Idar granite, granophyre and micro-granite is frequently a very handsome rock of from coarse to medium, and occasionally fine, grain, in colours varying from shades of grey, cream, salmon-pink and darker reddish and purple tints, mottled in the usual way by the ferro-magnesian minerals and occasionally diversified by moderately large porphyritic crystals of felspar.

Specific gravity.

From the specific gravities of 8 typical specimens it appears that the lightest rock has a value of 2·607 $(\frac{25}{434})$ and the heaviest 2·767 $(\frac{25}{453})$, the mean of the eight being 2·674.

General mineral composition.

The prevalence of orthoclase and microcline as the chief felspar ingredients places the Idar rock among the potash granites with generally a leaning towards the adamellite and monzonite subgroups in certain cases. The amount of quartz varies somewhat, but it is never absent. The dark minerals are biotite chiefly, and hornblende secondarily, and there are the usual minor accessories of iron ores, apatite, sphene, zircon, together with the rarer mineral topaz in one case. Muscovite is absent as an original constituent.

Chemical composition.

So far as it goes this is borne out by the single complete chemical analysis that has so far been made. The analysis is of one of the hornblendic varieties, which, on account of the amount of plagioclase relative to the potash felspar present, seems to lie near to adamellite or monzonite. The specimen is from Kawa on the western side of Idar State (lat. 23° 52′, long. 72° 57′), and the analysis was made by Dr. Christie in the Geological Survey laboratory. Although this variety is fairly commonly distributed in the State it is not as prevalent as the biotite variety: there can be no doubt that the standard type as found round about Idar town would be on the whole richer in potash than the sample chosen for analysis, which was taken for other special reasons.

ANALYSIS OF IDAR GRANITE.

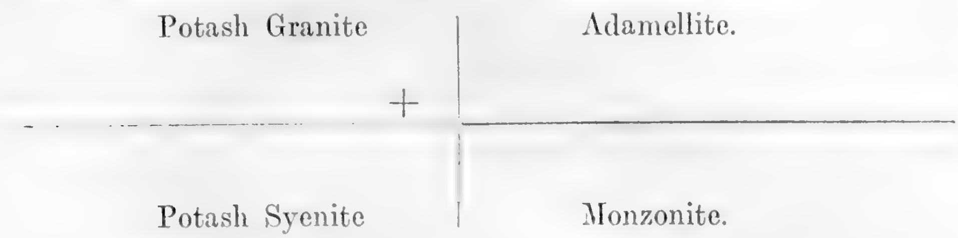
(*Hornblende variety.*)

Kawa.

SiO_2	66·04
Al_2O_3	14·77
Fe_2O_3	1·18
FeO	4·41
MgO	0·98
CaO	2·95
Na_2O	2·56
K_2O	5·25
H_2O (below 108° C.)	·21
H_2O (above 108° C.)	·71
TiO_2	·69
ZrO_2	·03
CO_2	—
P_2O_5	trace
Cl	trace
SO_3	trace
Cr_2O_3	—
MnO	·11
BaO	·02
SrO	trace
	99·91

Specific Gravity = 2·72

Considering this analysis alone, it is evident, from the percentage of silica being just over 66, that this particular sample belongs to the granite family. On the other hand, considering the percentages of K_2O (5·25), Na_2O (2·56) and CaO (2·95), one would be inclined to place it with the adamellite sub-family but coming near to banatite (the most acid of the monzonite sub-family) on one side and potash granite or potash syenite on the other :—



Inasmuch, however, as this specimen is more basic than the typical Idar rock, containing, as it obviously does, less quartz, more soda-lime felspar and more of the ferro-magnesian minerals than the latter, it becomes obvious that the more normal Idar rock will be correctly placed among the potash granites.

Varieties of the granite.

One may divide the Idar granites into the following varieties :—(1) with biotite predominant, (2) microgranitic and granophyric variety, (3) with hornblende in abundance, (4) with topaz (?) and pinite.

Biotite granite.

As examples of the first, which is the most common type, I may instance the isolated tor, 3 miles S.S.E. of Idar town (specimen No. $\frac{25}{433}$, 12444, Pl. 14, fig. 1), also the temple hill immediately south of Idar town (No. $\frac{25}{453}$, 12445) and the rock from 2 miles E.S.E. of Idar, $\frac{25}{439}$. All these are rather coarse-grained, porphyritic varieties, of pale salmon-pink or creamy pink colour. The commonest form of the potash felspar is microcline, which is in overwhelming proportion to any other felspar. It builds all the porphyritic phenocrysts, which by their colour give the predominant tint to the rock as a whole. These felspar phenocrysts are not very sharply marked off from the ground-mass. Their generally idiomorphic shape is well enough seen, showing that most of these porphyritic elements belong to an earlier generation, but the actual borders and outline are vague and mixed with, or interrupted by, the finer-grained ground-mass, and each phenocryst seems to have included within itself hypidiomorphic quartz granules. Microcline in granites is commonly supposed to have been the last mineral to consolidate, and this in the case of the Idar rocks seems to be true enough for the non-porphyritic elements, but not so for the phenocrysts in their entirety. Probably the facts in our case are that the microcline phenocrysts began to crystallise first, and after attaining a certain size in the pasty magma, finished last as regards their bordering layers. Carlsbad twins are sometimes seen, more particularly in orthoclase when it is present.

Plagioclase is very subordinate in the more typical biotite-bearing rock. It occurs in small individuals giving extinctions up to 10° and 14° on each side of the twinning line, and therefore is probably albite or basic oligoclase. It is particularly well seen in $\frac{25}{435}$ (12445). Larger amounts in lath-shaped sections are sometimes seen, as in $\frac{25}{434}$ (12447) from Laloda hill, a reddish granite (adamellite) that does not weather into tors.

Quartz is generally present in fairly large lumps and grains, slightly amethystine-grey in colour, and in sufficient quantity to be typical of granite. Like most other constituents it has no particular outline, being hypidiomorphic (subhedral) everywhere. In a similar but more finely granular, condition it occurs included in the microcline.

Biotite is almost universally present as large individuals, or as a few aggregated together. It has very great absorption, the pleochroism being X, pale yellowish or brownish green, Y and Z, very dark brown to black (basal sections being sometimes distinctly pleochroic, as in 12454), or quite black and opaque, as in $\frac{25}{438}$ (12449) from near Laloda. The biotite generally includes iron ores in considerable quantity and is spotted in many places, suggesting pleochroic halos, though owing to the strong absorption these are not visibly pleochroic. Apatite is also included and in the Asai hill rock, $\frac{26}{508}$ (12460), is present in very many small prisms. The same is the case with $\frac{25}{439}$ (12446), from 2 miles E.S.E. of Idar town. Occasionally, as in $\frac{25}{428}$ (12453) from the west end of Berna plateau, the biotite is in groups or nests of small individuals aggregated together. In this case it is much more generally green in tint than brown and suggests that these aggregations are really small xenoliths.

Muscovite, though normally absent in all the Idar granites, appears sparingly along with biotite in one example, $\frac{25}{427}$ (12452), from the north end of the Berna plateau.

Accessories, as iron ores, and apatite, zircon, etc., are sparingly present, and are frequently included in the biotite as just mentioned.

Basic cognate xenoliths.

This variety of the granite, as indeed many of the varieties often contains dark, fine-grained patches (cognate xenoliths of Harker). No. $\frac{25}{436}$ (12450, Pl. 14, fig. 2) is such a rather fine-grained xenolith enclosed within $\frac{25}{438}$ from near Laloda. This fine-grained inclusion contains a fair amount of quartz, microcline, plagioclase, and biotite having dark, green and yellow pleochroism.

Micro-granites and granophyres.

Fine-grained micro-granites and granophyres are fairly well represented by many specimens, such as $\frac{25}{391}$ (12462) from Satharva or Govandi, $\frac{26}{506}$ (12464) from Hamirgad and $\frac{25}{429}$ (12465) from Jamla. Most contain, in rather scattered distribution, phenocrysts of microcline, orthoclase, quartz and biotite set in a micro-granitic or granophyric ground-mass. Many also show basic cognate xenoliths (as do the normal granites) containing much biotite, some small white garnets (?) and quartz grains, *e.g.*, $\frac{25}{429}$ (12465). The Jamla rock, $\frac{25}{429}$ suggests a passage over into the coarser varieties of the quartz-porphyries, not only petrologically and texturally, but also by its geographical position in the immediate neighbourhood of a group of typical quartz-porphyry hills.

Among the micro-granites, $\frac{25}{453}$ (12463, Pl. 14, fig. 3), from 1 mile north of Wantra, is somewhat exceptional. This rock is very dark and fine-grained, with sparing, widely distributed phenocrysts. It is the heaviest of any of the Idar granitic rocks, the specific gravity being 2·767. In the fine-grained ground-mass of microcline, plagioclase and quartz, the rare, large porphyritic felspars occur and also large numbers of moderately large, ragged plates of biotite of the usual type, together with similar groups of granules of pale green diopside changing into uralitic hornblende. The diopside is sometimes intergrown with the biotite.

Good examples of granophyric structure in the ground-mass are exhibited by $\frac{25}{431}$, (12468), from 1 mile W.S.W. of Kesarpur (Jamla neighbourhood). This rock is characterised by orthoclase with Carlsbad twins, and not microcline. The micrographic quartz and felspar frequently surrounds the orthoclase grains with mutual optical continuity. In other cases quartz grains similarly form nuclei for a similar optical orientation of the micrographic intergrowth. $\frac{26}{506}$ (12464, Pl. 14, fig. 4), from north of Hamirgad and west of

Wantra hill, is a purplish-grey rock with much very beautiful micropegmatite, the felspar being microcline and orthoclase with Carlsbad twins ; $\frac{25}{450}$, from Ora, is a dull purple micro-granite with abundant quartz, microcline and orthoclase and with micropegmatite. Biotite is scarce.

With hornblende.

A moderate proportion of the granite of Idar State has green hornblende in addition to biotite, and the quantity is sometimes large. In the rock at the foot of the temple hill S.E. of Dhabal, $\frac{25}{430}$ (12478), a finely porphyritic handsome rock, the hornblende (basal sections of which give Hooker's green and greenish yellow pleochroism) is not very largely developed. $\frac{25}{432}$, at Dungri near Bhadresar, contains a fair amount, and also $\frac{26}{504}$ from Viravada, the pleochroism of which is very noticeable in greenish yellow (X), bright green (Y), and greenish blue (Z) tints, suggestive of pargasite. There is (?) a little sphene or leucoxene surrounding the iron ore in the biotite. The Kawa rock, $\frac{26}{5\ 4}$ (12470, Pl. 14, fig. 5), already mentioned, and of which a chemical analysis has been quoted, is also a handsome rock, porphyritic with dull pink crystals of microcline, and mottled grey and black ground-mass. It contains much microcline and quartz, also plagioclase (albite-oligoclase), green-yellow hornblende and biotite, the two latter grown together in clusters. Other similar rocks, such as the very coarse Mohr rock, $\frac{25}{441}$ (12472), belong to this category.

With (?) topaz.

On the eastern face of Dharol hill there is a variety of the granite $\frac{26}{510}$, (12480). Pl. 14, fig. 6 of pale pink colour and medium grain, containing bleached biotite of the palest drab colours, very much plagioclase (albite-oligoclase), much microcline and some quartz crowded with inclusions. It also contains a few rather small plates of a brilliant white colour, with rather high refractive index and weak double refraction, they are biaxial and positive. In another rock, $\frac{26}{511}$ the same mineral shows a good basal cleavage giving straight extinctions. I have referred this mineral tentatively to topaz. At the valley head, ½ mile south of Nadri, $\frac{26}{513}$ occurs, resembling $\frac{26}{510}$ so exactly that they are probably a single band in the granite.

With pinite.

On both the western and eastern edges of this same hill, apparently near the edge of the Idar granite, occur masses and veins of the granite containing bright yellow pinite as the sole dark mineral. Sometimes veins of the pinite with quartz appear in the granite running N. E.—S. W. The pinite is very soft, loses colour before the blowpipe and is doubtfully fusible. It has the optical characteristics of muscovite and also the cleavage. The pale lemon-yellow colour makes the rock very visible on the hill side and foot-hills of the Dharol mass (Specimen Nos. $\frac{26}{515}$—$\frac{26}{519}$).

QUARTZ-PORPHYRY.

General appearance.

More or less associated with, but also in a slightly distinctive grouping to, the bosses of Idar granite, come the not very dissimilar rocky tors and rugged masses of quartz-porphyry (see Pl. 7, fig. 2). As a whole this hypabyssal rock is distinctly differentiated from the Idar granite, although local passages through micro-granite seem to be established, as in the tor $1\frac{3}{4}$ miles S.W. of Jamla (specimen No. $\frac{25}{429}$-12465). In large masses it weathers a characteristic dark colour, which renders it easily recognisable even at a distance; whilst in the hand-specimen the same dark-coloured compact ground-mass, sometimes almost as compact as a pitchstone, and grains of amethystine quartz, and sometimes pink felspar phenocrysts, distinguish it readily from the neighbouring and associated granite.

Distribution.

Its geographical distribution is essentially more local than that of the Idar granite, as can be seen from the map, where it is confined to two areas, one in a little group of isolated hills between Jamla and Sabli, and the other in another mass or group lying south of Mundeti and east of Vasai.

In the former the quartz-porphyry, $\frac{25}{454}$, forms a central area in the middle of the Jamla Delhi Quartzite hill-mass, with branching offshoots into the surrounding quartzite. It also builds the isolated little hills of Likhi $\frac{25}{457}$ and those near Chhapra, Dholpur, Khandiol, and even seven or eight other scattered bosses of various size round about Sabli ($\frac{25}{458}$).

In the latter (Mundeti) area, it builds the more connected and massive hill containing the 1,167 ft., 1,279 ft. and 1,142 ft. summits, as well as the more detached hummocky little masses due south of Malasa and round about Khalvad.

There are a very few other isolated occurrences of the quartz-porphyry as at $1\frac{1}{2}$ miles due south of Mau.

Intrusive relation to the Delhi Quartzite.

In the field the quartz-porphyry is occasionally seen to be distinctly intrusive, ramifying into the Delhi Quartzite, as is well seen in the hilly mass N.E. of Jamla, also between Vasai and Malasa where irregular intrusive contacts (but without extra metamorphism) against the quartzite are common. This is often made apparent by the porphyry directly truncating the strike of the quartzite, as at the south-eastern corner of the little lake near Malasa, and by inclusions of quartzite in the porphyry. The little conical boss, marked 859 ft., rising about 70 feet above the plain one mile to the west of Malasa (specimen No. $\frac{26}{520}$) and which is very flinty and compact to the eye, contains included fragments of quartzite well seen on the weathered surface ($\frac{26}{521}$). A few bi-pyramidal quartz crystals are seen in the rock, but generally the quartz is completely rounded. It seems likely that this conical neck is very nearly natural as regards its outline, judging by the large number of fragments left sticking to its present surface.

No bedded flows.

The quartz-porphyry is never found in bedded or banded flows in this area, showing that it has never functioned as an extrusive rhyolitic lava.

Microscopical appearances.

In thin sections of the varieties of the quartz-porphyry there occur the usual phenocrysts of quartz, felspar (microcline, orthoclase and plagioclase) as well as biotite in the form of ragged strings, tufts and long trains of aggregated flakes (12488, Pl. 15, fig. 1). The relative abundance of these phenocrysts varies, but they are never absent altogether (as in the Malani rhyolites), whilst they are generally present in some profusion. The quartz and felspar show good crystal outlines, which, as is usual in such rocks, are here and there corroded by the solvent action of the base. Sometimes, however, the outlines are irregular as if the crystals had been fractured. It is noteworthy that microcline, which is so often the dominant felspar as a porphyritic element in the granites, is also abundant as phenocrysts in the porphyries. Hornblende (with blue-green and yellow pleochroism) can be seen among the tufts of biotite in the rock of the Likhi exposure $\frac{25}{457}$, 12490, Pl. 15, fig. 2).

Xenoliths.

Xenoliths, such as $\frac{25}{458}$ (12491) from near Sabli, are as common as, or more so than, in the granites and micro-granites. The basic varieties of these xenoliths consist largely of hornblende and biotite, and in some cases the rock becomes quite crowded with many forms of xenoliths that almost remind one of an agglomerate. The Sabli xenoliths, $\frac{25}{458}$—$\frac{25}{459}$ (12491-2, Pl. 15, fig. 3) are particularly rich both in hornblende and in sphene. There are long laths of plagioclase in 12491.

Ground-mass.

The ground-mass varies considerably in size of grain. Ordinarily the quartz-felspar mosaic, as in $\frac{25}{454}$ (12487) from north-east of Jamla, can, by suitable illumination in the thin section and with a sufficiently high magnification, be resolved into quartz and felspar, but the kind of felspar cannot be distinguished. The minute flakes of biotite can also be equally well examined as regards colour, pleochroism, cleavage, etc. Hornblende also in some cases, as in the rock ¾ mile south of Likhi, in blue-green and yellow tints can be seen among the larger nests of biotite.

A series of more and less fine-grained representatives, as regards the ground-mass, can be easily sorted out, among which at last we reach a stage where it is almost or quite amorphous and cryptocrystalline. An excellent example of the last is afforded by the rock of the little hill west of Malasa, $\frac{26}{520}$ (12493, Pl. 15, fig. 4), which is the most compact and blackest as to base that I have collected among these porphyries. A certain fluxional structure in this case may be detected by the trains of iron ore, biotite and hornblende flakes.

Micropegmatite.

Another feature that links these porphyries with the microgranites and granophyres, is the prevalence of micropegmatite in the ground-mass of some of the coarser-grained examples. It occurs surrounding the phenocrysts, of orthoclase, and microcline, as in $\frac{25}{455}$, from the centre of the Jamla hill mass. In this case it is evident that the action of the ground-mass on the felspar phenocrysts at least has not been in the direction of solution of them with production of the usual corroded outlines, but has resulted in continuous crystallisation round the phenocrysts as nuclei, producing a very narrow "court" as in the many cases cited by LaTouche in the Western Rajputana rhyolites.[1]

Possible hypabyssal equivalent of the Malani rhyolites.

On the whole, and in a general way, there is a considerable resemblance between these quartz-porphyries and some of the Malani rhyolites described by LaTouche (*loc. cit.* pp. 78-88). The presence of frequent microcline among the phenocrysts, and

[1] *Mem., Geol. Surv. India,* Vol. XXXV, pt. 1.

of biotite predominating over the hornblende, in my Idar examples constitutes the greatest point of difference. There can be no doubt, however, that although these rocks in Idar (which are in the form of bosses, plugs and irregular intrusive masses) only show a few cases of petrological passage into the Idar granite by means of fine-grained micro-granite and granophyre, their whole mineral constitution suggests that they may easily represent a somewhat more hypabyssal form of the several varieties of the Idar granite, although all real connection between the two probably lies too deeply seated to have been exposed (except rarely) at the present surface of the ground. As the very similar granites of Siwana and Jalor are considered by LaTouche to be generally equivalent in age to a large portion of the Malani rhyolite series (*loc. cit.* p. 25) it may well be that the quartz-porphyries of Idar are a petrological connecting link between a granite of the Idar, Siwana and Jalor types and the bedded Malani rhyolite flows. I do not mean that the Idar porphyry was the actual vent rock of the rhyolites as now exposed in Western Rajputana, but that they constitute vents of a similar related material that further north became extrusive as the acid Malani flows.

QUARTZ VEINS.

An important ridge feature.

Although vein-quartz has been parenthetically mentioned in connection with many of the foregoing formations, such as the Aravallis, Delhi Quartzite and Phyllite Series, it remains true that all such material thus referred to is of minor importance, the veins being small in thickness, irregular in position and building no special surface feature. The quartz veins now about to be described differ fundamentally from the above, for they have a considerable thickness, rise up into well-marked and quite noticeable ridge features and they continue, albeit with a broken continuity, through distances of very many miles, keeping their direction steady and their width normal.

Confined to Aravalli calc-gneiss.

Although the known occurrences, which are separately coloured on the map, keep to Aravalli country, and generally to that occupied by the calc-gneiss or by the latter in combination with bosses of Idar granite, these veins, like so many other particular formations in Idar, actually show up (in every case but one or two) as elongated ridgelets completely surrounded by alluvium. At the outcrop $1\frac{1}{2}$ miles south-west of Dharol town, and again at Vera on sheet 119 (Bombay Survey), however, a little calc-gneiss is exposed in contact with the vein.

Distribution.

Their geographical distribution is very simply stated by reference to the map. Beginning near Medh (a few miles east of Vadali) there is one small hillock, $1\frac{3}{4}$ miles N.byE. of Medh. This is followed by a short ridge, 1 mile S.W. of Medh, on which the altitude number 822 appears. This strikes W.byN. pointing directly to the next outcrop, 6 miles away and lying under the south end of the Dharol hill, a short ridgelet marked 761. Thereafter towards the west, west-south-west and south-west, there follows in close succession, with from $\frac{1}{4}$ to 1 mile intervals only, a continuous string of these ridges passing *viâ* Dobhara, Kambosana, and Wadtol to Vera. Here the direction changes and the curve of outcrop returns on itself *viâ* the 742 ft. ridgelet $1\frac{1}{2}$ miles west of Wasan and the 753 ft. hill 1 mile south-by-east of Hathoj.

Probably a continuous vein.

The general uniformity in width of these detached outcrops (about $\frac{1}{8}$ mile) from Dharol hill to Hathoj, and their continuously regular outcrop that builds a single broken line of hills, makes it highly probable that we are dealing with one continuous vein, partially obliterated by denudation or locally nipped out, and that extends through a distance of over 10 or 12 miles.

Beyond Hathoj there are a closely placed set of three somewhat irregular short ridges of vein quartz near Arsabda, and again one small outcrop west of Lembhoi and north of Rani Tank and lying north of the mass of granite surrounding Idar town.

Far away from these localities there remains the little ridge south of Nadri and $1\frac{1}{2}$ miles west of Adopodara, also the steep little hill $1\frac{3}{4}$ miles N.W.byN. of Titoi (Tintoi).

Field relations.

The ridges in section appear usually as small triangles with steep little sides, about 100 feet high by 100 yards in width. It seems quite certain that these quartz veins have no connection with the Delhi Quartzite. They are not of the even, fine-grained texture of the latter, and never show any structure that could be suggested as bedding. Although, in one or two places in the Bamanvada area there are cases of some difficulty, inasmuch as the veins appear to have invaded the Delhi

Quartzite in a more or less irregular and incomplete way, there is no mistaking the long chain of veins in the western part of Idar for anything but a pure vein rock of some order.

Brecciation and other features.

Another feature is the brecciation that they frequently show, specimen No. $\frac{25}{480}$ (12517, Pl. 15, fig. 5) and $\frac{25}{472}$ (12518, Pl. 15, fig. 6) are examples of this. Under the microscope also, there are certain characteristics attending the structure of these veins that are only seen in them. The silica in crystallising has not as a rule imitated the even, granulitic appearance of that in the Delhi Quartzite, but appears more in the form of radiating and parallel fibrous groupings of chalcedonic micro-crystals, specimen No. $\frac{26}{467}$ (12516). Occasionally, as in No. $\frac{26}{467}$ (12516) from summit of small hill 1 mile N.E. of Rupal, blurred felspar shapes appear and the grating structure of microcline (impossible to mistake) in one instance is faithfully represented (12517). This seems to suggest that these veins may be regarded as an ultra-acid differentiation product of some acid magma, such as that of the Idar granite, or else that actual granite or other acid igneous rock has been silicified *in situ*. I regret that these rocks have not as yet been studied as closely as they deserve, for equally well-developed ultra-acid reefs of this nature are well-known in many parts of the Archæan of India.

BASIC DYKES.

Feeble development.

In contrast with the acid division of younger intrusive igneous rocks, which we have seen to be well represented in Idar State, there are no corresponding igneous masses of an intermediate composition, for instance no syenites and no diorites, whilst there are only a very few feebly developed examples of hypabyssal, or plutonic basic, character. They make an entirely insignificant show on the map and are generally incapable of representation, only one or two being sufficiently large to be outlined on the 1 inch =1 mile map in separate colour.

Outcrops between Khed Brahma and Kawa.

The first of these that I shall refer to is found along one line of strike cropping out at 3 or 4 places above the alluvium (which are probably all connected) namely, 2½ miles S.byW. of Khed Brahma, ½ mile N.E. of Rera, and one larger and wider outcrop forming part of the hill at Kawa.

Olivine dolerite.

At the first locality the rock is a narrow dyke, 1 foot wide, intrusive along the bedding-planes of the calc-gneiss series, specimen No. $\frac{25}{461}$ (12496, Pl. 16, fig. 1). In the hand-specimen it is a dark grey, almost compact-looking rock. Under the microscope it is fine-grained and almost, or altogether, holo-crystalline, consisting of large and small lath-shaped plagioclase crystals with the extinction angles of labradorite, augite in clusters of hypidiomorphic grains, partly ophitic as regards the felspar, and of pale violet-brown colours, slightly pleochroic from pinkish brown to yellowish brown. It is here and there seen to be changing to carbonates which also fill in a few rounded gas pores and replace some possible traces of glassy base. Olivine, in rather large roughly idiomorphic grains, is not very numerous and is also partly changing to carbonates. There is some iron ore. The rock is therefore an olivine dolerite or perhaps basalt.

At the locality ½ mile N.E. of Rera there is a group of low hills of apparently the same rock, but specimens from this locality have apparently not been collected. Besides this the basic dyke-rock crops out in a desultory way through the alluvium to the east, south, and south-west of Rera for half a mile or so.

Kawa dyke.

At 1 mile N.N.W. of Kawa village the presumed continuation of this dyke, No. $\frac{25}{462}$ (12497, Pl. 16, fig. 2 nat. light fig. 3 crossed nicols) has widened out to 100 yards or so, become coarser grained, and, besides the labradorite (with symmetrical extinctions of the albite twin lamellæ up to 31°) and olivine and iron ores as before, it contains a fair amount of biotite with which the iron ore is associated. The pyroxene has become less deeply coloured, and is full of brown diallagic interpositions. It is very conspicuously ophitic over large areas in the slide (12497). The rock is typically gabbro-like in the arrangement of the minerals. At the south end of the Kawa hill the thickness has increased to perhaps 200 yards, but the composition and structure of $\frac{26}{464}$ (12498) remains the same as that of $\frac{26}{462}$ (12497), whilst a finer-grained variety from the same locality, $\frac{25}{463}$ (12499), shows the pyroxene largely replaced by uralitic hornblende, and there is no olivine. This dyke is intrusive through the Idar granite, and has given rise to a hybrid contact variety which will presently be described. The Kawa dyke from this description is clearly an olivine dolerite, or gabbro, with biotite.

Chemical composition.

A chemical analysis of the Kawa dyke (specimen No. $\frac{25}{464}$) has been kindly made by Dr. Christie in the laboratory of the Geological Survey. It is as follows :—

Specific Gravity	3·00
SiO_2	50·23
Al_2O_3	16·51
Fe_2O_3	3·83
FeO	8·26
MgO	5·[illegible]8
CaO	9·53
Na_2O	2·07
K_2O	1·04
H_2O (below 108° C.)	·08
H_2O (above 108° C.)	·63
TiO_2	1·41
ZnO_2	trace
CO_2	trace
P_2O_5	·31
SO_3 (total S as)	·23
Cr_2O_3	·01
MnO	·14
BaO	·02
SrO	trace
	99·78

Bodi dyke.

Of the remaining basic dykes, there is only one, namely that at Bodi, $\frac{26}{549}$ (12500), where the material is sufficiently preserved to be recognisable. The dyke is about 6 feet wide and imperfectly exposed on the pathway to Paliapar, intruding the biotite schist of that area (see p. 62). It appears as a fine-grained, black rock. In thin section the plagioclase is in long lath-shaped forms arranged in beautiful cruciform or star-shaped clusters, and is probably labradorite. The augite is of a dull brownish yellow colour and is present as hypidiomorphic granules and patches. There is no quartz, a fair amount of iron-ore, no residual glassy base that can be detected, no porphyritic elements and no ophitic structure. The dyke is bordered by a still finer-grained selvage No. $\frac{26}{551}$ (12501, Pl. 16, fig. 4), which has a particularly beautiful appearance in thin section.

Bamanvada dykes.

A number of other, and very probably similar, basic dykes, appear among nearly all of the Bamanvada and neighbouring groups of Aravalli rocks, in a perfectly irregular and indescribable way, impossible of mapping—

specimens Nos. $\frac{26}{548}$ and $\frac{26}{552}$—$\frac{26}{555}$ (12502 to 12511). They also penetrate the white pyroxene of that area. All are too much altered to be worth attempting to describe in any detail; but long blades of plagioclase, and probably remnants of pyroxene and amphibole and even olivine, can often be recognised with some difficulty. Some of these venis are 2 to 3 feet thick.

Correlation.

In his account of the basic dykes of Western Rajputana, Mr. LaTouche (*loc. cit.* p. 91) includes a description by Sir T. Holland of a rock very similar to those described by me above, namely that forming the ordinary dykes of that part of Rajputana, such as the large dyke south of Jalor $\frac{11}{715}$ which cut the rhyolites and granites. The description is that of an olivine dolerite with biotite, agreeing so remarkably with my Khed Brahma and Kawa rocks that it is evident that besides the acid igneous rocks there is a further link connecting together also the igneous basic rocks of the two areas.

The rarer tinguaite, described by Holland on the next page of LaTouche's memoir, has not, however, been identified in the Idar region.

KAWA HYBRID ROCK.

A mixture of basic dyke and Idar granite.

The Kawa basic dyke, besides being intrusive among the calc-gneiss, also penetrates, as already stated, the granite of Idar type at the south end of the little hill near Kawa village. In doing so the two rocks have become closely associated one with the other, producing along the zone of contact a rock of an abnormal composite character, which I am disposed to regard as of the nature of those which Mr. Harker has described as "hybrid" rocks.[1]

Field section.

The section exposed at the south face of the Kawa hill is as follows: to the west the basic rock—$\frac{25}{463}$, $\frac{25}{464}$—already described, forms the main mass of the crest of the ridge running away to the north. To the east, and forming a little knoll at the south-east extremity of the ridge, normal Idar porphyritic granite is exposed. But coming between the two along a N.N.E.—S.S.W. line, there is a band, roughly some 50 feet wide, consisting of the composite or hybrid rock, $\frac{25}{269}$ (12514), rather intimately veined by the basic dyke and under-

[1] "Natural History of Igneous Rocks" 1909, p. 340 *et seq.*; also "Tertiary Igneous Rocks of Skye" *Mem., G. S. of Scotland*, 1904, and Carrock Fell, *Q. J. G. S.*, Vol. LI, 1895, etc.

lying steeply to the W.N.W. Abundant rock is exposed on the slope, but it is in a lumpy, boulder-like way, the rock being rounded and weathered out into separate masses instead of presenting a clean surface of continuous rock.

Appearance and mineral composition.

This mixed basified acid rock has a striking appearance, being a coarse, dark and light rock, glistening with large poikilitic plates of biotite. Only two specimens were gathered of this rock, namely, $\frac{25}{469}$ (12514, Pl. 16, fig. 5) from the locality now under description and $\frac{25}{470}$ (12515) from a short distance away to the north. Both are almost identical, but the first is coarser and consists of a fair amount of orthoclase, some scattered porphyritic crystals still remaining, abundant lath-shaped plagioclase (albite-oligoclase) and quartz, a fair amount of pyroxene in rather small idiomorphic and hypidiomorphic grains, often gathered together into clusters and showing a change here and there to uralitic hornblende, a large amount of biotite in great ophitic plates, and, as accessories, iron ores and rather much apatite.

Interpretation suggested.

If the above rock, as is suggested, is of the composite or hybrid kind due to chemical reaction between the two rock bodies, such as a basifying of the granite or other very intimate mixture of the two rocks, it follows that whilst the quartz and orthoclase of the granite have remained, all the usually dominant microcline has disappeared, and there results an abundance of plagioclase (albite-oligoclase); whilst the amount of biotite has been largely reinforced and so also apparently that of the apatite. From the point of view of the basic rock, the more basic plagioclase (labradorite) has disappeared, as also has the olivine, whilst the pyroxene has persisted in more or less patchy groupings.

Except on the supposition of some such commingling of material and chemical rearrangement having taken place, it is difficult to classify a rock of such abnormal mineral constitution among the ordinary igneous rocks. Its actual position in the section exactly between the two supposed parent rocks, and the veining of it by the basic igneous rock, are also suggestive.

Chemical composition.

From the appended table of analyses made by Dr. Christie in which are shown the chemical compositions of two specimens of the Kawa hybrid, that of the Kawa olivine-dolerite and that of the Kawa granite, side by side for comparison, it is clear that the resulting mixture-rock has the composition of a potash syenite from a chemical point of view. Mineralogically, however, it has too much both of quartz and of plagioclase, whilst it has too little orthoclase for it to be called a syenite. From the point of view of the mineral components, then, it stands marked as a mixture rock, not a syenite, such as would have resulted had the molecules been allowed appropriate play under magma conditions, nor yet a simple mechanical entanglement of the one rock within the other, but a hybrid rock in which partial chemical reactions only have taken place giving abnormal results :—

	Kawa hybrid, $\frac{25}{469}$	Kawa hybrid, $\frac{25}{470}$	Kawa olivine dolerite, $\frac{25}{464}$	Kawa granite, $\frac{26}{514}$
S. G.	2·83	2·87	3·00	2·72 average of 3 specimens.
SiO_2	63·54	57·20	50·23	66·04
Al_2O_3	14·28	14·78	16·51	14·77
Fe_2O_3	2·68	2·12	3·83	1·18
FeO	5·24	7·43	8·26	4·41
MgO	1·02	3·23	5·48	0·98
CaO	4·38	6·48	9·53	2·95
Na_2O	1·98	2·25	2·07	2·56
K_2O	3·90	3·00	1·04	5·25
H_2O (below 108° C.)	·09	·11	·08	·21
H_2O (above 108° C.)	·91	1·39	·63	·71
TiO_2	1·53	1·70	1·41	·69
ZnO_2	·01	·01	trace	·03
CO_2	. .	. .	trace	. .
P_2O_5	·24	·32	·31	trace
Cl	trace	. .	. .	trace
(Total S as) SO_3 .	·05	·05	·23	trace
Cr_2O_3	. .	·01	·01	. .
MnO	·11	·13	·14	·11
BaO	·07	·05	·02	·02
SrO	trace	trace	trace	trace
	100·03	100·26	99·78	99·91

Additional remarks.

A few additional points that may be noticed with reference to the chemical and mineral composition of this hybrid rock are, first, the specific gravity.

This is 2·83 in one case and 2·87 in the other, the mean being 2·85. Now that of the granite (adamellite) is 2·72 and that of the olivine dolerite or gabbro is 3·00, the mean of which is 2·86, or agreeing with that of the hybrid rock—which is what we should expect. Similar mean values calculated for many of the chief constituents such as the iron (both Fe_2O_3 and FeO) magnesia, lime and potash show the same thing and verify the intermediate chemical character of the hybrid rock as compared with that of the granite and dolerite, the exceptions being the alumina and soda. Secondly, the Kawa basic rock in chemical contents agrees better with olivine dolerite, Canner (see Hatch: *Petrology*, p. 224), than with olivine gabbro. The ophitic structure and the nature of the rock as a dyke are also in favour of this. This conclusion then tells against any such supposition as that the Kawa hybrid might be due to 'magmatic segregation.' Thirdly, as regards the abundant large plates of biotite present in the Kawa hybrid, to account for this is essential in any theory of the rock as a hybrid produced by reaction between distinct rocks; because neither in the coarse normal granite (Idar type) nor in the even, medium-grained dolerite rock of the invading dyke do there appear any such very large plates of biotite. Apparently *à propos* of such a case as this, Harker (Geology of the Small Isles, *Mem., G. S. of Scotland*, 1908, p. 111) says: "but it can scarcely be doubted that if the granite magma had invaded and incorporated gabbros and diorites as well as eucrites and peridotites, biotite would have been a conspicuous product of the reactions." Although our case at Kawa is apparently the opposite of this, inasmuch as it was the olivine dolerite or gabbro that invaded the granite, the nature of the mixture would probably have been the same.

AHMEDNAGAR (HIMATNAGAR) SANDSTONE SERIES.

A relatively young formation. No fossils.

It will readily be seen that the presence of ordinary conglomerate, freestone in large quantity and simple shales in the composition of this series, together with their almost undisturbed, horizontal lie, point to the series being a relatively young one in the geological history of this part of India. That it also comes very high up among the historical rocks generally, is also to be inferred from several surrounding facts that will presently be mentioned. Unfortunately, no determinable fossil remains have been preserved within the comparatively small thickness exposed, so that we are unable to rely on any palæontological evidence in support of this. Whatever its exact age, it is significant that it constitutes the sole representative in the State of any of the stratigraphical systems from Cambrian to Recent, with the exception of the Deccan Trap and Laterite, which however are only found marginally in the State.

Distribution.

As the name implies, this formation is well exposed at Ahmednagar (Himatnagar), the present capital of Idar State, and especially in the Hathmati river section in the neighbourhood of the town (see Pl. 7, fig. 1). It is also seen in a few outcrops a mile or two north of the town and appearing above the alluvium as rough, low hillocks, and in the Sabarmati river-bed along a stretch of several miles near Eklara where Idar State marches with Baroda, and where the rock forms a pavement and undercliff below the Recent river deposits.

Its most characteristic occurrences, however, lie to the east of Ahmednagar in a series of slightly elevated plateaux with well-marked, steep, scarped edges. They lie with a pronounced unconformity either on Idar granite, as at Ghorvada, Berna and Wantra, on the Delhi Quartzite, as at Pedhmala, or on the Aravallis as at Bodi. From the little capping of this sandstone on the summit of Ghorvada hill, height 832 feet, to the similar but broader capping on the Berna hill, height 695 feet, we may deduce a drop of 137 feet in $3\frac{1}{4}$ miles horizontal distance, that is 1 in 125, which is the equivalent of a dip of 0·27′.

Owing to the same dip in the Berna plateau the southern portion of this little table-land levels out near Agiol towards the alluvium in that direction and, in the neighbouring Wamoj-Dhundhar plateau, finally sinks under the alluvium. The general appearance of these little capping outliers of the younger rock series is shown in the sketches (see text figs. 23, 24).

Lithological varieties.

Owing to the slight amount of the dip angle, and the disconnected exposures, no serial sections can be given illustrating any varying lithology of it as a whole. All that it is possible to do is to mention a few varieties such as are locally found.

Sandstone: colour and grain.

The prevailing rock is a sandstone, whose colours are white with pinkish shades and streaks, and with occasional ferruginous concretions as large as a hen's egg. The lower portion near the base is conglomeratic and of a purplish tint, and it is sometimes coloured brick-red, chocolate-brown, and rarely dark ferruginous brown. It

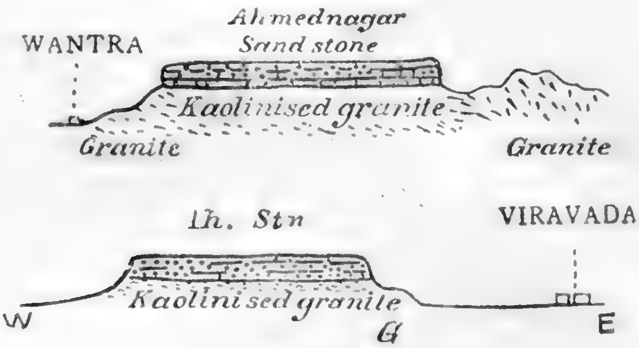


Fig. 23.

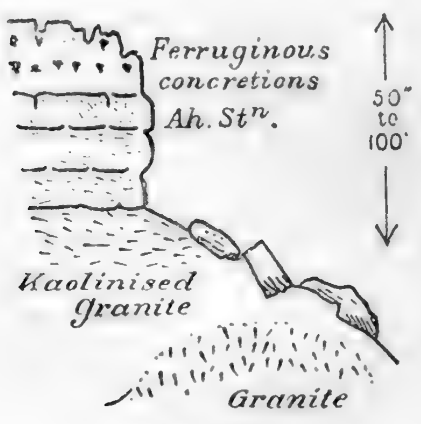


Fig 24.

is generally fine-grained and rather loosely aggregated, although coarser varieties of millstonegrit type are sometimes found, as at the Berna quarries.

Freestone: quarries.

The cementing material is siliceous and ferruginous, and the rock in several of its layers makes an excellent freestone, especially the paler-coloured kinds, and it is much quarried in and exported from the neighbourhood of Ahmednagar for architectural and engineering purposes. The best quarries are at Shaogar a little north of Ahmednagar (see Economic section). Cross or current-bedding is common. There is probably a thickness of about 100 to 200 feet altogether exposed.

Quartzite or quartzitic sandstone.

In some places the siliceous cement has given rise to a glassy quartzite or quartzitic sandstone or conglomerate, as north of Ahmednagar, at Ghoravada, Wantra and Berna hills.

Thin sections of these rocks all show the more or less rounded grains of quartz to be entirely distinct (12523 Pl. 16, fig. 6). Even the most glassy and hardened kinds never show anything resembling the completely recrystallised interlocking quartz areas which are so characteristic of the Delhi Quartzite. The bedding is always quite distinct.

Shales, lithomarge and kaolin.

With the sandstone runs are many shaly layers and others of mottled pink and white calcareous clay or lithomarge. Strings and veins of calcite run through it, as at Katwar, 3 miles S.W. of Ahmednagar. Layers of kaolin are found locally, especially in the Sabarmate river sections at Eklara (which are coincident with the Baroda kaolin deposits)[1] at the base of the section where it rests on the Idar granite.

Similar layers appear under the sandstone or quartzitic sandstone at Wantra hill. It would appear that the kaolin produced by the surface alteration of the granite has been preserved in these localities from removal by the capping of hard standstone.

At Eklara the river banks are 100 feet high, with the kaolin in horizontal beds, associated with pink and yellow clays, sandstone and conglomerate. Along with the kaolin are large grains and rounded lumps of quartz (also derived from the disintegration of the granite). The following characteristic sections (text figs. 25, 26 and 27) may be seen down the Sabarmati river south of Eklara. Some of the shales here are brilliantly and pleasingly coloured in shades of white, cream, yellow, lilac, pink, inky purple, brownish red and dark brown. The northern limit of this series (as far as one can say of a horizontal formation) in the river-bed is at Deria village on the right bank.

Limonite.

Limonite occurs among the shales and conglomerates or gritty layers at several places. Locally, as seen near the palace at Ahmednagar, small pockets and lumps of it have been formed in a bright yellow sandstone matrix, where it possesses a rectangular arrangement of the fibres resembling the twin lamellæ of microcline or as if replacing woody fibre (specimen No. $\frac{25}{415}$). Examined by my colleague Mr. Tipper in the

[1] See Sambasiva Iyer: Sketch of the Mineral Resources of the Baroda State, p. 1.

Geological Survey laboratory, its specific gravity was found to be 3·94 and it yielded 7 per cent. of water (see also p. 148). The

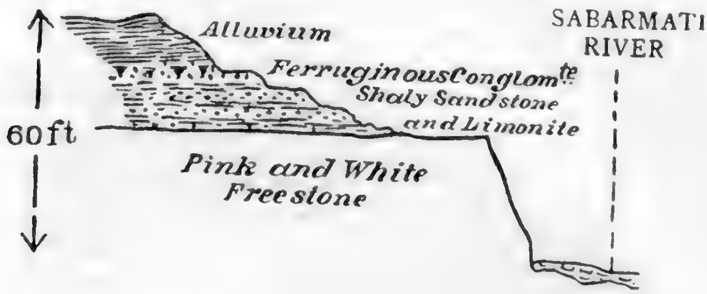


Fig. 25.

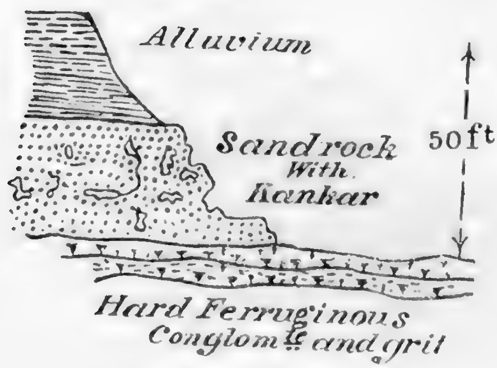


Fig. 26.

Fig. 27.

only part which forms a bed 1 to 2 feet thick, is very sandy or siliceous at its upper surface (specimen No. $\frac{25}{425}$) and suggests a very ferruginous porphyry with entirely silicified patches that often present the contours of porphyritic felspars. Globular concretionary masses, somewhat impure also occur.

Plant remains ?

In the quartzitic or silicified conglomerate forming the little hill near the granite, 2 miles N. by E. of Ahmednagar ($\frac{26}{460}$) there are a few dubious plant remains, entirely unrecognisable, as also a little south of Berna. At first the highly silicified layers of rock found near the granite here, and also at Wantra and Berna hills, made one consider whether this effect was in any way a contact effect of the granite. Besides much general evidence to the contrary, specimen No. $\frac{26}{461}$ is entirely against any such fanciful theory. It contains many felspar grains entirely kaolinised, and was taken from the junction layer between the two. Again, the sandstone of the same hill, which forms a capping to it with concretionary lumps of limonite 1 to 2 inches across, is only specially hardened and silicified in certain beds. It is not as a whole harder than the usual run of the sandstone and there are associated with it beds of white freestone not more indurated than the ordinary Ahmednagar sandstone.

Age of the Ahmednagar Sandstone.

As expressed in R. B. Foote's "Geology of Baroda" and in Sambasiva Iyer's "Sketch of the Mineral Resources of the Baroda State," the presence of lateritic layers associated with the sandstone series of the Sabarmati river, has led these two observers to regard this Ahmednagar Sandstone series as being of Eocene age. I am unable to accept this conclusion, partly because I think the lateritic layers (as seen chiefly in the river sections) are purely surface phenomena, and are not seen in any good massive quarry section, and partly because the whole series, and especially the valuable freestone runs, seem very faithfully to reproduce those of the Drangadra freestone of N.E. Kathiawar,[1] the Songir sandstone of Baroda[2] and possibly also the Barmer sandstone of Western Rajputana.[3] The horizon of the first is generally accepted as Umia, *e.g.*, Jurassic-Cretaceous (or Cretaceous, according to the most recent views), whilst that of Songir is considered to be marine Cretaceous, and to such a horizon I am constrained to refer the Ahmednagar Sandstone, with but little reservation on account of the absence of fossils.

ALLUVIUM AND SURFACE DEPOSITS.

Largely developed.

The wide development of deposits of Recent age in Idar State, at first sight, seems to merit a more liberal treatment than, I regret, I have been able

[1] Fedden, *Mem., Geol. Surv. India*, Vol. XXI, pt. 1, p. 63.
[2] Sambasiva Iyer, *loc. cit.* p. 90.
[3] Blanford, *Rec., G. S. I.*, Vol. X, pp. 11, 18 and LaTouche, *Mem., G. S. I.*, Vol. XXXV, p. 33.

to give to it; it is apparent at a glance that quite the major portion of the State is shrouded in alluvium and other surface deposits. On the other hand these surface accumulations and the soils they carry, require special treatment, quite dissimilar from that given to the solid geology of the area, and need a survey of their own to be adequately treated. This no doubt will be undertaken in the future as occasion demands, but its scope will not with advantage be restricted to the limits of any State.

Some general features.

Meanwhile the following notes may be of some interest. One may say that the more level plain areas, such as that between Ahmednagar and Berna, are covered by a sandy clay to a depth of about 30 feet, but to the north of this line there are more irregularities, and along certain directions little hills of alluvium and blown sand make a feature that is shown on the map. I may instance the little set of hillocks east of Badoli, on which the summits marked 711, 683, 757 and 716 appear, and also a multitude of similar but more sandy hills near Medhasan, Kabola and Bakrol. Much of this country is almost barren, but the more clayey parts in hollows grow dry crops, such as Indian corn, etc. All the more sandy soil that comes above the Ahmednagar Sandstone series is quite waste land. In many parts, especially those that are open to the sweeping south-west winds, the blown-sand accumulates so deeply along the ordinary (unmetalled) roads that wheeled traffic is rendered very difficult. Notwithstanding this there is no typical dune formation, such as is so common in Western Rajputana and other desert areas. On the other hand such parts of the State as are defended by encircling Delhi Quartzite hills, have frequently become to a large extent immune to the sand invasion. A notable example of this is the old Archæan peneplain in the Jesangpur-Bamanvada area.

Sections in alluvium.

Beautiful sections of alluvium are exposed in the river cliffs below Ahmednagar (Himatnagar) town, as at Harpa, where beds of from 100 to 200 feet in thickness occupy the whole cliff section. They consist of ordinary alluvium with kankar and conglomerate beds of the usual khaki colour. In the granite country, as is natural, the sands of the present river-bed are of a very coarse nature and are chiefly composed of quartz and felspar.

Loess, kankar, etc.

Much of the sandy alluvium of Idar State is probably more of the nature of wind-borne loess rather than the result of the purely alluvial action of running water. This is shown by the banking up of it in the neighbourhood of many of the hilly features. I may instance the northern end of the Berna plateau, the western edge of the Delhi Quartzite country almost everywhere, and the western scarps of the Mundeti hills. As regards the Berna plateau, which may be singled out as a type, it may be said that whilst the valley alluvium to the north keeps more or less to a uniform height, round the foot of the scarp the alluvium and loess seem to swathe in the granite and Delhi Quartzite, completely hiding them except here and there. It is not a mere covering of a few feet, but, from the rivulet beds which cut deeply through it, there must be 40 to 50 feet of it.

Section near Berna.

A general section in the neighbourhood of Berna village is instructive as illustrating both the passage up of the Idar granite into the Ahmednagar Sandstone above by means of an intermediate layer of kaolinised granite and also the appearance of the alluvium to the west (text fig. 28).

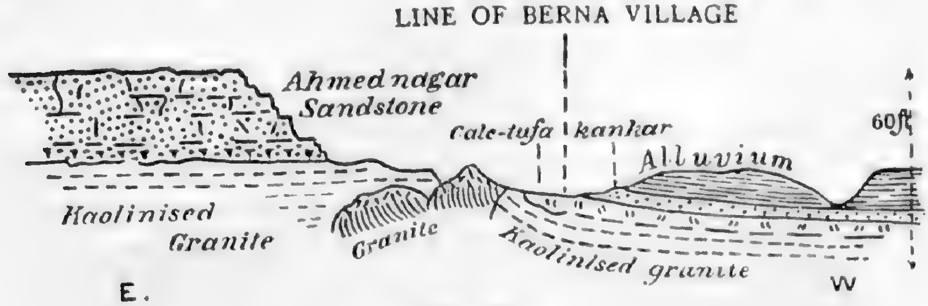


Fig. 28.

Immediately beneath the Ahmednagar Sandstone and its often conglomeratic basal bed, there is in nearly every section round the northern part of the Berna plateau, a layer many feet thick but naturally varying, of kaolinised granite in which the granitic structure is quite plainly preserved still. Here and there emerge fragments of good sound granite. The kaolinised variety changes rather suddenly at Berna into one where the fragments of kaolinised felspar, etc., are more scarce, and there is much dazzling white carbonate of lime in great patches, very soft and powdery. This is near the granite; a few yards away this becomes somewhat harder calcareous tufa, with no trace of felspar, quartz, etc., and of a patchy white and creamy yellow colour. This passes up into an ordinary kankar layer in alluvium and then follows ordinary alluvium with the thicknesses as shown in the section.

Kankar quarries.

The kankar at the base of the alluvium is being quarried at Berna and similar kankar pits are frequently seen at other places as at Jamla and Malasa. The soft white powdery carbonate of lime is also seen at Jamla.

Gravels.

The main river-beds and the torrent beds higher up among the hills are naturally filled with gravel and torrent boulders of the usual kind found in countries subject to torrential rain-fall that has a very limited period of duration. Along the bigger rivers these not only are found as a very recent filling of the actual channel, but are also intercalated with the typical alluvium of clay, kankar, etc. None of these gravels and coarse sands were found in any part of the State to carry any gold, although I tested them frequently, the chief heavy concentrate always consisting of magnetite, ilmenite, diopside and garnet. A very few grains of monazite were detected in one sample by my colleague Mr. Tipper.

Foraminiferal sands.

Although no miliolite of the nature of Porbander stone has been discovered as yet in Idar State, foraminifera have been detected in the Recent river accumulations along the Sabarmati river, showing that their minute tests must have been blown inland as far as this.

ECONOMIC MINERALS.

A concise tabular statement.

During the descriptive part of this memoir, certain minerals of economic, or possibly economic, importance, have been referred to in more or less detail as their mention arose in connection with the general geological account of the area. It will be well to present here a list of all these together, as a concise statement for the purpose of easy reference; and in addition to add somewhat to the descriptions of a few that seem to possess special points of interest, either because of their large development or their intrinsic importance. The list is arranged alphabetically.

It may be remarked that no metalliferous mineral veins of any degree of importance are known with certainty to occur in Idar State. All the better developed mineral occurrences belong to the non-metallic group and are principally of the nature of bedded or banded deposits:—

ABRASIVES: The only abrasives, besides garnet sand (which can be obtained in many of the stream beds) are *mill-stones*, which are made for local use at several places from mica-schist and quartz-schist, and *hones* from the Mundeti Series, near Malasa, which are exported to a small extent (see p. 59). The Ahmednagar sandstone in its finer and harder varieties may make a good material for *whetstones* and *circular grindstones*.

AHMEDNAGAR SANDSTONE: *See* BUILDING MATERIALS, ETC.

ALLANITE: *See* RARE EARTHS.

ASBESTOS: *See* MAGNESIAN MINERALS.

BOWENITE: *See* MAGNESIAN MINERALS.

BUILDING MATERIALS AND CLAYS: Idar State contains abundant building materials and clays of many kinds, ranging from the beautiful pale grey and reddish *granite* slabs of the Idar granite to the kaolin of the Sabarmati River near Eklara and elsewhere. Demand for these materials in India now-a-days is chiefly from a utilitarian point of view, and confined to the larger towns and cities of India and for roads and railways. Impure *marbles* and coccolitic marbles from all the calc-gneiss areas, and good *limestone* from Bhetali and the neighbourhood would doubtless afford much ornamental stone if there were any demand for it. At present such material is merely used on the railway locally for bridge-work, and was formerly used in temple building as at Bhetali. Of *clays*, besides the ordinary clays for brick-work, which are sufficiently abundant, mention may be made of the *kaolin* of Eklara and many other places, which is identical with that on the other side of the Sabarmati River in Baroda State recently extracted to a certain extent. Its chief uses of course are other than for building purposes, and from this point of view it is reasonable to believe that large supplies of good material can be obtained from the surface disintegrated layers of the Idar granite, where they have been preserved from destruction at the base of the Ahmednagar Sandstone by cappings of the same, or by thick alluvium. It would doubtless be advisable for the State to keep these deposits in mind, and, in the absence of special initiative, to watch the progress made in development of these same deposits by the neighbouring State of Baroda. At some time or other in the industrial growth of India it seems quite likely that these kaolin deposits may become a not unimportant asset in connection with the manufacture of superior pottery and as a "filler" in cotton cloth and paper making. Reference may be made to "A sketch of the Mineral Resources of the Baroda State" by U. S. Sambhasiva Iyer for further details and for a complete analysis of the kaolin by C. S. Fawcitt of Bangalore, which shows it to be very nearly identical with kaolinite and washed China clay from Cornwall. The *Ahmednagar Sandstone* is a product that for some time has shown signs of active development. It is present in enormous quantities, easily obtainable, easily worked with the chisel, and it forms a pleasantly tinted and apparently extremely sound free-stone in many of its horizontal runs. It has been reported on very favourably by Bombay architects, and is probably superior for fine work to Porbander stone, with which however in Bombay it could only doubtfully compete for rough stone structures. A large sample of this excellent building material was presented to the Geological Survey, where it is now exposed to view in the collection of Indian building stones. I consider the stone an economic asset to the State and one that should be pushed as far as possible in the large towns on the railway. Its selling price in Bombay before the present extension of the railway was Rs. 3-8 per cubic foot, but this has since been reduced, I am informed, to Rs. 1-4 per cubic foot. *Kankar* for lime making is a very constant accompaniment to the alluvium in most parts of Idar, especially near its base, as at Berna hill and Malasa, whence it can be easily extracted in good quantity and quality.

All the above building and other allied materials are available in almost inexhaustible amounts. It would doubtless be worth while for the State to have some special large-scale surveys made of some of these, such as the kaolin and freestone, from the point of view of their richer and more promising beds. Although not of great intrinsic value such materials in the aggregate have a very considerable value.

CHROMITE : *See* MAGNESIAN ROCKS.

CLAYS : *See* BUILDING MATERIAL, ETC.

DOLOMITE : *See* MAGNESIAN ROCKS.

GRINDSTONE AND HONES : *See* ABRASIVES.

IRON ORES : Idar is not rich in ores of iron, nor would they be of much use without coal or other abundant fuel. The massive igneous rocks and crystalline schists exhibit no special development of them as magmatic or other segregations. Limonite is found in the Ahmednagar Sandstone locally (see p. 141).

JADE-LIKE MINERAL: *See* PYROXENE.

KANKAR, KAOLIN: *See* BUILDING MATERIAL, ETC.

MAGNESIAN MINERALS: Considerable beds of minerals containing much magnesia have been discovered in the State during my survey. They will be found described in general terms under the heading "Magnesian Phase associated with the Delhi Quartzite" (p. 97). They embrace steatite (talc), asbestos, serpentine, bowenite, magnesite and dolomite; and with them is included chromite. *Steatite* is the best represented, and though only of variable quality from medium to good, so far as known at present, is in such large amounts that it is reasonable to hope that some economic use may be found for it at no distant date in Indian markets. The largest development known, as found in the hollow in the Delhi Quartzite hills on the footpath between Dev Mori and Kundol, amounts to over 2,000,000 tons down to a vertical depth of 20 feet over a surface area of about 1 mile by 200 feet. It has been briefly described with plan and sections in a short note by me (*Records, Geological Survey of India*, Vol. XLII, pt. 1, 1912), and other genetically allied extensive deposits are known at Ghanta (an outlying patch of Sadra State enclosed within Idar territory) also in the knee-shaped bend of the hills between Kokapur and Vartha, and S.W. of Thuravas. As already indicated the quality is fair to good, but somewhat flaky, so that it does not readily grind to an impalpable powder. But some specimens are much better than others, so that it is reasonable to hope that detailed surveys with adequate opening up of all the deposits where exposed, and also where covered, might reveal seams of purer material. Steatite is now put to such varied uses other than as French chalk and for gasburners that, with a little enterprise on the part of any firm exploiting it, it should yield a valuable outturn. An extension of the railway from Modasa towards Meghraj would greatly increase the chance of such a mineral becoming utilised.

Besides steatite, it is fairly certain that any adequate opening up of the area would yield other minerals of value. Among these is *asbestos* of the hornblende variety, at present known from several pits sunk in the Dev Mori-Kundol area (see p. 100). This again is a mineral of ever-increasing usefulness in the arts. Since the opening up of the serpentine asbestos of Thetford, Canada (which has a much stronger fibre than hornblende asbestos), there has been a tendency to unduly disparage the hornblende variety. For very many purposes to which the substance is put this quality of great strength of fibre is a matter of no moment as compared with purity, silkiness, softness, flexibility and length of fibre, in which qualities the Idar asbestos is particularly good. It can be dug up in sticks of about a foot long which soften readily on macerating them in plain running water yielding a perfect fibre without any hard cores. It is probable that large amounts are realisable, although here again the State might be well advised to take every measure to have the quantity available ascertained by more excavation work than I was able to undertake during my limited operations. Its ordinary uses for mill-board and steam-packing, etc., are well known, but the following quotation from "Mineral Industry" for 1914, p. 51, may be read with interest in this connection :—

"Each year brings new uses and new demands for asbestos and an ever increasing market. The demand for building purposes, *e.g.*, shingles, asbestos lumber and sheathing will doubtless increase year by year as lumber becomes more scarce and more expensive; furthermore its use as a heat-resisting and especially as an insulatory material will necessarily increase and, so far as is known, it cannot be satisfactorily replaced by any substitute. Asbestos cement sheets are being extensively employed as a fire-proof and moisture-proof material in the construction of sanatoria, barracks, schools, motion-picture houses, etc. In brief, asbestos, together with cement, would seem to be destined to take a most important place as a future building material for many reasons because of its adaptability and cheapness."

Another mineral or ornamental stone associated with the steatite deposits is *serpentine*. This is feebly exposed at a few points as already known, especially in the Thuravas and Kokapur-Vartha areas; but the indications are that it would be found in large masses below the covered parts within all the areas of the magnesian rocks. Some of the varieties are sufficiently handsome when polished for indoor decorative stone-work and for other small carved objects (see further details pp. 104, 108). Small traces of the hard variety of serpentine known as *bowenite*, are found associated with the white pyroxene of Bamanvada. *Magnesite*, *dolomite* and *chromite* also occur sparingly within the same areas as so far explored and as described in the earlier part of this report.

Manganese : No large deposits of manganese ores are known in the State. Besides a few narrow veinlets in the Delhi Quartzite near Meghraj in the form of pyrolusite (see p. 115), manganese ores occur near Vartha in an impregnation belt among the Delhi Quartzite as described (see p. 105). Although the belt is fairly wide and the surface indications prolific, the exposure are so poor that without deep trenching it is impossible to say whether the slight but extensive evidence of metasomatic replacement of the Delhi Quartzite by ferruginous and manganiferous solutions will anywhere be found to denote an ore of marketable value. The locality might well be worth further testing.

MICA: Muscovite mica is only known at a few places, as in the pegmatite veins at Bodi (p. 63). The mica plates being small (½ inch to 1½ inches across) and the pegmatite veins few and thin, it is doubtful whether any economic importance attaches to these deposits.

PYROXENE: Extensive beds of white or pale grey pyroxene have been described near Bamanvada (p. 67). It may have some value as an ornamental stone for small carved work on account of its pleasing colours and faint translucency. With it occurs *tremolite* (see p. 69) which occasionally becomes rather compact, forming a very rough jade-stone. Small quantities only are known and the quality is much below that of true jade.

PYROLUSITE: *See* MANGANESE.

QUARTZ VEINS: These have been briefly described at p. 129. Their striking features and the large scale on which they are developed are however only equalled by the total absence in them of any economic minerals, so far as exposed. *Rose quartz* of a rather pale variety is known at Reda (see p. 73).

RARE EARTHS: Minerals of the rare earths are represented by *allanite*, rather abundantly developed in an aplite vein near Khed Brahma (see p. 40) and by a few grains of *monazite* detected in the sands collected from the larger river-beds.

STEATITE, SERPENTINE, TALC: *See* MAGNESIAN MINERALS.

LOCALITY INDEX.

	Latitude N.	Longitude E.
	° ′	° ′
Abharpur	23 44	73 24
Adpodara	23 33	73 13
Ahmednagar (Himatnagar)	23 36	73 2
Anthri	24 1	73 14
Asai hill	23 55	73 4
Babsar	23 59	72 57
Badoli	23 50	73 8
Bakrol	23 32	73 21
Bamanvada	23 36	73 22
Bamna	23 40	73 15
Bebar Nani	23 38	73 18
Berna	23 36	73 5
Bhadardi	23 44	73 5
Bhadresar	23 45	73 5
Bhatkota	23 33	73 20
Bhetali	23 43	73 22
Bhutavada	23 45	73 21
Bodi	23 32	73 14
Bokhar	23 37	73 12
Bolundra	23 35	73 21
Bornala	23 45	73 26

	Latitude N.	Longitude E.
	° ′	° ′
Chandap	23 56	72 55
Chhapra (1)	24 1	73 14
Chhapra (2)	23 43	73 11
Chithoda	23 55	73 23
Chitrori	23 46	72 53
Chorimal	23 53	73 23
Chorivad	23 53	73 11
Damavas	23 59	73 11
Danmauri	24 12	73 3
Dantroli	23 54	73 3
Dedhalia	23 33	73 26
Dedhrota	23 37	72 54
Deria	23 46	72 51
Derol	24 2	73 10
Desotar	23 48	72 56
Dev Mori	23 40	73 28
Dhabal	23 40	73 4
Dharol	23 59	73 3
Dhechania	23 51	73 14
Dholpur	23 42	73 6
Dhuleta	23 39	73 15
Dhundhar	23 34	73 9
Dijio	24 4	73 10

	Latitude N.	Longitude E.
	° ′	° ′
Dobhara	23 58	73 0
Dungri	23 44	73 4
Eklara	23 45	72 52
Fatepur	23 42	73 14
Gadadar	23 38	73 22
Gadra (Gadhada)	24 4	73 1
Ghanta	23 36	73 27
Ghanti	23 47	73 16
Ghorvada	23 40	73 6
Golwara	23 54	72 54
Gota	23 59	73 7
Hamirgad	23 37	73 7
Hamirpur	23 27	73 13
Hathoj	23 57	73 0
Himatnagar (Ahmednagar)	23 36	73 2
Hunj	23 38	73 13
Idar	23 51	73 4
Isri	23 38	73 31
Jalia	23 50	73 21
Jamla	23 41	73 3

	Latitude N.	Longitude E.
	° ′	° ′
Janali	23 39	73 19
Jesangpur	23 43	73 23
Kalol	24 1	73 12
Kambosana	23 58	72 59
Kanadara	23 51	73 21
Kaniol	23 40	73 6
Kapreta	23 42	73 13
Karanpur	23 42	73 22
Kasangad	23 48	73 16
Kasangod	23 49	73 16
Kathroti	23 53	73 14
Kawa	23 53	72 58
Kesarpur	23 41	73 5
Khalvad	23 48	73 16
Khandiol	23 42	73 7
Khed (or Khedgal)	23 40	73 9
Khed Brahma	24 2	73 6
Khedwa	24 7	73 10
Kheradi	23 41	73 21
Khercha (Kherancha)	23 39	73 25
Kherod	24 14	73 4
Kokapur	23 31	73 28
Kundel	23 36	73 26

	Latitude N.	Longitude E.
	° ′	° ′
Kundol	23 38	73 30
Kuski	23 38	73 25
Laloda	23 49	73 4
Lembhoi	23 52	73 3
Likhi	23 42	73 5
Lilchha	23 46	73 16
Lokhan	23 43	73 16
Mahadevpura	23 34	73 10
Malasa	23 49	73 14
Manpara	23 47	72 55
Matora	24 7	73 4
Mau	23 44	73 15
Medh	23 57	73 10
Medhasan	23 33	73 18
Meghraj	23 30	73 35
Meravada	23 41	73 24
Meru	23 45	73 22
Mhor	24 1	72 57
Modasa	23 28	73 21
Modhri	23 42	73 19
Morad	23 58	73 5
Munai	23 45	73 13

	Latitude N.	Longitude E.
	° ′	° ′
Mundeti	23 50	73 14
Nadri (1)	23 33	73 12
Nadri (2)	24 0	73 3
Nankhi	23 42	73 12
Nau	24 14	73 6
Navalpur	23 36	73 13
Navugam	23 43	73 27
Nawawas	23 56	72 55
Od	23 44	73 26
Ora	23 50	72 55
Pal	23 56	73 25
Pala (Palo)	23 42	73 25
Paliapar	23 33	73 15
Pedhmala	23 31	73 12
Posina (1) (outside map to north)	24 23	73 6
Posina (2)	23 45	73 10
Proia	24 3	73 9
Punasan	23 39	73 14
Raighad	23 36	73 13
Raisangpur	23 53	73 24
Rampur	23 40	73 25

	Latitude N.	Longitude E.
	° ′	° ′
Reda	23 55	73 0
Rera (Reda)	23 55	73 0
Rudadi	23 41	73 26
Ruvach	23 44	73 8
Sabalvada	23 53	73 1
Sabli	23 44	73 7
Samalpar	23 41	73 25
Samlaji	23 41	73 27
Sangal	23 33	73 29
Sardoi	23 34	73 19
Satharva	23 57	73 3
Sathrol	23 39	73 17
Semlia	24 9	73 4
Shaogar	23 37	73 1
Sisasan	23 50	73 15
Sobheda	23 38	73 9
Sodpur	23 38	73 24
Sunak	23 37	73 21
Surajpura	23 36	73 9
Surpur	23 43	73 6
Talau	24 6	73 12
Talod (outside map to south)	23 21	73 0

	Latitude N.	Longitude E.
	° ′	° ′
Tembana Math	23 41	73 17
Thuravas	23 43	73 16
Timri	24 14	73 6
Titoi (Tintoi)	23 35	73 23
Torda	23 48	73 21
Ubsal	23 48	73 23
Umedpura	23 53	72 52
Vadali	23 57	73 6
Vagdi	23 35	73 13
Vagesari	23 49	73 17
Vaghodar	23 35	73 20
Vandiol	23 38	73 24
Vanta	23 35	73 18
Vantadi	23 39	73 16
Vartha	23 32	73 23
Vasai	23 48	73 12
Vavdi	23 37	73 10
Veherabar	23 55	72 57
Venpui	23 44	73 27
Vera	23 57	72 57
Vijapar	23 39	73 24
Viravada	23 36	73 6
Vivau	23 59	73 6

	Latitude N.	Longitude E.
	° ′	° ′
Wadtol	23 57	72 58
Walren	24 5	73 10
Wamoj	23 35	73 7
Wantra	23 37	73 8
Wasan	23 57	72 59

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FIG. 1. CALC-GNEISS WITH APLITE VEINS, DHAROL.

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FIG. 2. CALC-GNEISS, KHED BRAHMA.

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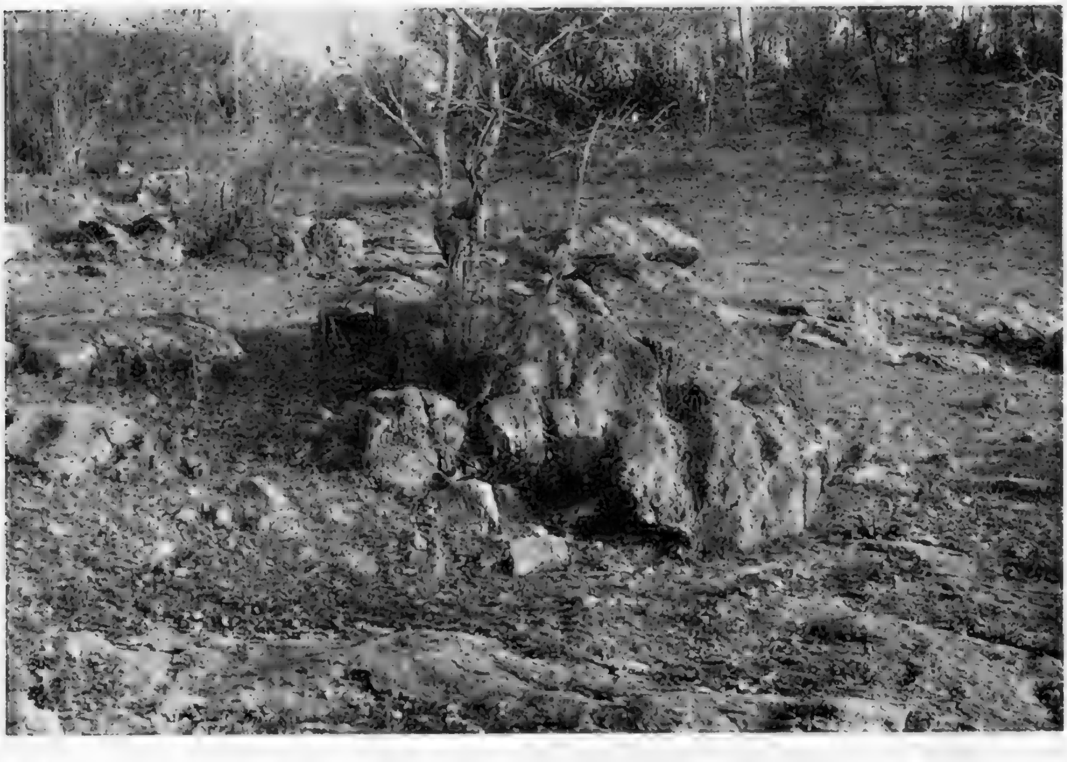

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FIG. 2. DELHI QUARTZITE BLOCKS IN BIOTITE-GNEISS, NEAR DIJIO.

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BIOTITE-GNEISS WITH APLITE VEINS, 858 ft. HILL, DAMAVAS.

FIG. 1. DIP IN DELHI QUARTZITE, NEAR MAU.

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FIG. 2. DIP SLOPE IN DELHI QUARTZITE, HARNAV R., MIDDLE SPUR.

FIG. 1. BALANCED BLOCK OF IDAR GRANITE NEAR VASNA.

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FIG. 2. DELHI QUARTZITE RIDGE N. OF CHORIVAD WITH ARAVALLIS IN FOREGROUND.

FIG. 1. GRANITE BOSS, NEAR IDAR.

Photographs by C. S. Middlemiss. *G. S. I. Calcutta.*

FIG. 2. WEATHERING OF IDAR GRANITE.

FIG. 1. AHMEDNAGAR SANDSTONE, HATHMATI R.

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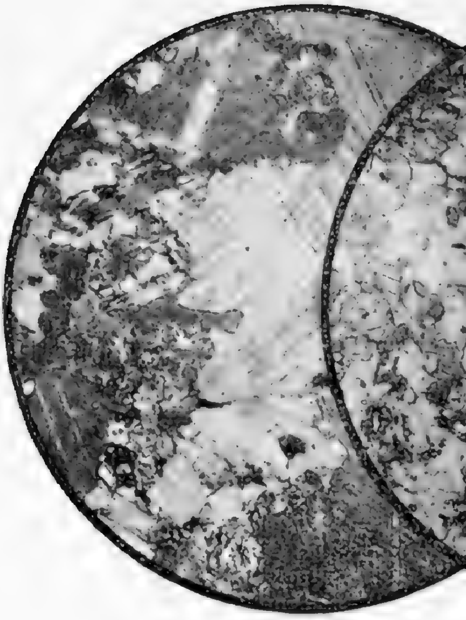
FIG. 2. QUARTZ-PORPHYRY TOR, SABLI.



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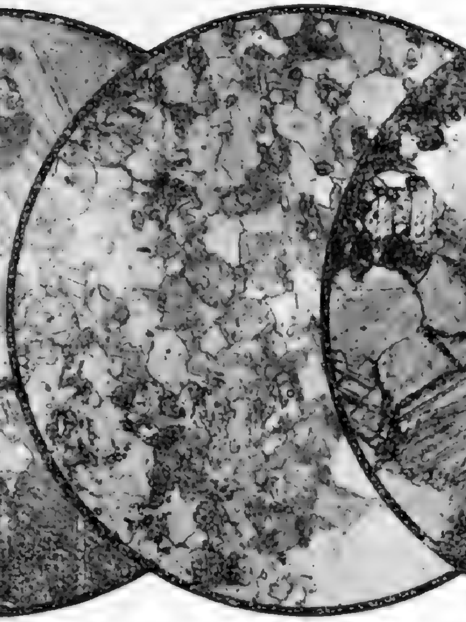

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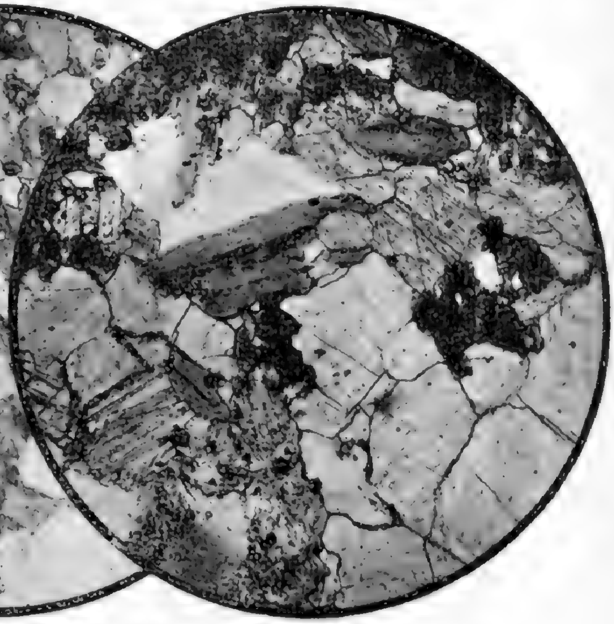

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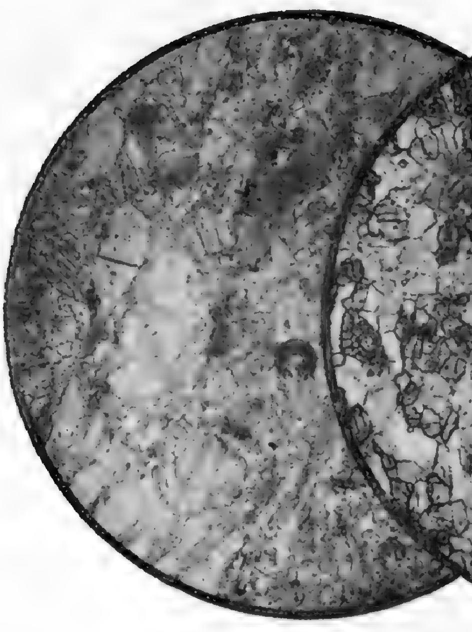

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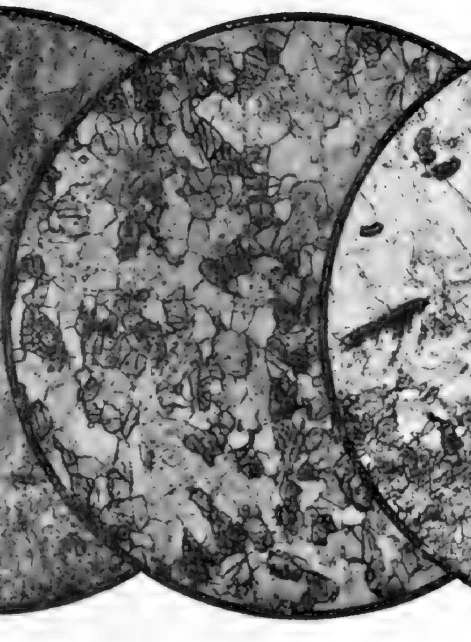

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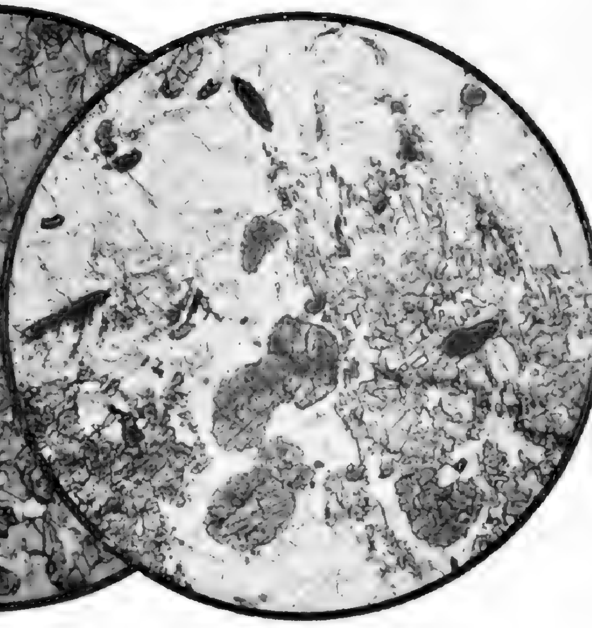

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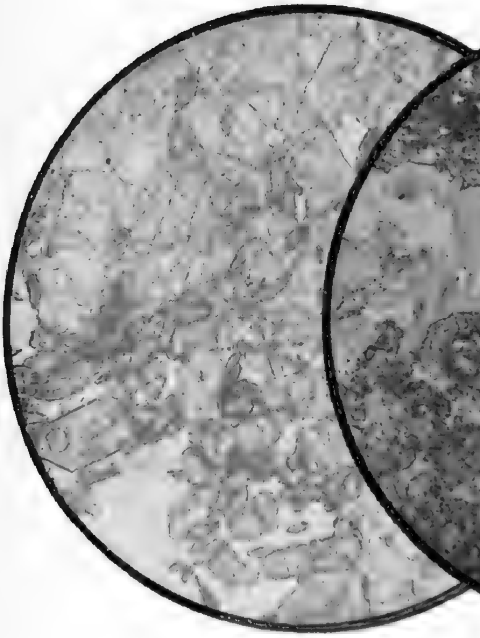

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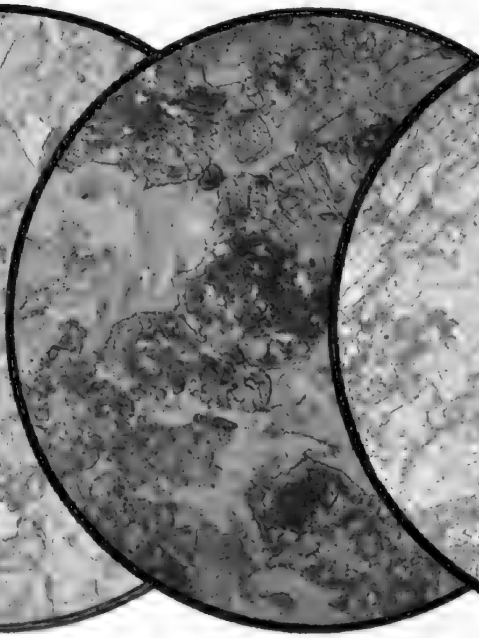

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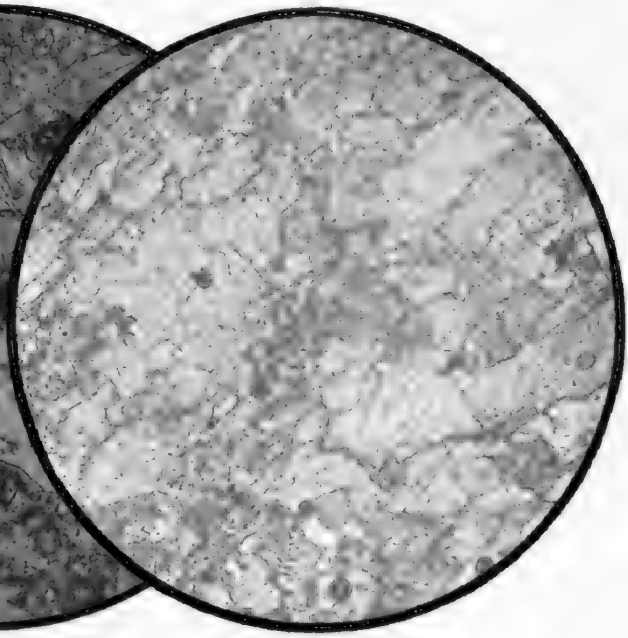

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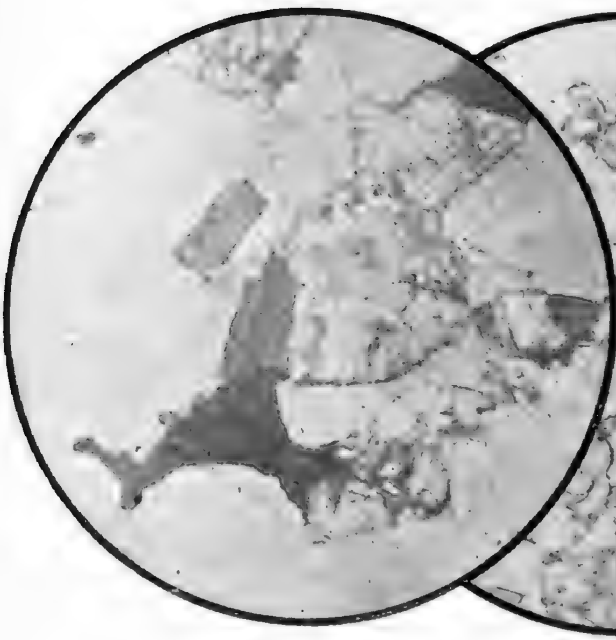

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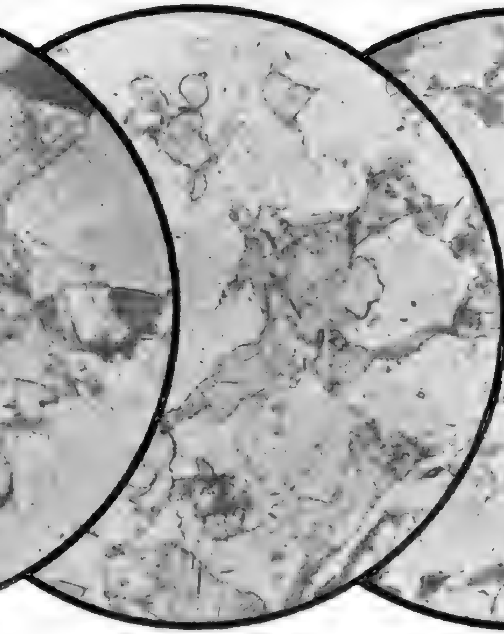

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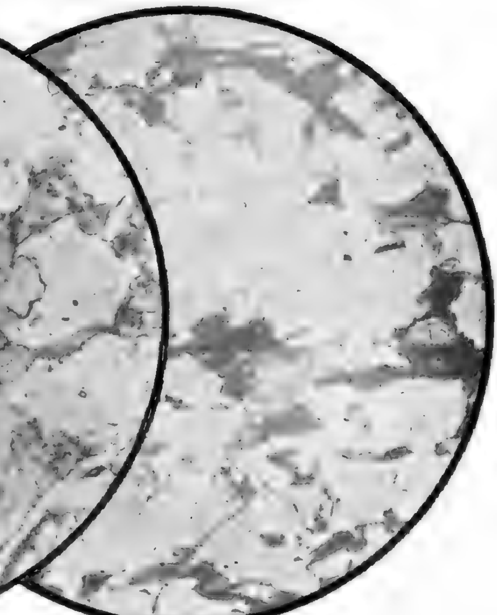

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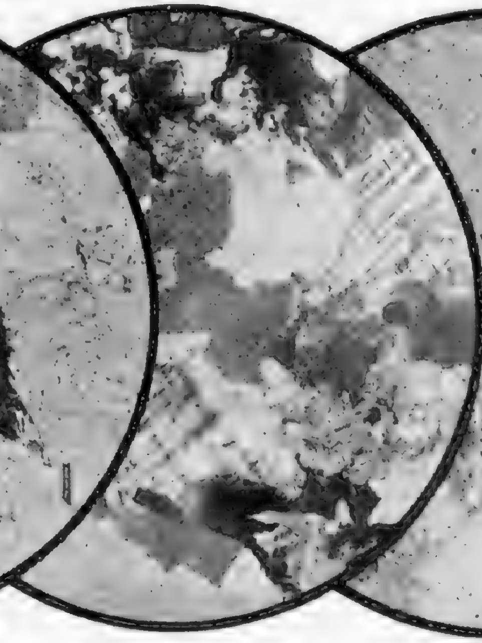

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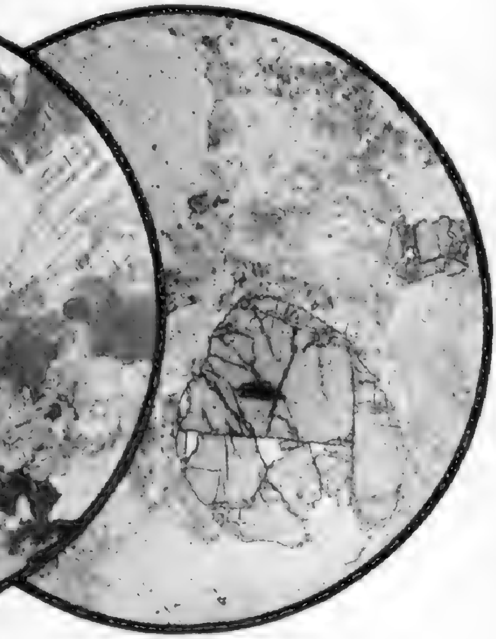

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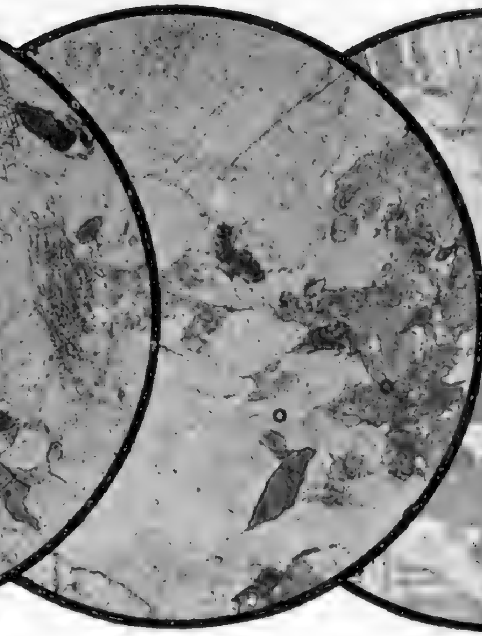

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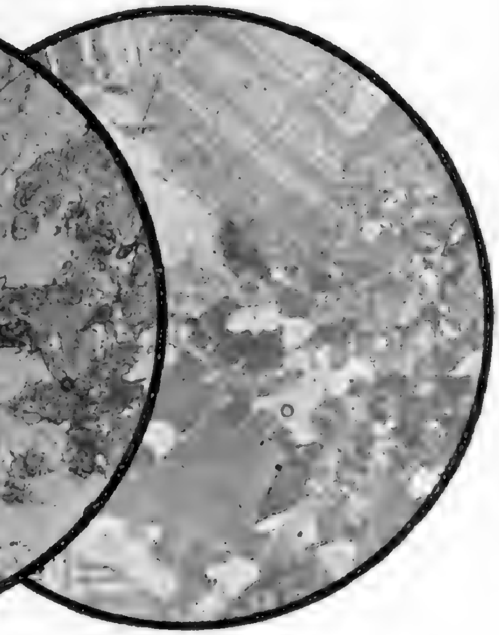

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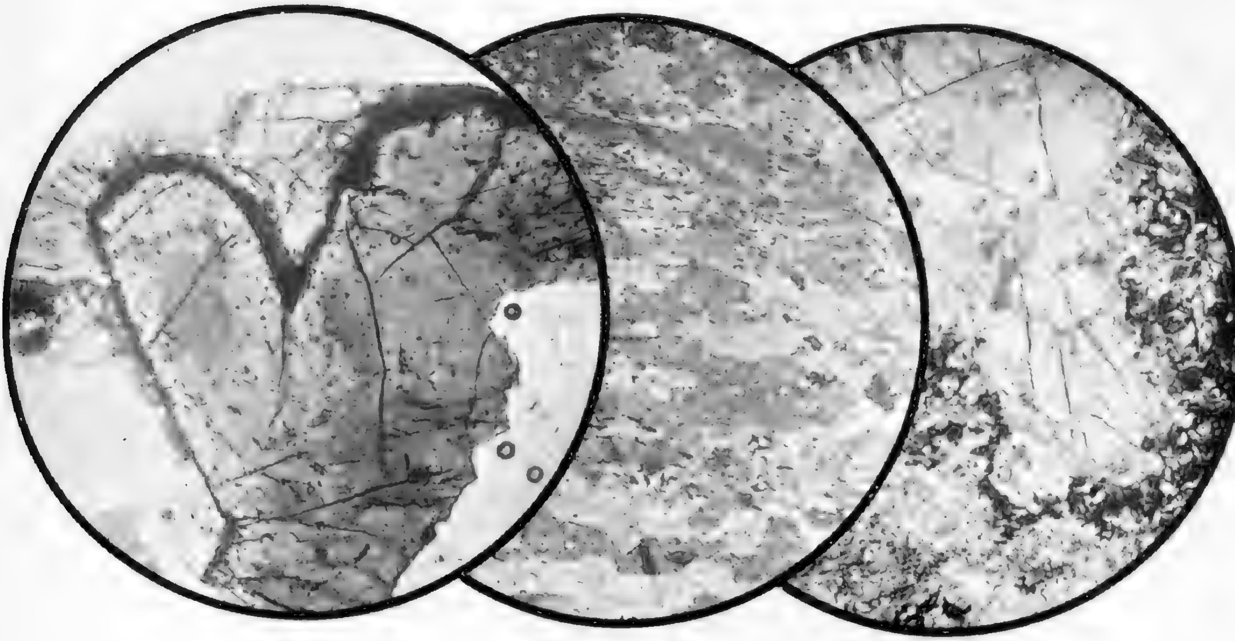

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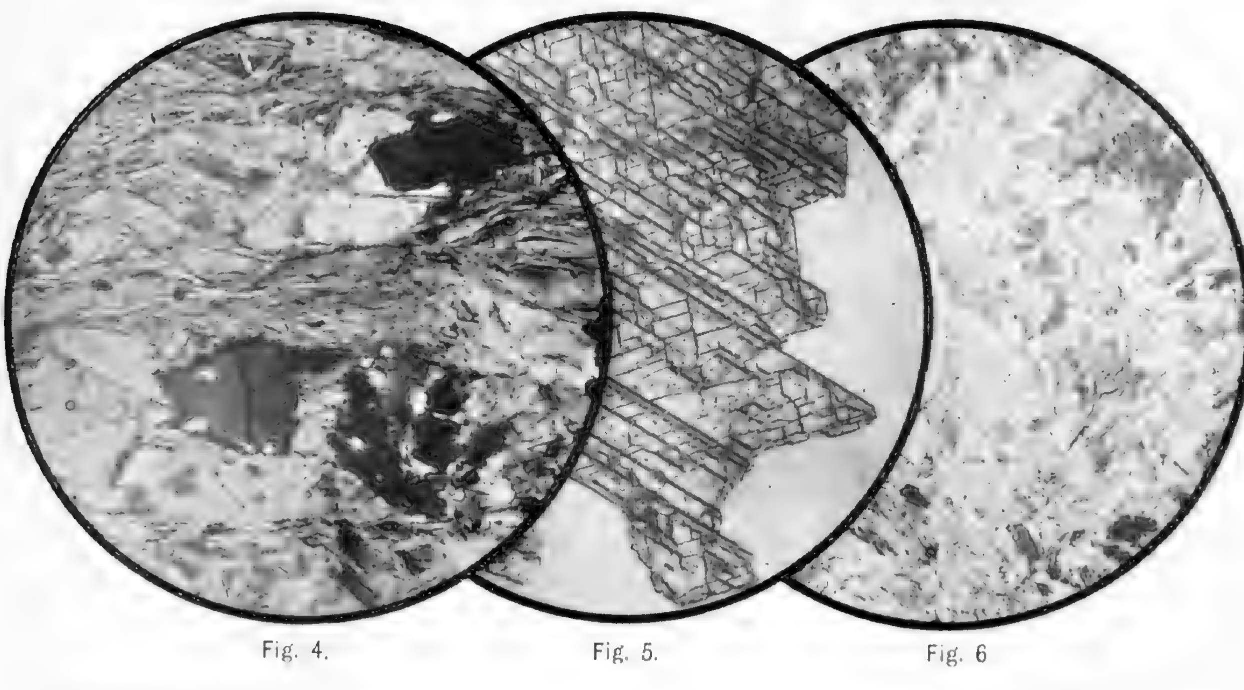

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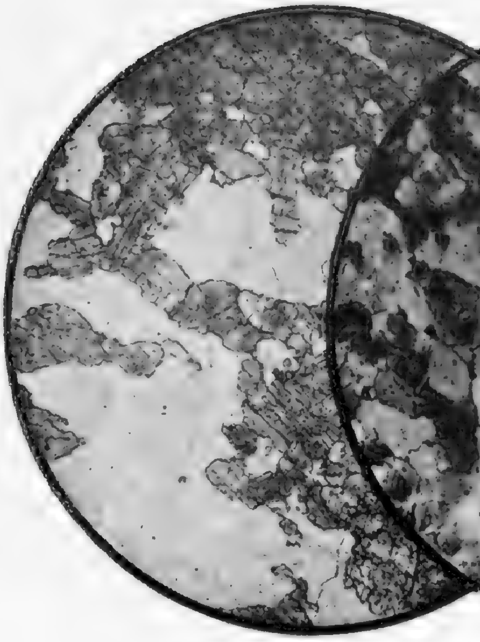
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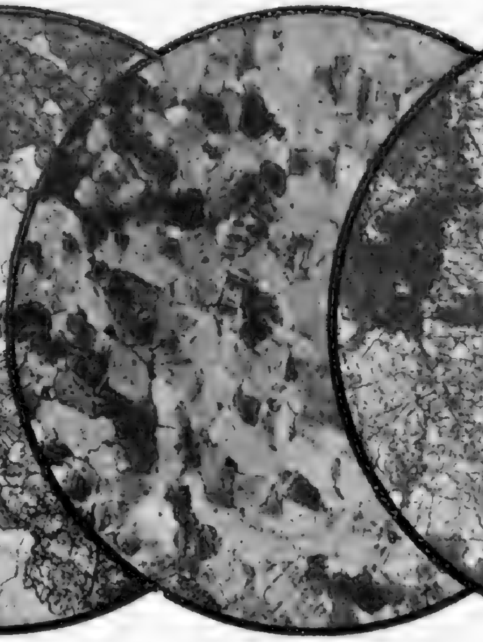
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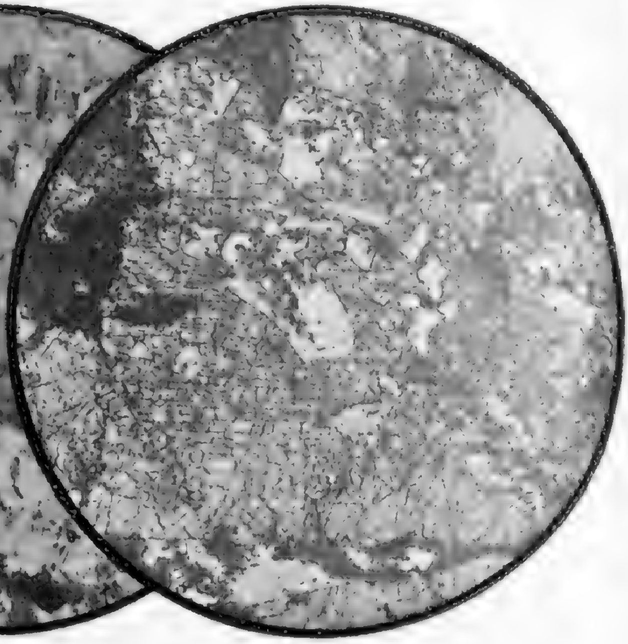
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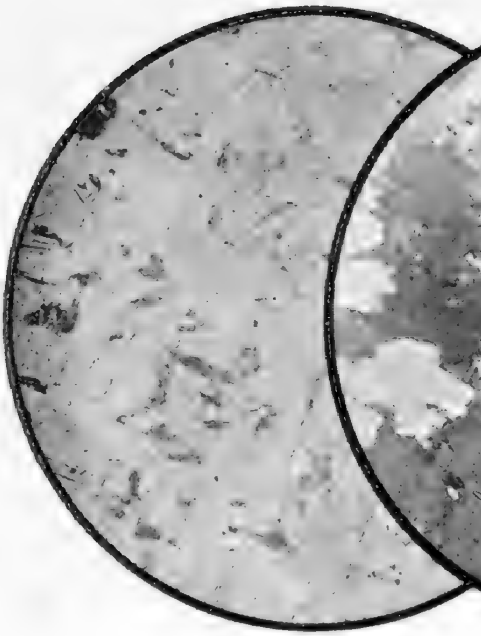
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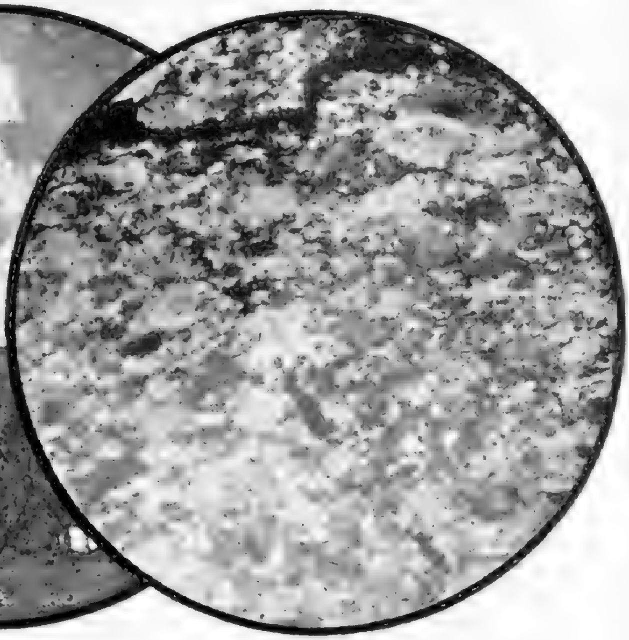
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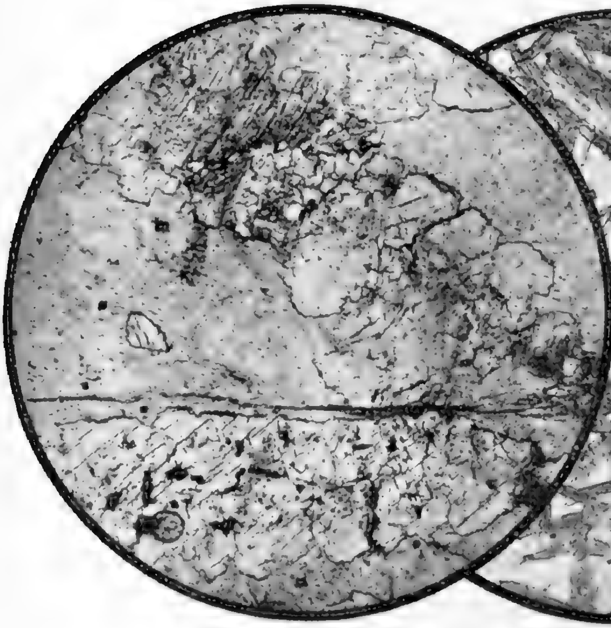

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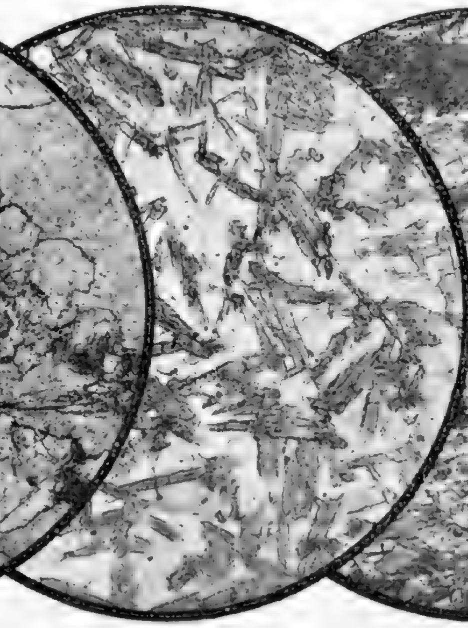

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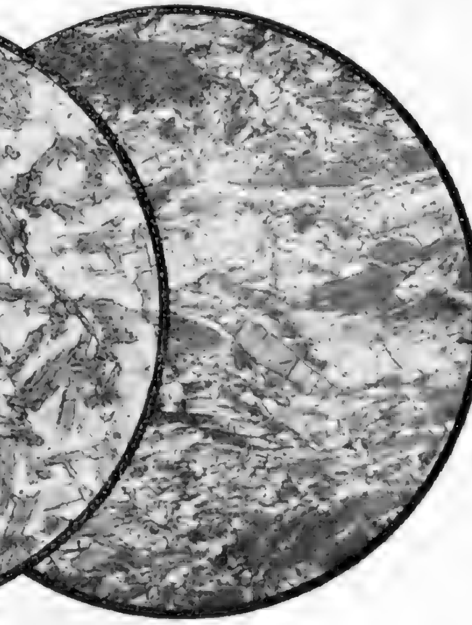

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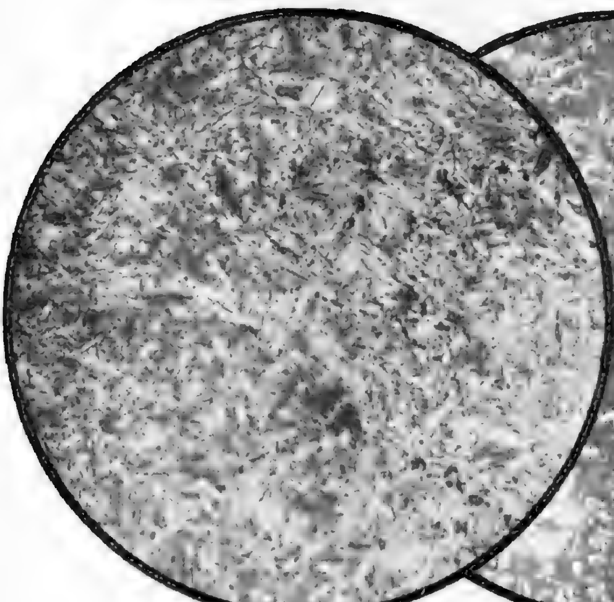

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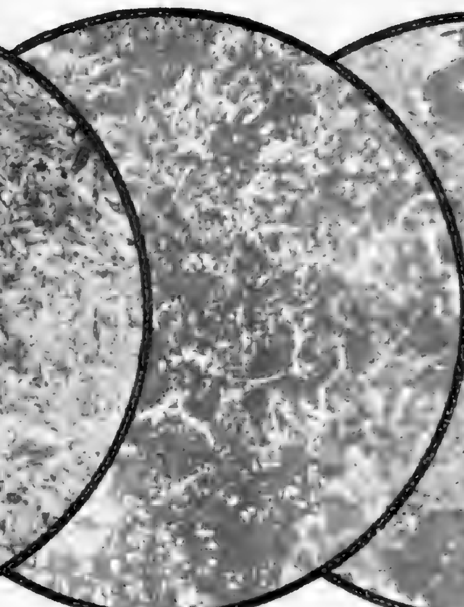

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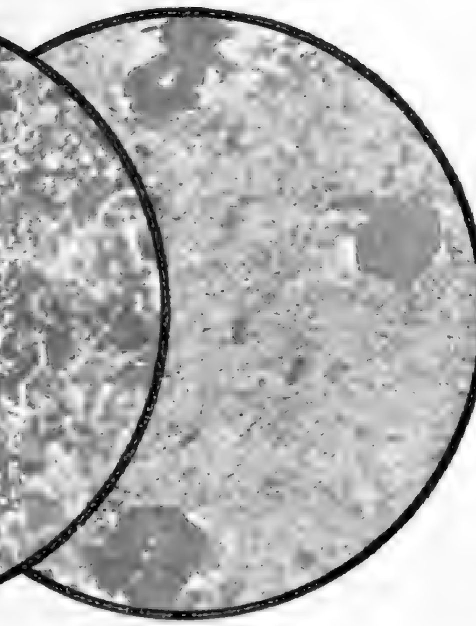

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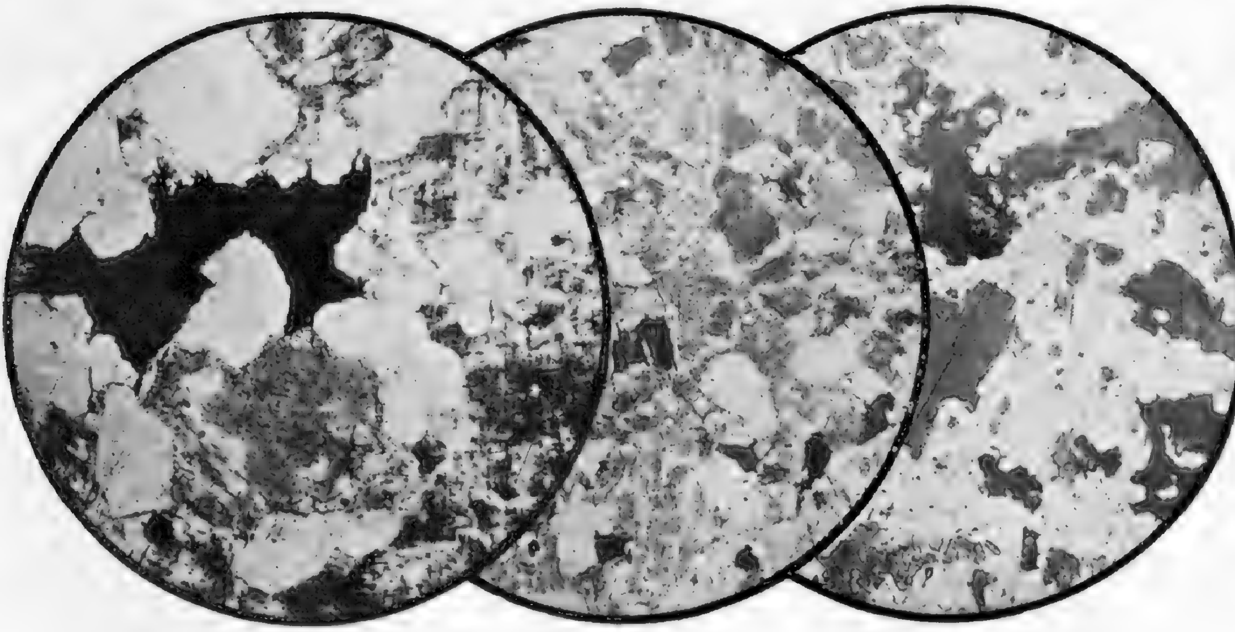

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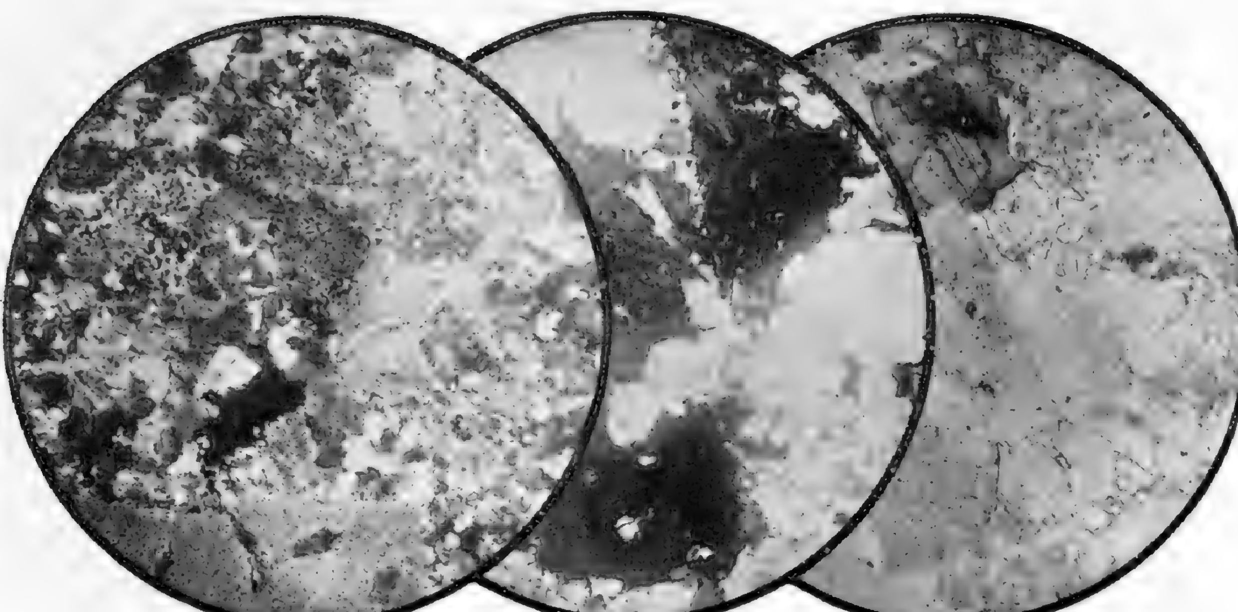

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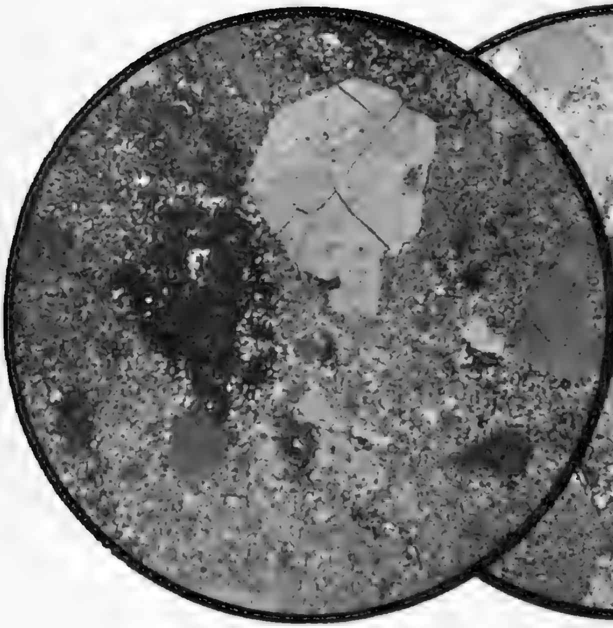

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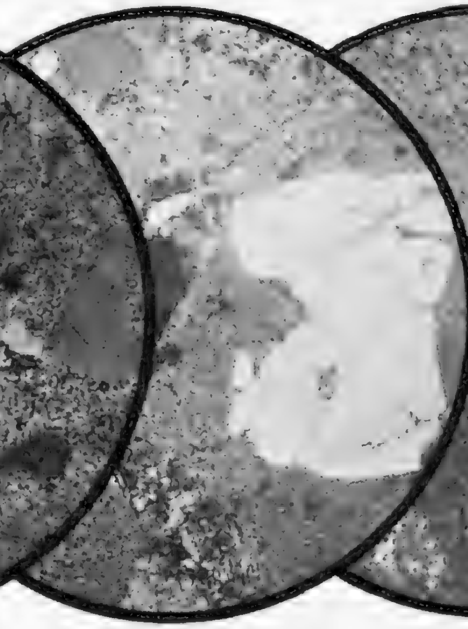

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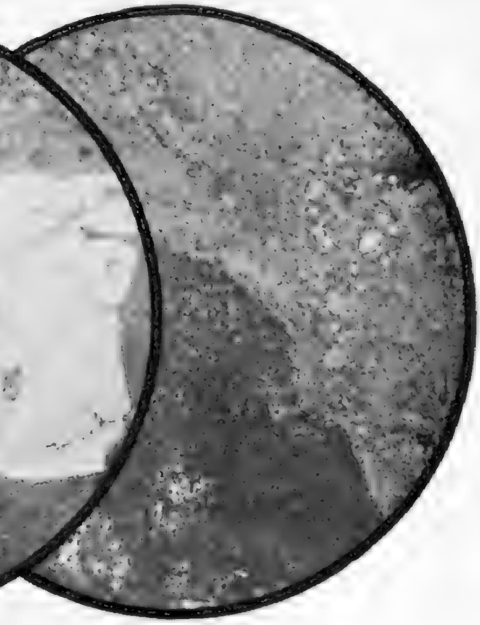

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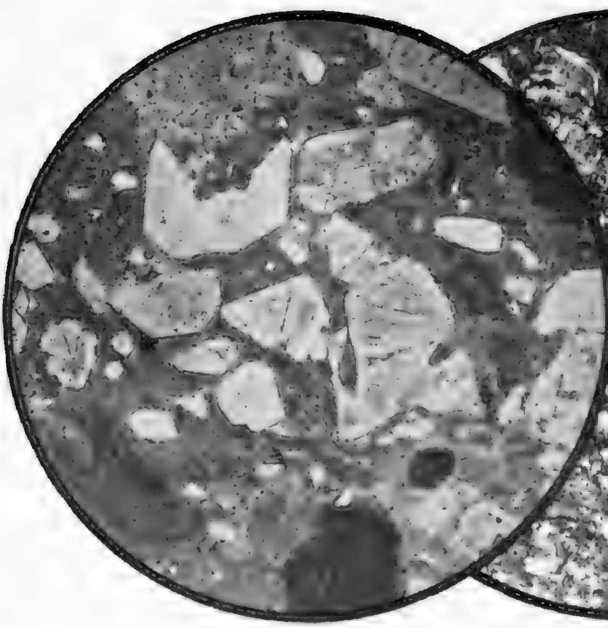

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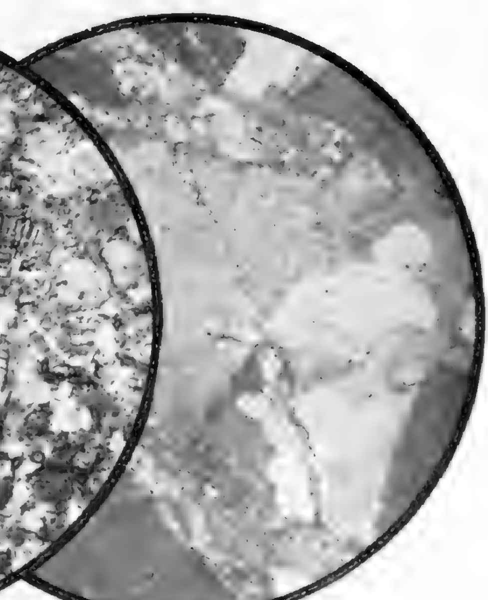

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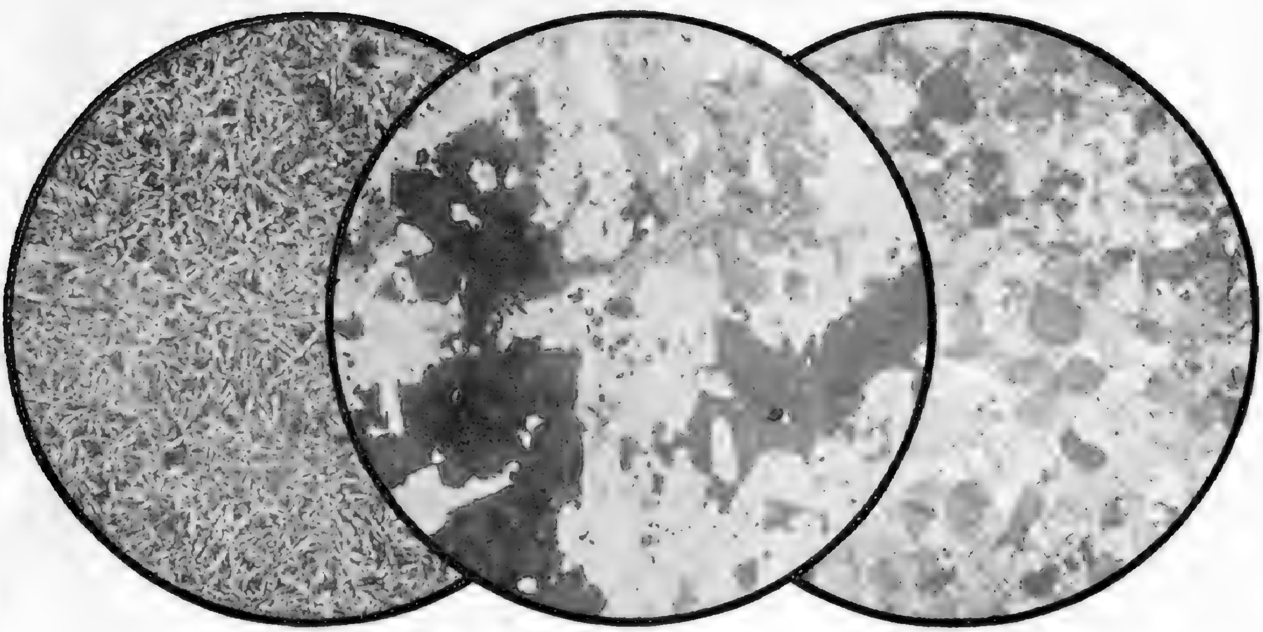

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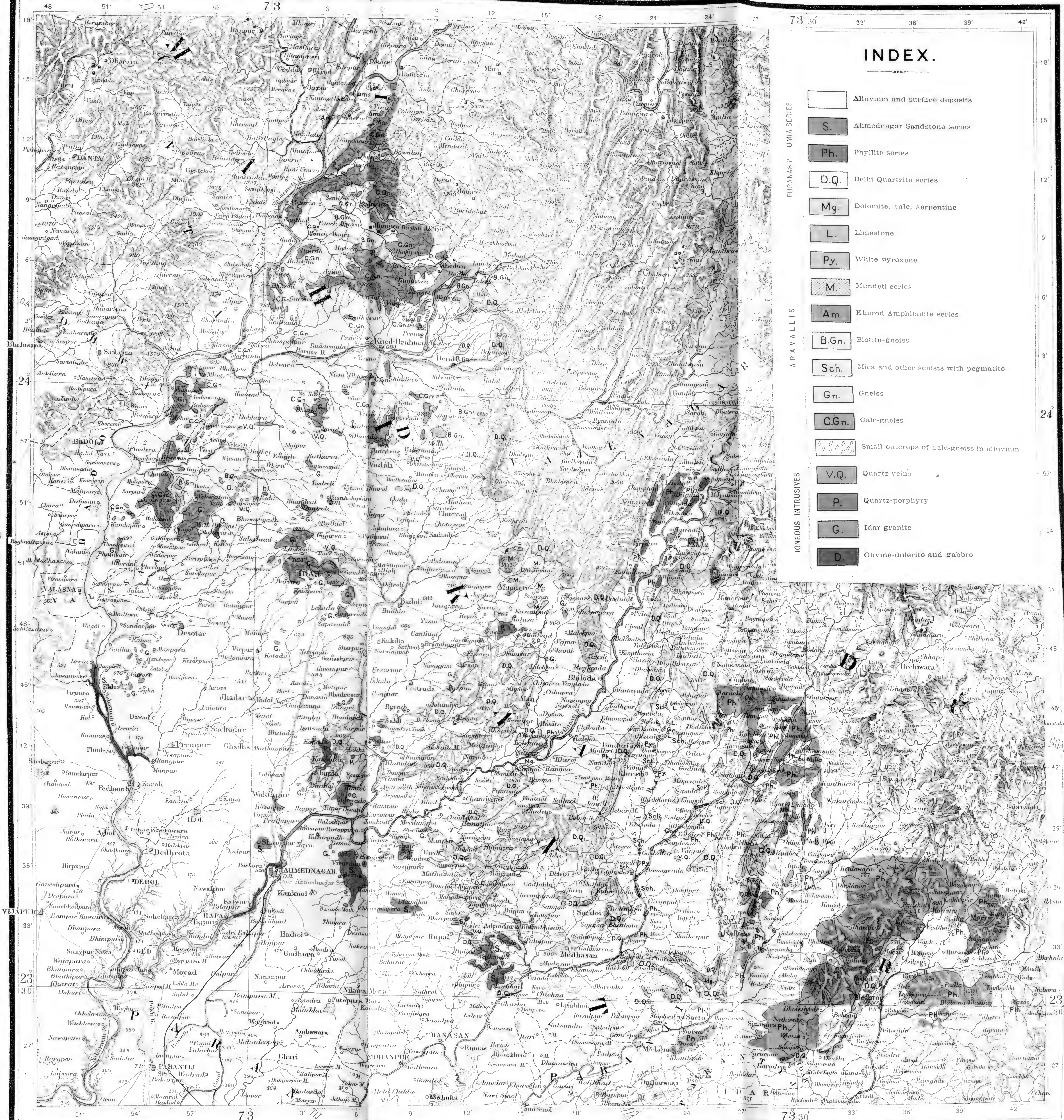

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THE GEOLOGY AND ORE DEPOSITS OF THE TAVOY DISTRICT. BY J. COGGIN BROWN, O.B.E., D.SC., *Superintendent,* AND A. M. HERON, D.SC., *Officiating Superintendent, Geological Survey of India.*

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA

THE GEOLOGY AND ORE DEPOSITS OF THE TAVOY DISTRICT. BY J. COGGIN BROWN, O.B.E., D.SC., *Superintendent,* AND A. M. HERON, D.SC., *Officiating Superintendent, Geological Survey of India.* (With Plates 18 to 25.)

PART I.

CHAPTER I.

INTRODUCTION.

The Tavoy district is in the Tenasserim Division of Burma, lying between 13° 16′ and 15° 6′ N. and 97° 46′ and 99° 12′ E., with an area of 5,308 square miles. On the north lies Amherst District, on the south Mergui, on the east Siam, and on the west the Bay of Bengal. It is a rugged tract, 150 miles long and 60 miles broad at its widest part, built up entirely of mountains, save for the cultivated basin of the Tavoy river and a narrow strip along the sea coast. The mountain ranges run generally north and south and are covered with dense tropical forest of tall evergreen trees and heavy undergrowth; where this has been cleared luxuriant bamboo jungle takes its place.

The climate is on the whole a pleasant one, except for its humidity, and the intense heat of the hot season is tempered by sea breezes. During the cold season the thermometer at midday scarcely ever reaches 92° in the shade and occasionally in the early morning falls as low as 57°. Between December and February dense fogs prevail in the mornings, but do not continue above about 2,000 feet. In March and April there are occasional squalls of wind and rain, and about the beginning of May violent electric disturbances usher in the south-west monsoon, which lasts until October. The rainfall is a very heavy one and, for the four years ending 1917, averaged 214 inches in Tavoy town. Much greater falls than this have been recorded from mines situated at high elevations on the Central Range.

The district has at various times formed part of the dominions of the Kings of Siam, Pegu, and Ava, but its early history is obscure. In 1757 it was a province of Siam, but in 1759 it was conquered by the Emperor Alaungpaya. From that time until 1824, when it was handed over to British troops, the country was torn by internal strife and raided by the Siamese. The total population at the census of 1911 was 135,293 souls, of whom 120,000 were Burmese and 11,000 Karens, but largely owing to the mining boom during the war, helped by the natural growth of the population, the figures rapidly increased and it has been unofficially estimated at about 200,000 in 1918.

The only permanently cultivated land is on the coastal strip and in the valley of the Tavoy river and its tributaries. Elsewhere the Karens and others practise "taung-ya," a system in which the forest is burnt, crops grown for a season or two and the ground then abandoned for a new location. The total land under cultivation is probably less than 300 square miles, which gives some idea of the extent of the forests which cover the district. The population is to all intents and purposes confined to the cultivated valley of the Tavoy river and to the mining camps and the roads leading to them.[1]

BIBLIOGRAPHY.

In the following list, which is arranged in chronological order, except as regards recent papers, an attempt has been made to include every work of importance dealing with the geology or ore deposits of the Tavoy district. As regards the latter a few papers dealing with the mineral occurrences of the adjoining Mergui district are also included.

The date of the commencement of tin mining in Tavoy is unknown, but judging from the extent and character of the ancient workings, it must have been carried on for a very long

[1] For a fuller account of Tavoy, the article in the Gazetteer of British India may be consulted with advantage. The details given here are taken from it.

time. The earliest reference extant to the occurrence of tin in Burma refers to Tavoy, and was made in 1599 by Ralph Fitch, who remarked that on his journey from Pegu to Malacca he passed by "many of the ports of Pegu, as Martauan, the Island of Taui (Tavoy), from whence commeth great store of tinne, which serueth all India."

1829. J. Low. "Observations on the Geological Appearances and General Features of portions of the Malayan Peninsula, and of the Countries lying betwixt it and 18° North Latitude." *Asiatic Researches*, Vol. XVIII, Pt. 1, pp. 128—162, and *Journ. Roy. Asiatic Soc.*, Vol. III, pp. 305—326.

The author states that grey granite is the prevailing rock throughout Tavoy. He notices briefly stream-tin occurrences near the Nay Dang pass into Siam.

1839. J. W. Helfer. Second Report. "The Provinces of Ye, Tavoy and Mergui, on the Tenasserim Coast." Fol., 76 pp., Calcutta.

Describes occurrences of tin ore in Metamio, a tract of country about 60 miles long and from 8 to 12 miles broad, of which the latitude of Tavoy forms the centre; in Palou and Woomboo; in Mergui and the Islands. Mentions briefly the Burmese methods of streaming.

1841. G. B. Tremenheere. "Report on the Tin of the Province of Mergui." *Journ. Asiatic Soc. Bengal*, Vol. X, pp. 845—851; Vol. XI, pp. 289—290.

Under Siamese rule extensive works for recovering tin ore were carried out. The following localities are enumerated :—

(1) Thengdon river, in the immediate vicinity of the coal mines on the Great Tenasserim.

(2) Thabawlick river, which unites with the Thakiet three miles above the junction of the latter with the Little Tenasserim.

(3) Four tributaries of the Little Tenasserim,—

(*a*) Khamoungtang river.
(*b*) Engdaw river.
(*c*) Kyeng river.
(*d*) Thapyu river.

The occurrence of wolfram sand is noted in the Loundoungin river.

4. Kahan, a small hill near the Zedavoun pagoda on the right bank of the Tenasserim, 11 miles from Mergui, where a vein, three feet wide, was seen in white sandstone.

1842. G. B. Tremenheere. "Second Report on the Tin of Mergui." *Journ. Asiatic Soc. Bengal*, Vol. XI, pp. 839—852.

Records the shipment of specimens of Mergui tin ores to England.

1843. G. B. Tremenheere. "Report of a Visit to the Pakchun river, and of some Tin localities in the southern portion of the Tenasserim Provinces." *Journ. Asiatic Soc., Bengal*, Vol. XII, pp. 523—534.

Describes streaming operations on a tributary of the Maliwun river, and the Siamese tin works and smelter near Renong, together with the occurrence of cassiterite at Bokpyin.

1843. J. Forbes Royle. "On the Tin Mines of Tenasserim Province." *Proc. Geol. Soc.*, Vol. IV, pp. 165—167.

This paper summarizes Helfer's and Tremenheere's observations. It states that Helfer discovered tin ore near Loadut, about 110 miles north-north-east of Maulmain, and that in 1840 he reported the country to the north of the Pakchan river to contain the richest stanniferous deposits within the Tenasserim province.

Tremenheere's opinion is that the tin of the Tenasserim provinces occurs chiefly in the beds and banks of those rivers which issue from the primitive mountains.

1846. G. B. Tremenheere and Sir C. Lemon. "Report on the Tin of the province of Mergui in Tenasserim, in the northern part of the Malayan Peninsula." *Trans. Roy. Geol. Soc. Cornwall*, Vol. VI, pp. 68—75.

A reprint of the earlier articles from the *Journal of the Asiatic Society of Bengal.*

1849. E. O'Riley. "Remarks on the Metalliferous Deposits and Mineral Productions of the Tenasserim Province." *Journ. Ind. Archipelago*, Vol. III, pp. 724—743.

Enumerates localities where stream tin has been worked including the following :—

(a) Maliwun and the tributaries of the Pakchan.
(b) Bokpyin river.
(c) Upper reaches of the Lenya.
(d) Thengdau river near the coal mine on the Great Tenasserim.
(e) Thabauleik on the Little Tenasserim.
(f) Kamoungtan, Engdaw and Thapyan in the same locality.
(g) Yamon, 20 miles from Mergui.
(h) In the Taungbyauk valley.
(i) Headwaters of the Great Tenasserim.
(j) Upper courses of streams flowing into the Henzai Bay.

1850. F. Mason. "The Natural Productions of Burmah, or Notes on the Fauna, Flora, and Minerals of the Tenasserim Provinces, and the Burman Empire." 2 Vols., Moulmein.

This work is an encyclopedic account of the natural history of Tenasserim, with a portion devoted to geology and mineralogy. It also contains a brief description of tin mines in Mergui and a reference to the occurrence of wolfram. According to the author :—"Tin is abundant in the Provinces, commencing in the mountains in which Tavoy and Henzai rivers have their rise, the northern limit of tin in the Provinces, to the southern boundary of Mergui, Pakchan river. The richest locality in the province of Tavoy is nearly opposite the city of Tavoy on the eastern side of the mountains." Regarding wolfram Dr. Mason writes :—"The tungstate of iron or wolfram sand much resembles tin, and it is found in most neighbourhoods where that ore is obtained, and for which it is often mistaken. One of the Assistant Commissioners at Mergui a few years ago, reported several valuable deposits of tin, not before known, and he raised furnaces on the ground to smelt the ore; but although he tried hard, and increased the heat to the highest point he was capable of doing, still the ore remained refractory and would not turn into tin. He attributed the fault to his furnaces and came away with large specimens of his tin ore, which proved on examination to be tungsten, or wolfram sand."

1852. G. B. Tremenheere, E. O'Riley and T. Oldham. "Report on the Tin and other Mineral Productions of the Tenasserim Provinces." *Sel. Rec. Beng. Govt.*, Vol. VI, pp. 21—44.

A collection of papers including Tremenheere's 1841 report together with Dr. T. Oldham's remarks relative to the discovery of ores of tin, etc., in Tenasserim, and a report by E. O'Riley on the Henzai Basin. The latter refers to sluicing operations carried on in the Onhbinkwin chaung and to the occurrence of tin ore mixed with wolfram in certain streams falling into the Basin.

1856. T. Oldham. "Notes on the Coal-Fields and Tin-Stone Deposits of the Tenasserim Provinces." *Sel. Rec. Govt. India*, No. X, pp. 31—67.

In this paper Dr. Oldham first suggested the term "Mergui Series," for the ancient sedimentary rocks of Lower Tenasserim.

1859. J. W. Helfer. "Gedruckte und ungedruckte Schriften über die Tenasserim Provinzen, den Mergui Archipel und die Andaman Inseln." *Mitth. k. k. Geogr. Ges.*, Vol. III, pp. 167—390.

A resumé of Helfer's observations in Tenasserim.

1870. H. S. Tremenheere. "Note on Tin in Tenasserim." *Min. Journ.*, Vol. XL, p. 919.

1872. M. Fryar. "Report on some Mineraliferous localities in Tenasserim." *Ind. Economist*, Vol. IV, pp. 42—43.

1882. F. Mason and W. Theobald. "Burma, its Peoples and Productions; or, Notes on the Fauna, Flora and Minerals of Tenasserim, Pegu and Burma." 2 vols., Hertford.

It is reported that samples of tin ore from various localities in the Tavoy district were displayed at an exhibition in London in 1861. About 1873, an attempt was made to work the gravels and veins at Maliwun in Mergui under European management, but after three years of work, in one of which 17 tons of cleaned ore and 7 tons of metal were exported, the concessionaires, Messrs.

Strang, Steel and Co., Ltd., resigned their lease. From 1894 to 1897, the property was held by the Jelibu Mining and Trading Co., Ltd., whose operations have been described by Parry. The amount of ore exported during the three years was 3,407 cwts.[1]

1897. R. Parry. "Report on Tin-mining in the Malay States of Perak and Selangor, and in Mergui." Rangoon.

In 1905, Snow published the results of his prospecting operations in the same locality, and following on these the Burma Development Syndicate took out a mining lease which is still in existence. A large dressing plant was installed but mining operations have never been successful and are confined at present to small-scale ground sluicing operations.

During the years 1888 to 1892, a systematic exploration of the tin-bearing deposits of the Mergui and Tavoy districts was carried out under the orders of Government, by a party of prospectors under the superintendence of T. W. H. Hughes of the Geological Survey of India, the results of which were published in two reports.

1889. T. W. H. Hughes. "Tin Mining in Mergui district." *Rec., Geol. Surv. Ind.*, Vol. XXII, pp. 188—208.

This gives detailed particulars of each deposit examined, the nature of the country and the conditions of labour.

1893. T. W. H. Hughes. "Report on the Prospecting Operations, Mergui District, 1891-92." *Rec., Geol. Surv. Ind.*, Vol. XXVI, pp. 40—53.

This paper deals mainly with details for the administration of the fields. Reports drawn up by Messrs. Ross Clunis and Primrose, the prospectors attached to the party, are given in appendices. The opinion is expressed that the deposits generally are sufficiently large and accessible to prove remunerative under economical management, and that as the country is opened up payable deposits will be found to the north and east of the area examined.

1904. K. M. Foss. "The Occurrence of Tin and Gold in Lower Burma." *Min. Journ.*, Vol. LXXVI, pp. 505—506.

[1] T. H. D. La Touche. "Bibliography of Indian Geology and Physical Geography," Calcutta, 1918, p. 481.

Another investigation of the tin-ore deposits in Lower Burma was undertaken by J. J. A. Page of the Geological Survey of India during the years 1907 to 1912. Full reports of this geologist's work have not been published, but abstracts of the first two seasons' results are available as follows:—

1908. T. H. Holland. "General Report of the Geological Survey of India for 1907." *Rec., Geol. Surv. Ind.*, Vol. XXXVII, pp. 1—56.

Cassiterite is said to be found under the following four conditions:—

(*a*) As a constituent of decomposed pegmatite rich in tourmaline and muscovite.

(*b*) In massive quartz segregations in and on the outskirts of granitic hills.

(*c*) In quartz veins and stringers in ground adjacent to decomposing pegmatite.

(*f*) Hill-side talus accumulations due to disintegration of classes, (*a*), (*b*), and (*c*), extending to gravel deposits along the stream valleys and in alluvial flats.

Numerous examples of each of these kinds of deposits are given.

1909. T. H. Holland. "General Report of the Geological Survey of India for 1908." *Rec., Geol. Surv. Ind.*, Vol. XXXVIII, pp. 53—60.

Gives localities in the Tavoy and Mergui districts where cassiterite and wolfram occur. Ground sluicing for tin-ore was carried on during the monsoon season at the following localities in Tavoy district:—

(*a*) The Maungmeshaung river.

(*b*) Onhbinkwin.

(*c*) The Hindu river and its tributary streams including the Heinda.

(*d*) Old workings in the vicinity of the granites near Wagon, and about the village of Pagaye.

Recent Literature on the Tungsten Deposits of Burma.

In listing the literature dealing with the tungsten and tin deposits of Tavoy which has appeared during the past five or six years, it is more convenient to adopt an alphabetical arrangement than the chronological one followed in the case of the earlier papers.

1. W. R. C. Beadon . "Tavoy and its Wolfram Industry during the past decade." Fol. pp. 76, privately printed, Rangoon, 1918.

2. A. W. G. Bleeck . "On some Occurrences of Wolframite Lodes and Deposits in the Tavoy District, in Lower Burma." *Rec., Geol. Surv. Ind.*, Vol. XLIII, Pt. 1, pp. 48—74.

3. J. Coggin Brown . "The Origin of the Wolfram-bearing Veins of the Tavoy District." *Journ. Asiatic Soc. Bengal*, N. S., Vol. XIII, No. 2, pp. ccii-cciii. Summary only. 1917.

4. J. Coggin Brown . "Economic Geology of Tavoy." *Lectures delivered at Tavoy under the auspices of the Mining Advisory Board*, Superintendent Government Printing, Rangoon, 1918.

5. J. Coggin Brown . "The Genesis of Tungsten Ores." *Geol. Mag.*, Jan. 1919, pp. 23—33.

6. J. Coggin Brown . "Solubility of Tungsten Minerals." *Min. and Sci. Press*, Vol. CXV, pp. 302—303, 1917.

7. J. Coggin Brown . "The Cassiterite Deposits of Tavoy." *Rec., Geol. Surv. Ind.*, Vol. XLIX, Pt. 1, pp. 23—33, 1918.

8. J. Coggin Brown and A. M. Heron. "The Distribution of the Ores of Tungsten and Tin in Burma." *Rec. Geol. Surv. Ind.*, Vol. L, Pt. 2, pp 101—121.

8a. J. Coggin Brown . "Tungsten Ore Deposits of Burma." *Mining Mag.*, Vol. XXII, No. 4, p. 241.[1]

9. J. Morrow Campbell "The Ore Minerals of Tavoy." *Mining Mag.*, Vol. 20, pp. 76—89 1919, and privately printed.

These numerals are quoted instead of the full references in the following pages.

[1] See also, J. Coggin Brown and A. M . Heron, "The Northern Extension of the Wolfram-bearing zone in Burma." *Rec., Geol. Surv ., Ind.*, Vol. LIV, Pt. 2, pp. 235 237, 1922.

10. J. Morrow Campbell "Water in Rock Magmas and Veins." *Mining Mag.*, Vol. XXI, No. 6, 1919.

10a. J. Morrow Campbell "Tungsten Deposits of Burma and Their Origin." *Econ. Geol.*, Vol. XV, No. 6, pp. 511—534.

11. H. D. Griffiths . "The Wolframite Industry of Lower Burma." *Mining Mag.*, Vol. X, pp. 440—451, 1914.

12. H. D. Griffiths . "The Wolfram Deposits of Burma. *Mining Mag.*, Vol. XVII, pp. 60—66 1917.

13 H. D. Griffiths . "The Kanbauk Wolfram Mine." *Mining Mag.*, Vol. XVII, pp. 211—219, 1917.

14. W. R. Jones . . "Tin and Wolfram Lodes." *Mining Mag.*, Vol. XVII, p. 230, 1917.

15. W. R. Jones . "The Origin of Wolfram Deposits." *Mining Mag.*, Vol. XVIII, pp. 319—320 and *Lectures delivered at Tavoy under the auspices of the Mining Advisory Board,* Superintendent Government Printing, Rangoon, 1918, pp. 33—44.

16. W. R. Jones . . "Tungsten in Manganese Ore." *Eng. and Min. Journ.*, Vol. CVI, p. 779, 1918.

16a. W. R. Jones . . "Tin and Tungsten Deposits." *Inst. Min. Me'., 18th March 1920*, *Mining Mag.*, Vol. XXII, No. 4, p. 243.

17. C. M. Lyons . . "Methods of Alluvial Mining applicable to Tavoy Conditions." *Lectures delivered at Tavoy under the auspices of the Mining Advisory Board*, Superintendent Government Printing, Rangoon, pp. 45—54, 1918.

18. G. N. Marks . . "Recent Progress of Wolfram Mining in Tavoy." *Lectures delivered at Tavoy under the auspices of the Mining Advisory Board*, Superintendent Government Printing, Rangoon, pp. 23—32, 1918.

19. E. MAXWELL-LEFROY "Mining in the Tavoy District of Lower Burma." *Min. and Sci. Press*, Vol. CIX, p. 448, 1914.

20. E. MAXWELL-LEFROY "Wolframite Mining in the Tavoy District in Lower Burma." *Trans. Inst. Min. and Met.*, Vol. XXV, pp. 83—100, 1916.

21. C. M. P. WRIGHT . "The Economics of Small Mine Management in Tavoy." *Lectures delivered at Tavoy under the auspices of the Mining Advisory Board*, Superintendent Government Printing, Rangoon, pp. 1—10, 1918.

CHAPTER II.

GEOLOGY.

The predominant rocks of the Tavoy District are an assemblage of sedimentaries, highly folded and indurated, but little metamorphosed, to which the term Mergui Series was given by Dr. T. Oldham. These are so extensively intruded by masses of granite in the form of large and small bosses that the area occupied by granite outcrops is nearly as great as that occupied by the Mergui Series.

In the interior of the district are two areas of Tertiary rocks deposited in tectonic basins on the surface of the Merguis, one along the course of the Great Tenasserim River, and the other in the broad valley occupied by the Kamaungthwe and the Ban, the two rivers which join at Myitta to form the Great Tenasserim.

In the lower portions of the valleys and along the coast, recent deposits are at present accumulating, but it is only in the estuarine portion of the Tavoy River and in the Heinze Basin that they attain any considerable thickness or that alluvial plains of silt are found. In the larger valleys patches of boulder beds and clays are occasionally seen, which are newer than the Tertiaries and older than the alluvials of the present day; these may be late Tertiary or sub-recent, probably the latter, and are so referred to below. The Moulmein limestone, so conspicuously developed in the districts to the north, has not been recognised with certainty in Tavoy.

The Mergui Series.

Lithology.

The Mergui Series is essentially a formation of hardened and crushed shales and agglomerates, with greatly subordinate quartzites, limestones and conglomerates, and is characterised by monotonous uniformity of type over great areas and over immense thicknesses of strata measured across the strike.

It is largely owing to this uniformity that it has been impossible to decipher the nature of the folding to which the Merguis have been subjected, but even if distinctive horizons had been present they could have been traced over very limited tracts, so difficult is geological work in the remainder on account of its uninhabited and trackless nature and the thick mantle of forest and soil.

Strike.

The general strike of the Mergui Series is north-north-west-south-south-east, the same direction as the trend of the mountain ranges and the longer axes of the granite intrusions; this is also the most usual strike of the wolfram-bearing quartz veins. Locally the strike may vary from north-south to north-west-south-east.

Dip.

The dip, where it can be seen, is always high, from 60° to vertical, and is very irregular. The tectonic structure of the district cannot be made out, but it is probable that the Mergui Series is repeated several times in an east to west section, in closely pressed folds.

Faulting.

For the above noted reasons, faulting cannot be traced except in a few of the larger mines where surveys are kept. In these, unfortunately for mining operations, small strike faults are found to be very numerous in both sedimentaries and granite, but data are as yet insufficient to warrant general conclusions. In the granite of the Paungdaw intrusion several horizontal faults occur, but not so far as is known in the sedimentaries, where however underground mining is not nearly so extensive.

None of these faults are of structural importance as far as is known at present, their throws being in the neighbourhood of a hundred feet as a maximum. There is a possibility that a large fault runs through the Heinze Basin, but no direct evidence of its presence has been obtained; the conjecture is tentatively advanced in view of the marked subsidence which has taken place in the Basin, the disturbance of the rocks underlying the Kanbauk valley (which however may be otherwise explained), and the remarkably flat lie of the veins on three concessions near Kanbauk—Medaw Kambay (Meimnadaung on the map), Taungshuntaung (near Taungyinin) and Pachaung. These three localities are on a straight line, parallel to the general strike and corresponding roughly to the long axis of the Heinze Basin. They are the only mines, with the exception of Heinda, where veins with low dips are the general rule.

Weathering.

The ultimate weathered product of the sedimentaries is a brownish-red clayey soil which covers all the hillsides except where granite is the underlying rock. The conditions favouring atmospheric alteration are at their maximum in this country of luxuriant vegetation and excessive rainfall and it is almost impossible to find fresh rock except in streams. Decomposition has penetrated to a remarkable depth below surface, so much so that only a few exploration adits have touched fresh rock. The first stage is the oxidation of the ferrous constituent to ferric oxides and hydrates and the opening of the close and irregular joint-planes, so that a red or brown rock is produced, still hard, but breaking up into splinters. Passing upwards, this is seen to soften and lose coherence until it becomes a compact lithomarge, mottled in shades of brown, red and purple. This varies considerably in thickness, depending on the slope of the ground, being thin or absent on steep hillsides and thick on flat land. It again in its turn is broken up by superficial creep and the disintegrating action of tree roots, graduating, with the addition of a certain amount of organic vegetable matter, into the red clayey soil of the surface. Laterite is found only on low-lying flat land, where the subsoil is water-logged for most of the year, such as bottoms of the broader valleys, where the streams have little erosive power, but are not slow enough to deposit silt. In these situations it is common, but attains only a moderate thickness, three feet being about the maximum.

Age.

The position of the Mergui Series in the geological scale is very doubtful. No fossils have yet been found in it. The Moulmein limestone is proved by its fossils to be Carboniferous, and there is every reason to believe, short of actual junction sections, that this formation overlies the Merguis in the districts to the north and south. This would make the latter pre-Carboniferous at least. Its general facies of great thicknesses of uniformly argillaceous strata, with subordinate limestones and quartzites, is suggestive of the Dharwars or the Transition (Pre-Cambrian) systems of the Himalayas, though the metamorphism of the Mergui Series is of lesser degree.

Lithological similarity or state of metamorphism are of course unreliable criteria in correlation, but we may say with fair probability that the Merguis are Dharwarian (Archaean) or Transition (Pre-Cambrian) in age, with a proviso that, in spite of the absence of fossils, they may conceivably be as late as Older Palaeozoic.

Argillites.

The correct designation for the fine-grained rocks is somewhat difficult to decide upon. Locally, amongst the mining men of the district, they are always spoken of as schists, but although this term is better than shale, it nevertheless conveys an idea of greater metamorphism than has affected the rocks. Here and there, close to granite intrusions, they are converted into phyllites and split along foliation planes with shining micaceous surfaces, but only in rare and extreme cases could they be called mica-schists. They have as a rule no cleavage and so are hardly slates, while they are too hard and too obscurely stratified to be called shales, though shales and mudstones they certainly were originally. The term argillite is probably the most suitable.

For the greater part they are hard and fine-grained rocks of a blue-grey to black colour when fresh, with obscure bedding and with only an incipient cleavage. Near contacts small crystals of pyrites are common in them. Jointing is very close, splintery and irregular and where the rocks are slightly affected by weathering without being decomposed into lithomarge, they break up easily into small angular fragments. In stream-sections, where expanses of fresh rock are seen, stratification can at times be made out by differences of colour and texture, and in some cases true slaty cleavage has been produced.

In the strip of Merguis forming the narrow coastal plain in the south of the district, between Mindat and Pe, metamorphism has gone further than is usual, doubtless owing to the numerous large and small intrusions of granite and pegmatite which invade the rock, and they are largely phyllites and in places even mica-schists, with white pyroxene and garnet produced near the granite contacts.

The most frequent contact effect is the production of a compact and very tough quartzite of a paler colour than the original argillite probably from the fusion and recrystallisation of the silica of the argillite, with also perhaps the addition of some silica derived from the granite during its consolidation. This often extends for yards from the granite and, being a very resistant rock, is a common site for waterfalls on the streams as they descend from the higher lands occupied by granite to the normal softer Merguis below. Sometimes this siliceous rock is banded in layers of slightly varying composition, the more resistant of which stand out in relief on weathering.

Several zones of carbonaceous argillites have been noted, as for instance that which is exposed in cuttings on the main Siam road about 11¼ miles from Tavoy. It carries small crystals of andalusite, sillimanite and pyrite, with finely divided graphite. There are here three parallel bands intercalated in the normal argillites, traceable to the north-west as far as the Hermyingyi road, and a thinner bed, on the strike continuation, near Kadutaung (Doodaung) and Kanbauk. Similar rocks are extensively developed in the upper Zinba valley between the stream and the frontier of Siam. It is noteworthy that these rocks do not acquire on weathering the reddish-brown colour of the decomposed normal argillites but remain black and give rise to a blackish soil.

Greywackes or agglomerates.

Types which can best be described as "greywackes" or fine agglomerates are next in importance to the fine argillites, predominating over them in the country extending from Tavoy town to the Mintha granite intrusion in the south of the district, and lying between the estuary of the Tavoy river and the Paungdaw granite area. They are also exhibited at intervals in the gorge of the Great Tenasserim river where it breaks across the strike of the ranges between Myitta and Sinbyudaing. These appear to be the rocks described by Dr. Oldham as "pseudo-porphyritic grits and conglomerates."

They are dark grey, almost black, when fresh, weathering to an ashy or brown colour, and consist of a confused and structureless jumble of small angular fragments of fine-grained rocks in a fine matrix identical with the material of the argillites.

The fragments are of quartz, slate, fine quartzite, felspar, etc., and are normally in size smaller than a grain of wheat, with an occasional one as large as a hazel nut, and a very few rounded pieces of granite about three inches in diameter were seen. Incidentally the presence of the last mentioned proves the existence of a granite older than the Mergui Series, which has up to the present not been found. In hand specimens and in the field these rocks strongly resemble volcanic tuffs, and as coarse agglomerates of indubitable volcanic origin have been found in the Mergui Archipelago, they must be the finer ejectamenta of paroxysmal eruptions. They are extremely hard and tough, are unaltered except for induration, and show no stratification nor cleavage.

Systems of almost vertical joints, 6 inches to 3 feet apart traverse them fairly regularly, and there are also less definite vertical cross-joints, perpendicular to these, and horizontal joints. Amongst them are broad bands of fine-grained unstratified argillites of the Mergui Series, with an incipient cleavage parallel to the general strike.

Usually these agglomerates or greywackes form wide bars across the streams, with cascades and rapids, and the higher ridges are made up of them, owing to their superior resistance to denudation as compared with the argillites.

Quartzites.

Impure sandstone quartzites are met with, but not commonly, as a sandy modification of the argillites and interbedded with them. A broad zone of purer quartzites crosses the Tavoy river above and below Shintabi and is excellently exposed on the road between Shintabi and Pachaung. They are fine-grained, unstratified rocks with irregular and shattery jointing, showing under the microscope a mosaic of quartz clouded with aluminous material, and are traversed by veinlets of finer quartz. Their clastic origin is obscured by subsequent changes, and, as is usual in fairly pure sandstones, metamorphism has been much more effective than in the associated clay rocks.

Although they do not rise to great heights they form bold and rugged ridges and the picturesque gorge of the Tavoy river between Kyaukshat and Sanchi is cut through them. Above and below the narrows, where the river passes over more easily eroded argillites, the valley opens out to a broad "strath."

Conglomerates.

Apart from the agglomerates, true conglomerates appear to be very rare. A coarse conglomerate, with well rounded pebbles, is recorded from near Pachaung, but neither of the authors has seen it *in situ*.

Limestones.

Thin-bedded and usually impure limestones of blackish or red colour, though sometimes crystalline, have been seen at various localities in river beds, with field relationships to the Merguis leaving little doubt that they form part of them, as for example, between Yapu and Migyaunglaung on the Tavoy river, several points on the Ban and its tributaries and near the Siam frontier.

The outcrops on the Tavoy river, of which there are five, are flat expanses projecting a foot or two above the lowest water-level. The limestone is both massive and in thin shaly beds which dip to south-west and west-south-west at 40°. There are two varieties, one fine-grained, homogeneous and unaltered, though much shattered, the other white and saccharoidal, full of irregular knots and streaks of ferruginous and clayey material. The exposures are completely surrounded by thick recent deposits of river sand and gravel, so that it is impossible to say definitely that they belong to the Merguis, though it is probable. Other occurrences, however, have been stated by Mr. Sethu Rama Rau and Mr. Vinayak Rao to be interbedded with the Merguis.

It is probable that the limestone appears more in streams than on land, because it is easily acted on by the humic acids from the abundant vegetation, and so below a soil covering is rapidly dissolved and removed, while it is comparatively resistant to the mechanical erosion of the river and the feebler solvent effect of the purer river water.

Certain limestone occurrences at a height of 1,500 to 2,000 feet above the Great Tenasserim, and also that uncovered in the Kanbauk alluvial workings and near Pagaye, may belong to the Moulmein limestone, so prominent in the Amherst and Mergui districts to the north and south, but this is doubtful.

Granite and Pegmatite.

Distribution.

The area over which granite appears at the surface is little inferior in extent to that occupied by the Mergui Series, and there is little doubt that the various intrusions, with the exception of the tourmaline pegmatites, are from the same magma, are of the same age and are continuous underground.

All the major granite bodies are markedly elongated parallel to the general strike, *i.e.*, about north-north-west-south-south-east, and have most of their lobes extending in the same direction.

The intrusions fall naturally into six groups :—

(*a*) the Moscos Islands,
(*b*) the Coastal Range,
(*c*) the Frontier Range,
(*d*) the Central intrusion { Sinbo-Sinma, Central Range proper and Paungdaw,
(*e*) the Mintha intrusion,
(*f*) the Amya intrusion.

(*a*) *The Moscos Islands.*—These islands lie parallel to the Tavoy coast, at a distance of fifteen to twenty miles off, from near the entrance to the Heinze Basin to south of Launglon. They have not been visited by a member of the party, but as seen from the steamers in passing, and from Rudmose Brown's[1] account, are largely built up of granite rocks.

(*b*) *The Coastal Range.*—The whole of the outer coast of the district from the northern boundary for 110 miles south to the mouth of the Tavoy river is a narrow belt of granite, interrupted only by the entrance to the Heinze Basin and a few unimportant streams. In the north, near Natkyizin and again at Kanbauk, the intrusion broadens and bifurcates, throwing out a southward and a northward pointing lobe, with narrow fingers of the Mergui sedimentaries running up valleys and partially dividing them from the main mass. The two lobes stretch out towards each other along a line parallel to the long axis of the main intrusion and probably mark a subsidiary axis of granite uprising. It would appear that in the high hills to the north of the district where Tavoy, Amherst and Siam meet, the Coastal and the Frontier intrusions unite.

(*c*) *The Frontier Range.*—This mass forms the high and continuous range of hills dividing Tavoy district from Siam. In the north it is about twelve miles broad within British territory, but narrows gradually as it is followed to the south-east, and also diminishes in elevation. Up the valleys of the Kin chaung and the Zinba chaung, two important tributaries joining the Tavoy river in its upper reaches, Mergui sediments extend a long distance into the heart of the intrusion, in the former case passing as a thin covering sheet over the summit of the range. In several localities near Sinbyudaing also, Merguis rise up the flanks of the granite core and conceal the granite underlying the axis of the range.

(*d*) *The Central intrusion.*—The Central intrusion or, more correctly, group of intrusions, comprises two main areas of exposure, and a large number of other cases where the granite appears through the sedimentaries in outcrops of smaller size. The northern main area, the Sinbo Sinma massif, is connected with the frontier intrusion by a strip of granite which forms the high and rugged watershed between the Heinze and Yebon chaungs and the Kamaungthwe; the boundaries here laid down are only an approximation owing to the great natural difficulties of the country. Two lobes extend south-eastward, the western of which, passing through Talaingya reappears through the Merguis in minor inliers east of Kyaukanya,

[1] Scottish Geographical Magazine, Vol. XXIII, No. 9.

near Kadwe and north of Pagaye. The rich veins of the Rangoon Mining Company's area south of Pagaye are in sedimentaries but indicate the extension of this lobe still farther to the south-east, doubtless a comparatively short distance below surface. The southern area has near its centre at Paungdaw an extensive capping of Mergui rocks rising from the low ground to a height of nearly 4,000 feet and resting on the flat domed top of the granite in the Paungdaw mining area. In a similar fashion to the Talaingya lobe just mentioned, this intrusion shows its subterranean presence in small outcrops of granite through the Merguis to the north-west, near Hermyingyi and Thitkado, between the two lobes of the northern part of the Central granite area, and also to the south-east near Yesin Taung (3,448).

It is worthy of note that the great majority of productive mines in Tavoy are on the Talaingya lobe of the northern portion (Byaukchaung, Bolintaung, Kyaukanya, Kadwe, Yewaing, Pagaye), on the northern end of the southern portion, called the Central Range, (Thitkado, Hermyingyi, Taungpila, Thingandon, Wagon) or around the Paungdaw capping.

(*e*) *The Mintha intrusion.*—This runs parallel with the coast into the Mergui district to the south to beyond Mergui town, and between it and the sea a narrow coastal plain of Mergui sedimentaries intervenes, wherein are numerous smaller bosses of granite and a considerable development of tourmaline-pegmatite, a rock distinct from the granite. To the east is a granite area on the Tavoy-Mergui border, which appears to lie in line with the southward extension of the Central intrusion, but is divided from the Mintha intrusion only by a narrow band of Mergui sedimentaries along the valley of the Pechaung, a thin covering over the underlying granite through which the latter appears in several places.

(*f*) *The Amya intrusion.*—This is a large mass of granite between the Great Tenasserim and the Banrivers. Owing to its remoteness and difficulty of access it has been examined only in hurried traverses by members of the party and its boundaries as shown are only approximations.

Composition.

The granite varies considerably in grain and texture but is of very uniform mineralogical composition all over the district and in fact wherever observed, as far north as the Yamethin district and south to the farthest extremity of Burma.

It contains abundant quartz, both orthoclase and acid plagioclase, the former frequently as large phenocrysts, with sometimes microcline and micropegmatite. The mica is usually biotite, but towards the peripheries of the bosses, biotite becomes scarce or is absent and muscovite occurs instead; the proportion of quartz also increases. Hornblende is rare and always in small quantity.

Accessory minerals are remarkably scarce in the granite itself, apart from veins. Iron pyrites is locally common and is probably an original accessory. In the numerous microscope sections examined sphene was seen only once, and zircon, enclosed in biotite, is as infrequent. Apatite, ilmenite, etc., were not observed. The latter however probably occurs, at least near the granite margin, as it forms the chief constituent of heavy concentrates from stream sands and granite soils near the contacts. In these concentrates, magnetite, garnet, zircon and a greenish-white opaque monazite or other thorium-bearing mineral are found in lesser amount and are probably sparsely distributed in portions of the granite. Cassiterite, wolfram and, rarely, topaz are found in stream gravels and surface soil in or near mineralised areas, where they have originated mainly from quartz veins and greisens; they also may be present as disseminated grains in true granite.

Texture and structure.

Generally speaking the granite may be described as coarse-grained and porphyritic towards the centre of each intrusion, becoming finer and more uniform towards the edges. The transition is very gradual and there is little in the nature of a chilled edge at the actual contact, the rock there being much the same as it is fifty or a hundred feet within the mass. In a few cases pseudo-foliation has been developed near the contact, not a true gneissic structure produced by pressure, but one more analogous to fluxion-structure in a lava, and caused by slight motion in an almost consolidated magma, the finer crystals being drawn out in lines curving round the larger felspars. This is best seen near Myekhanbaw, where the zone of pseudo-foliation is about half a mile wide. Its real thickness measured in a direction normal to the original contact surface of the granite is much less, for the presence of a residual patch of the Merguis on an adjacent hill about 1,000 feet higher, shows that the granite had here a gently inclined upper surface and has not been deeply denuded.

On the western side of the Coastal Range the granite has been deeply trenched by the sea and excellent sections of deep-seated portions of the mass are available. There a banded arrangement of its constituents, similar to the one already described but on a much larger scale, is sometimes seen. Zones of extremely coarse material, poor in biotite, alternating with others of fine-grained, highly biotitic stuff, run in a direction approximately parallel with the general strike, but in detail undulating; there are also irregular veins of both types. This structure is not a gneissic banding due to intense crushing of a solidified rock, but is a fluxional effect of movement in a partly consolidated magma after segregation of the biotite. In both modifications the minerals show no signs of strain nor deformation, and are essentially the same, the only difference being in the proportion of biotite. The basic veins and bands are quite distinct from the greisen found on the granite peripheries; their mica is biotite and not a white mica and they carry no minerals such as wolfram and cassiterite.

The minerals of the granite generally are not dynamically metamorphosed; faults of small throw and slippage planes are common, but their effects reach only a few inches away from them and there is no general crushing nor re-arrangement of minerals.

Veins.

The veins characteristic of the margins of intrusions are described in the section on ore deposits, and repetition is unnecessary. Much less known regarding those peculiar to the deeper seated granite, as this has not been touched by mining operations and it is practically only on the seaward face of the Coastal Range that good sections are available. They comprise—

(*a*) Acid pegmatite veins. These are both coarse and fine in texture; in large veins (they are as much as 15 feet wide) the pegmatite is usually coarse, in small veins fine. They consist of quartz, white or grey felspar (rarely pink) and a little biotite. The last may be absent.

(*b*) Basic pegmatite veins. The same minerals as the granite, but with biotite in excess. Basic segregation patches of this composition occur.

Both "a" and "b" are represented in the light and dark banding described above, and, like it, are differentiation products of the normal granite but injected into fissures instead of remaining where they segregated.

(*c*) Quartz veins, as a rule smaller than the pegmatites and consisting of quartz only. They are probably the silica residuum of the granite after the other minerals had crystallised, and represent a stage in differentiation more advanced than that of the pegmatites.

(*d*) Basic intrusions. These are dykes of basic rock, in origin extraneous to the granite, localised in certain places—for instance Danithagya in the extreme north of the coast, near Kandaung, between Kyaungdaung-maw-gyi and Mawshyi, and near Tavoy Point. They run irregularly, and vary greatly in size, the largest observed, an exceptionally wide one, being 20 feet across. Generally they are fine-grained and their minerals are much altered and difficult to determine. Three slides from Danithagya showed :—

(1) A coarse aggregate of brown and green hornblende or biotite, a little sphene and apatite, in a ground-mass of quartz and acid plagioclase.

(2) Laths and clusters of hornblende in a finely crystalline ground-mass of plagioclase.

(3) Coarse actinolite, yellowish mica and much olivine or white pyroxene, with grains of black iron ores.

(4) Near Bok they appear to be basalts in which the augite has been largely chloritised and the felspars replaced by calcite and scaly decomposition products. Here they traverse the Mergui argillites also, and probably do so elsewhere, but this is the only point where Merguis are exposed on the shore, and on land they probably weather so readily as to be easily missed.

Near Tavoy Point, the southernmost extremity of the Coastal Range, three microscope sections examined gave :—

(5) A fine-grained rock consisting of grains and rods of hornblende, laths of felspar and epidote.

(6) A similar rock with quartz instead of felspar.

(7) Felspar phenocrysts in a ground-mass of plagioclase and indeterminate green rods, probably hornblende.

The above examples serve to show the somewhat heterogeneous composition of the basic dykes; unfortunately it was impossible to devote to them the time necessary for working them out in detail.

(*e*) Tourmaline pegmatite. The tourmaline pegmatites of the district are later than the granite in time of intrusion and appear to be distinct from it so far as is known up to the present. They penetrate the latter and by fractional crystallisation of their minerals give rise to quartz-felspar veins and pure quartz veins. These are indistinguishable from the quartz-felspar pegmatites and quartz veins belonging to the granite, except in so far as they are of later age and cut across them. The relative ages of the basic dykes (*d*) and the tourmaline pegmatites are unknown, but both are subsequent to the granite.

Apophyses.

Besides veins of quartz, pegmatite and greisen, which are treated of in connection with ore-deposits, the granite sends off into the surrounding Mergui sedimentaries a few veins of fine-grained granite and felspar porphyry. They are seldom seen in the field, partly on account of their scarcity and also because they are small and occur in situations where they are liable to be covered by the extensive debris shed from the granite intrusions, but their fragments are sometimesfound in stream gravels.

Only three exposures of porphyry were seen *in situ*, on the Chidawlaw near the Great Tenasserim, near Natkyizin and on the shore at Bok (Kadwe). They consist of phenocrysts of quartz, kaolinised felspar and in some cases biotite, in a cryptocrystalline and granophyric ground-mass.

The Bok porphyry forms massive unjointed dykes on the shore, with smooth surfaces on which the large zoned pink orthoclase phenocrysts show with great distinctness. It bears fine-grained dark basic patches, in which the phenocrysts are much less numerous. These have sharp margins and are surrounded by rims of normal rock, but devoid of phenocrysts. The dyke-margins are sharp and without a fine-grained selvedge. The adjoining Merguis are locally indurated and turned pink at the junction and xenoliths of them are included in the dyke. The orthoclase phenocrysts are very large, zoned in various shades of pink, and include small plates of biotite. The other porphyritic minerals are corroded euhedral crystals of quartz and ragged green biotite intergrown with muscovite, in a granophyric ground-mass of quartz and felspar; black iron-ores are present. In hand specimens the green biotite strongly resembles hornblende, but the latter mineral was not found in any of the sections examined.

A connecting link between the Bok porphyry and the usual granite is seen at the right-angle bend of the Pe chaung, close to the margin of the Mintha intrusion but within it, surrounded by, and passing gradually into, normal granite. It is a coarse porphyritic granite with phenocrysts of orthoclase (of large size and including plates of green biotite), quartz showing corroded crystal outlines, acid plagioclase and large plates of green biotite, in a granitoid ground-mass of quartz and felspar without granophyre. In the ground-mass are small isolated hornblende crystals and clusters which appear to be largely hornblende, but containing also green biotite, epidote, apatite and iron-ores. In hand specimens this rock is very like the Bok porphyry, even to the large pink orthoclase and green hornblende-like biotite phenocrysts, and differs from it only in that hornblende and plagioclase are present in addition, and that the ground-mass is granitoid instead of granophyric.

Tourmaline pegmatite.

Tourmaline pegmatite occurs in isolated veins on the coast near the entrance to the Heinze Basin, at various points near the summit of the Frontier Range and on the Tavoy river below Yapu, but it is only on the coastal plain in the south, between the Mintha intrusion and the sea, that it is common or conspicuous. Here it outcrops as parallel veins of all sizes, usually in groups, running in the direction of the strike, and invading both Merguis and granite. The veins are often clustered closely together, as for instance at Kamyaing, where they are so crowded as to give the appearance of a single mass. The minerals composing it are orthoclase, quartz and tourmaline, the last often in large crystals or in groups of smaller ones. Muscovite is a subordinate constituent; sometimes both muscovite and tourmaline are absent, and the rock then becomes a quartz-orthoclase aggregate, with graphic intergrowth of the two minerals. This type is, in part at least, subsequent to the tourmaline bearing variety, as it is seen to cut the latter, *e.g.*, on the shore, 1 mile north-west of the mouth of the Kyan chaung. Garnet is an infrequent accessory.

No wolfram, cassiterite nor sulphide minerals have been detected in these veins and, as far as Tavoy district is concerned, the tourmaline pegmatites have no connection with the metalliferous veins. The latter have in Tavoy never been found to contain tourmaline and all known occurrences of tourmaline pegmatite are far from wolfram or tin bearing areas, with a single exception—at the remote Zinba mine.

In the Thaton district, however, tourmaline and wolfram occur together in quartz veins and on Belugyun Island, Moulmein, tourmaline and cassiterite. In Mergui district these tourmaline pegmatites are the principal source of the tin ore.

Jointing and weathering.

Generally the granite is very sparingly jointed, with the result that in exposed situations from which decomposed material is rapidly removed, as on the sea-coast and on steep slopes, it forms great curving surfaces of bare rock with only minor inequalities, and none of the fantastic sculpturing which characterises granite weathering in tropic lands of low rainfall and considerable temperature variations.

Occasional departures from the general paucity of joints have been noted, as for example the small intrusion on the shore west of Bok, where a coarse-grained and strongly biotitic granite is traversed by close, irregular joints and numerous slippage planes faulting the veins; Shittaunggyi, the next boss to the south, is an exceptionally pale-coloured quartzose and homogeneous rock, with a system of distinct, persistent, parallel and straight vertical joints, a foot or so apart, trending north-east—south-west and a much less definite set at right angles, also vertical.

Where weathered material is not readily removed, the granite is thoroughly rotten to a depth of in places as much as a hundred feet, becoming soft and reddish-yellow from the decay of the felspars and biotite, with the liberation of iron oxides and hydrous aluminous silicates. The surface soil is much lighter in colour and more sandy than that formed by the Merguis, so that it is not difficult to tell what is the underlying rock.

Between the softened outer layer and the solid rock there is a zone where decomposition is proceeding unevenly in ramifying channels, leaving less altered cores of all shapes and sizes, which ultimately succumb to decomposition. Hill torrents cut rapidly through this down to hard rock and choke their beds with great blocks dissected out from it. Huge boulders of similar origin are met with on the shore, and in deep artificial excavations such as monitor cuts. In many cases it is unnecessary to suppose their transport by cataclysmic floods to explain their presence—they have merely settled down as weathered, interstitial stuff has been removed from between them, helped no doubt by surface creep and by landslips.

On headlands along the coast there is a space of bare curving surfaces of rock, perhaps twenty or thirty feet in vertical height, between high water level of spring tides and the beginning of the forest. There the soil and soft rock are washed away by occasional monsoon gales but marine action is neither continuous enough nor violent enough to produce its characteristic erosion effects. This *glacis* shows a certain amount of platy jointing, thick slabs splitting off parallel to the surface, but to a much less extent than is seen in dry tropic climates with great temperature ranges. In an equable climate like that of Tavoy changes of temperature must have comparatively little effect; probably this is merely a laying bare by the waves of what has taken place below a recently removed soil-cap, and it is the circulating subsoil water charged with carbonic and humic acids and the seasonal changes of waterlogging and drying which produce weathering in zones roughly parallel to the ground surface. Between tide levels on head-lands there exists a jumbled scree of angular and subangular boulders produced by the rougher mechanical action of the waves, while in sheltered places between high and low water is a sloping platform of quaintly scalloped rock, fretted out by the solvent action of the water and by its mechanical action in its gentler phases. In the latter situation an occasional variety of jointing is that in which the granite breaks up into ovoids with concentric exfoliating layers an inch or two thick. This is probably an effect of original cooling taking place from numerous different centres in the magma. The condition is never seen under ordinary subaerial weathering, nor where water action is strong, probably because it is masked by ordinary weathering and denudation and requires special conditions to make it apparent.

Xenoliths.

Inclusions of Mergui rocks of all shapes and sizes are very common in the granite, especially of course near the peripheries of intrusions, but they also occur more sparingly in deep seated portions, such as in the sections exposed on the seaward face of the Coastal Range. They show surprisingly slight alteration, merely a little marginal bleaching and silicification.

Age.

The granite shows few indications of having been subjected to severe earth stresses, such as would be apparent if it had participated, as a solid rock, in the great compressive movements which uplifted the Indo-Malayan mountain chains. It may therefore either have been intruded towards the end of the period of folding, or if intruded earlier, must have remained in a plastic condition throughout the period of maximum activity; in any case it would appear that the granite accompanied the upheaval and was not an older intrusion fortuitously involved as part of a pre-existing rock association. But speculation regarding its exact age is better postponed until the geological survey of Tenasserim has proceeded further than it has at present, and especially until the relationships of the granite and the great Permo-Carboniferous limestone series have been studied in Amherst and Mergui districts.

Tertiary Rocks.

Locality.

Tertiary deposits are found along two belts, the one corresponding with the present-day valleys of the Ban and the Kamaungthwe, and the other to a less extent with that of the Great Tenasserim. They have been areas of depression along parallel axes, separated by a more elevated barrier about 20 miles wide, through which the Tenasserim has cut its way. The Tenasserim area is as yet very imperfectly explored and the following short account refers mainly to the Ban-Kamaungthwe basin.

Extent.

On the map the Tertiaries appear as a number of disconnected patches. It is not known whether these were separate basins in which deposition took place independently, or whether they all formed part of a continuous sheet of sediments which has been broken up by slight post-Tertiary earth-movements and the removal, by the present streams, of material from the upraised portions.

It is perhaps more likely that the latter is the case—that the Tertiaries were accumulated in a broad river-valley or possibly a lake, and are the remains of a more widespreading expanse than their present limits would indicate.

Topography. Looking eastwards from Paungdaw or the hill behind Kyaukmedaung, the wide depression containing the various patches of Tertiaries is a striking scenic feature; although in detail the Ban-Kamaungthwe basin is by no means flat-bottomed, yet, seen from some height above, the minor elevations with which it is diversified appear insignificant in comparison with the high and rugged country on all sides.

The bamboo jungle which covers it contrasts also with the uninterrupted evergreen forest on the encircling mountains, but this difference is due not only to different soil, but to a considerable extent to clearing and burning of the primeval forest by the local Karens, whose *taungya* cultivation methods are more easily pursued on the low rolling country. Fires, too, when started, travel more rapidly on flat land than on steep slopes. Once the big trees are destroyed bamboo at once establishes itself and holds the ground against other vegetation.

Composition. The Tertiary rocks consist mainly of conglomerates and shales, with also sandstones, usually coarse, false-bedded and with pebbly layers. There is a transition upwards from coarse deposits at the base to fine sediments above, so that, owing to the synclinal arrangement of the beds, conglomerates outcrop round the edges of the basins and shales occupy the centres. Near Kyaukton there are also thin impure limestones, and lenticular bands of lignite about 6 inches thick. The pebbles in the conglomerates comprise white (vein) quartz, Mergui quartzite and argillite, and granite, often in a ferruginous matrix. The shales are very finely laminated, and when damp are soft and flexible.

Age. Except for fragments of silicified and carbonised wood, included in shales and conglomeratic sandstones, no organic remains have been seen by members of the party. Fossil wood occurs mainly near Kyaukton on the Ban river, an don the Ayu chaung, a tributary of the Kamaungthwe. In the latter locality it is both silicified and converted into lignite, the largest trunk (lignite) being about 10 feet long and 1 foot in diameter. Pyrites occurs with the lignite. In the absence of fossil evidence the age of the Tertiaries cannot be definitely fixed but from their general facies and the presence of silicified wood they may be tentatively correlated with the Irrawadi stage of Burma of the Siwaliks of India.

Folding.

Towards the margins of the basins synclinal dips of 20°—40° predominate, with an exceptional case as high as 75°, but they flatten out to low angles or to near horizontality towards the centre, though even in flatly lying beds minor corrugations are frequent and everywhere the Tertiaries show irregular disturbance. Minor faults are also often seen.

Recent and sub-recent Formations.

Age.

These deposits are of two ages, and where both are seen in one section they are separated by a slight unconformity. The period of the older division is uncertain, for they may be uppermost Tertiary, but in the Great Tenasserim valley in Mergui similar beds lie unconformably on the Tertiary conglomerates above the horizon of the Theindaw-Kawmapyin coal. The newer beds are identical with, and stratigraphically continuous with, the materials now being laid down by the streams of the present day.

Older alluvium.

In the open upper valley of the Tavoy River, above Kaleinaung, the river is now cutting down through slightly consolidated horizontal sands and coarse conglomerates, forming cliffs about 20 feet in height, conglomerates at the base and sands above. At the head of the lower portion of the valley, near Doodaung (Kadutaung), similar conglomerates outcrop as bars across the stream, and elsewhere are probably widely spread but concealed by later accumulations. It is possible that the coarse boulder conglomerates upon which Tavoy civil station is built are of the same period, though they may equally well be of earlier (Tertiary) age; they carry both cassiterite and gold and present several difficult problems, such as the transport of such large fragments to the centre of a flat and open valley so far from hills and swift-flowing streams. The cassiterite and topaz bearing gravels, with a white clay matrix, which are profitably dredged for tin on the Hindu chaung, a tributary of the Tenasserim, are in all probability of the same age, whatever that age may be. An elephant tooth dredged from the tin-bearing gravels is closely allied to those of the modern Siamese elephant.

Exposed on the banks of the Tavoy River between tide limits near Tavoy town, are gently inclined clays overlaid by recent alluvium now in progress of deposition. Certain fossil crabs reserved as curiosities in local "pongyichaungs" (monasteries) are believed to come from these, and belong to species now living. If really from these beds, their age would be established as sub-recent.

Laterite.

Laterite, which has been referred to as a decomposition product of the Mergui rocks (p. 14) is probably of both recent and sub-recent age. It is doubtless in progress of formation at the present day, while the layers of it already in existence and cut through by the streams are of a slightly earlier date.

Newer alluvium.

"Eluvial" deposits on the hillsides, derived from the underlying rocks by weathering *in situ* or transported a little distance downhill by surface creep, have been described (pp. 14, 26). Broadly speaking they consist of a dark red clayey soil on the Mergui Series of rocks and a light red or yellow soil, more friable and much intermixed with angular quartz fragments, on the granite. Near the surface they are full of vegetable matter and pass downwards into variegated lithomarges and partially decomposed rock.

In the upper, torrential portions of stream courses, erosion predominates and deposition is merely local and temporary, and the stream passes through a jumble of angular blocks of the prevailing rock, with pebble-banks in pools and eddies. In a few exceptional places, where a temporary diminution of gradient occurs, a bench of coarse detritus may form in the steep portion of a valley, as for example at Hermyingyi, where the monitor workings are in such a bench, accumulated in a cup-shaped depression, and cut through by subsequent deepening of the channel of the present stream. These possibly owe their preservation to a landslide from the hill above.

Lower down the valleys, where deposition is more in balance with erosion, beds of gravel and sand tend to round off the inequalities of the valley floor. Through these the stream meanders, cutting them away in some places and simultaneously depositing at others. Flood-waters overtop the banks and spread fine sand and mud on any flat land on either side.

Transport of gravel ceases shortly below the highest point to which neap tides reach, but the scour of the ebb carries sand much further down the river.

The lowest sections of the valleys, where they join the estuarine flats of the Tavoy River, are level rice-plains traversed by ramifying tidal creeks. Here a fine silt is the only deposit. The land is but a foot or two above the high-water level of spring tides, and when high tides coincide with heavy rain, the mud-laden flood-waters are ponded up, overtop the banks and spread far and wide over the surrounding country. This happens frequently during the monsoon, and the flats are in fact water-covered for five or six months of the year. Deposition of the silt carried down from the hills is promoted by the mixing of salt water with the muddy river water, and it is retained by the dense growth of *dani* (Nipa fructans) and mangrove along the creeks and by the growing rice on the flats.

On the coast sand is almost the only sediment. Granite is the only rock which outcrops on the coast, and as it breaks up into its component mineral fragments, there is rarely any gravel or material intermediate in size between small boulders and sand. The latter forms shelving crescentic beaches between promontories and consists of shell-fragments, quartz and felspar. The finer sand, including most of the mica and decomposed felspar of the granite, and organic material, accumulates as a much flatter shelf which runs out from the toe of the steep beach of coarse sand and is uncovered at half tide. In the lagoons and mangrove swamps behind the beaches are alternating deposits of fine mud (kaolinitic and organic material) and coarse angular quartz-felspar sand, the latter washed directly from the granite.

Physical Geography.

Mountain masses.

The outline of the district and the main features of its topography are determined by the granite bosses, which all give rise to high ranges and rugged mountain masses. They are naturally classed in six groups (p. 184), each granite area being synonymous with an elevated tract.

As to the exterior outline of the district, on the west the coast-line is formed by the Coastal Range as far south as the mouth of the Tavoy River; southward from that point the Coastal Range disappears beneath the sea for a space (to reappear as Tavoy and King Islands) and the coast-line is shifted eastwards to the next line of intrusions, a series of small bosses which flank the Mintha mass.

Eastwards, the political boundary and actual watershed between British territory and Siam is the Frontier Range, which extends at a height of from 2,000 to 4,000 feet from the Amherst District past Tavoy and Mergui through the Isthmus of Kra into the Malay Peninsula. In the north the Coastal Range and the Frontier Range widen and join together in a transverse-running mountain mass, where the Tavoy and Amherst Districts and Siam meet. This is crossed by the Moulmein-Tavoy telegraph line over a pass about 300 feet high, used only by pedestrians, cattle and elephants. From the headwaters of the Tavoy River a thin sheet of Mergui sedimentaries extends to the summit, covering the granite, but it is essentially a granite ridge.

In the south the district boundary runs up a transverse ridge to the summit of Myinmoletkat (6,800 feet) and down to the Tenasserim River. This portion of country is little known geologically, but the Myinmoletkat group of peaks is in all probability granite. At all events here also the Tavoy District is cut off from outside communications by mountains, except for a narrow coastal strip three miles wide. The natural obstacles which isolate the district and form its boundaries on every side have doubtless had much to do with developing those special peculiarities which are said to distinguish the Tavoyan from other Burmans; they actually mark at least the limits of the Tavoyan dialect.

Not only is the district surrounded by granite ranges but all the higher land within it is occupied by granite; excluding the south it is almost correct to say that all land over about 3,000 feet in height is granite, with occasional sedimentary cappings; in the south, however, there are tracts of considerable elevation covered by sedimentaries of the Mergui Series, with doubtless granite underlying a little depth beneath, and indeed sometimes exposed in deep valleys cut down through the sedimentary covering.

It may be assumed that the granite intrusions have a more or less dome or wedge shaped upper surface, elongated in the direction of the trend of the mountain ranges or axes along which folding has taken place. According to the extent to which denudation has proceeded we may have the granite quite concealed by the overlying sedimentaries, or seen only where the dome has been deeply trenched, we may have the granite extensively exposed and dissected by mountain torrents, but with here and there patches of sedimentaries preserved and giving an idea of the height to which its upper limit rose, or it may be that all the overlying rocks and a great thickness of the granite itself have been removed.

Drainage system.

It is found that all the main valleys are occupied by rocks of the Mergui Series, often in quite narrow strips with high granite land on either side, and that the numerous granite bosses are seldom cut across by important streams. This preference for the sedimentaries is so marked that the usual explanation seems inadequate, *i.e.*, that the granite is more resistant to denudation than the Merguis. The possibility is suggested that the main drainage lines are still along tectonic hollows which originally lay between bulges in the upper strata caused by the intrusion of masses of granite, or, if not *caused* by its intrusion, were areas of low pressure, upraised during the folding movements, into which the granite found its way.

The drainage systems are three:—the coast, the Tavoy River valley and the Great Tenasserim valley.

The steep seaward slopes of the Coastal Range are drained by numerous small streams of trifling length and discharge, only at the Zadi chaung and the Heinze Basin, where the range is breached, does the drainage of a considerable area find its way to the sea.

The Heinze Basin is a narrow-mouthed bay, in shape resembling the Bay of San Francisco. Its greatest length from north to south is 18 miles and its greatest breadth about 6. Much of it is mangrove swamp, with ramifying tidal channels of unexpected depth. In the centre is a low island of Mergui rocks. The greatest depth of the Basin is 13 fathoms, just inside the entrance, and channels of 5 fathoms extend for some miles parallel to the longer axis of the bay; a depth of 5 fathoms is not met with in the adjacent sea for 6 miles outside the entrance, and the Basin is thus an area considerably below the level of the adjacent sea-bottom. To the north and south-east it is prolonged by valleys carrying fair-sized streams and numerous shorter ones come in from all sides. The disturbance of the eluvials in the adjoining mine of Kanbauk and the great depth to which they go below the present sea-level (pp. 101-2), are facts confirming the hypothesis that this neighbourhood has been comparatively recently depressed.

The Tavoy River rises in the extreme north, where the Coastal and the Frontier Ranges join, and flowing slightly east of south for some 90 miles, drains about half the district. On its western bank it receives no streams of any importance from the Coastal Range; all its main tributaries come from the east, from the Frontier Range and the western slopes of the high lands occupied by the

Central intrusion. It is tidal to 60 miles from its mouth and its lower valley comprises most of the inhabited and cultivated land of the district.

To the east of the Central intrusion is the valley of the Great Tenasserim, which is formed by the confluence of the Ban and the Kamaungthwe. The Ban rises in the mountain mass of Myinmoletkat (6,800 feet) and flows northward between the Amya intrusion and the southern portion of the Central intrusion.

The Kamaungthwe drains the high country between the Sinbo-Sinma mass and the Frontier Range, flowing south to meet the Ban at Myitta. The united stream finds its way eastwards round the north end of the Amya intrusion and then south-east and south between it and the Frontier Range. The Ban-Kamaungthwe and the Tenasserim valleys date from Tertiary times, as the fluviatile deposits occurring in them show.

Coast.

The coast is fringed entirely by granite and is a series of headlands alternating with bays, the latter now largely filled up with accumulations of sand and mud. Cliffs are absent. On headlands dense forest comes to 20 or 30 feet above high-water level, then there is a bare slope of curving surfaces of granite to about half-tide level and below that a pile of great boulders (p. 193).

Every bay has a crescentic sandspit with a lagoon behind it; the entrance to the lagoon is almost always at the south end of the spit. One description serves for all. The sandspit is composed of coarse sand, partly wave-borne and partly wind-blown, and it extends with rather a steep slope from half-tide level to the highest point to which waves can reach. At the toe of this slope is a flat of mud or very fine sand with an almost imperceptible fall out to sea (p. 198). The sandspit becomes bound by wiry grass and a purple creeping convolvulus and supports groves of casuarina trees and salt-loving shrubs.

The lagoon behind may be open water, mangrove swamp, or a salt marsh flooded only at spring tides, according as to how far silting up has proceeded. Twice a day the tide carries in and out its burden of sand and mud, leaving a certain amount entangled amongst the mangroves and other vegetation, and every rainstorm brings down rock and vegetable debris from the hills behind. Myriads of mol usca, hermit-crabs and other burrowing crustacea live in the lagoons, bringing up mud from below and adding their shells on death. Accumulation thus proceeds very rapidly and every stage may be seen, from a sandspit with open water behind, to a flat just about high-water level, which by drainage and embanking may be made suitable for paddy cultivation.

The position of the entrance channel near the south in every case is perhaps to be explained by the angle at which the monsoon current meets the coast. The bays face westwards and the monsoon waves come from the south or south-west, so that the southern shore of each bay is sheltered, while the northern horn is exposed and sand is piled up on it. Once a sandbank is established, the tidal drift, which sets parallel to the coast, tends to lengthen it, by distributing debris to north and south; the tidal current also carries in sand from the exposed headlands, where it is produced by the disintegration of the granite, to sheltered bays where it collects or drifts into the lagoons.

PART II.

CHAPTER III.

TUNGSTEN.

Properties.

Tungsten is a metallic element which gives rise to acid-forming oxides; it forms salts with several metals such as iron, manganese, calcium and lead. It is never found native but must be reduced from its ores to the metallic condition by chemical means. The mineral wolfram must have been noticed in the older tin mines of the world centuries ago, but it was not until the year 1781 that the Swedish chemist Scheele discovered a new acid in the mineral "Scheelite." To this the name tungstic acid was given later. It is derived from two Swedish words, "tung"=heavy and "sten" =stone. In 1783 the brothers D'Elhuyart proved that wolfram also contained tungsten, established the relationship between scheelite and wolfram and were the first to prepare the metal.

Its atomic weight is 184 and it is harder than glass. The specific gravity of the pure wrought metal is 18·81. Its melting point is said to be 3,267° C. (Longmuir and Mackay). Its tensile strength greatly increases on working and it can be drawn into very fine wire. Metallic tungsten is comparatively inert, it is almost unaffected by air or water at ordinary temperatures but it oxidises when heated in air. It is only acted upon slowly by the common acids but is rapidly attacked by fused oxidising salts, such as alkaline nitrates and peroxides. It alloys with many of the common metals and with cobalt and chromium forms one of the group of alloys known as stellite.

When treated with hydrochloric acid the tungsten minerals dissolve leaving the yellow trioxide, WO_3. On adding metallic zinc or tin to the acid solution, this trioxide is reduced and the solution turns blue owing to the formation of a lower oxide. On further reduction purple and brown compounds are produced which contain less oxygen.

Uses.

The chief use of tungsten is as an ingredient in the manufacture of tool steels, especially those varieties known as "high-speed" steels. The metals used to impart tensile strength, toughness, hardness and resistance to shock, to iron containing varying quantities of carbon, include nickel, chromium, manganese, tungsten, molybdenum, cobalt, vanadium, uranium, and titanium. The famous Damascus steel of the middle ages has been proved to contain both tungsten and chromium, though their addition was probably unintentional. The first modern use of tungsten in steel was made by Mushet in 1857, and his material contained from 6 per cent. to 8 per cent. of tungsten, 2 per cent. of manganese and a high percentage of carbon. It possessed the property of hardening without quenching in water and was capable of working at speeds and under conditions unequalled by the best carbon steel tempered with the utmost skill. The credit for the modern development, by heat treatment, of self-hardening steels, is said to be due to Messrs. Taylor and White, who introduced their products to the Paris exhibition in 1900.

The essential difference between high-speed steel, and ordinary carbon or cutting steel, is that the former is able to withstand very much higher temperatures when cutting. If the temperature of friction due to cutting reaches about 500°F., carbon steel tools begin to lose their hardness, and, as a consequence, the life of the tool on heavy cutting work is a very short one. With high-speed tools, the temperature can rise to, say, 1,150°F., or even higher, without the tool losing its hardness or cutting power, and such tools can consequently cut metals at feeds and speeds greatly exceeding anything obtainable with tools of ordinary carbon steel. This is especially important for exact work on a big scale, such for instance as boring a heavy gun or turning a long length of shafting, when it is necessary for the sake of accuracy to make a continuous finishing cut from end to end, without altering the tool and without running the risk of incurring sufficient wear on its edge to impair the exact diameter of the work.

Another great advantage of the modern high-speed tool lies in the comparative simplicity of its heat treatment, rendering the forging and hardening operations in the smithy considerably easier than when working with carbon tool steels, which must be heated to the correct "critical point" to obtain the best results. In heavy cutting work the nose or point of a high speed steel tool may become red hot, and yet such a tool will continue to cut for long periods in that state without breaking down.

Tungsten steels then, prepared with suitable admixtures of other metals, such as chromium and vanadium, are not only exceedingly hard, but, in addition, maintain their hardness at high temperatures. Speaking roughly, it may be said that the chromium in these steels provides the hardness, while tungsten produces the self-hardening properties by raising the temperature at which tempering begins.

A finished high speed steel as employed for making the best tools contains 18 per cent. to 20 per cent. of tungsten. Its qualities may be impaired or even destroyed by quite small quantities of certain other elements such as tin, sulphur, phosphorus, arsenic, manganese or copper. The necessity for preparing the ores used in the metallurgy of tungsten as clean as possible need not be emphasized, for errors are very costly and wasteful and deleterious impurities are not, as a rule, detected until an advanced stage in the manufacture or even after the tool has been put to work.

A recent American writer has drawn attention to the fact that, "whereas in the wars of the past brass and lead, were, next to steel, the most important 'martial metals,' to-day tungsten alloyed as high speed steel is the dominating factor. To deprive a nation of tungsten is to cripple its military power, and its industrial power in times of peace."

The introduction of high speed steel, according to the Advisory Council of Science and Industry of Australia, marks one of the greatest advances ever made in the metallurgy of iron and steel, and has completely revolutionized the machine shop business of the whole civilized world, affording largely increased outputs with commensurate lower costs. Another author states that under favourable conditions one man and one lathe can do as much work with high speed tungsten steels as five men and five lathes could formerly do with simple carbon steels.

Most of this account of the uses of tungsten has been prepared from the papers enumerated below and the reader who is desirous of following the subject further is referred to them.

(1) "The Manufacture and Uses of Ferro-alloys and Alloy Steels." *Advisory Council of Science and Industry, Commonwealth of Australia.* Bull. No. 9, Melbourne 1918.

(2) " Tungsten Minerals and Deposits." Frank L. Hess, *United States Geol. Surv.*, Bull. 652.
(3) " The Modern Development of High-Speed Tool Steel." Sir W. G. Armstrong Whitworth & Co. Ltd., 1919.
(4) " Tungsten, a lecture delivered before the Science Guild Exhibition, 30th August 1918," by Julius L. F. Vogel.

Manufacture.

High speed steel is made either in crucible furnaces or in the electric furnace. In the former practice the correct percentages of iron and of the alloys are melted together, considerable skill and experience being necessary both in this and in the forging and rolling operations on the finished ingot afterwards. In the latter the process may consist of melting the pure materials of the best quality, and thus using the furnace as a crucible, or, alternatively, melting from ordinary materials and taking advantage of the essential features of the furnace for refining and removing impurities.

Tungsten may be added to steel either in the form of the metallic powder or as an alloy with iron. Before the war abortive attempts had been made to establish the manufacture of tungsten in England, but competition with the powerful German makers was well nigh impossible, and steel makers generally obtained their supplies from that source, the turnover in the business at that time having reached a sum of more than £300,000 per annum. In August 1914 there was only a few months stock of metallic tungsten in the United Kingdom. Arrangements were made between the Government and the Committee of high speed steel makers and by July 1915, the High Speed Steel Alloys Co., Ltd., commenced delivering tungsten. About the same time a number of other firms also embarked on the manufacture of the metal and of the alloy ferro-tungsten. At the time of writing four firms in England produce metallic tungsten, two factories make ferro-tungsten by heating pure wolfram and carbon in the electric furnace, and three factories manufacture the same alloy by an alumino-thermic process.

In the chemical method the finely ground pure ore is mixed with soda and heated in special furnaces to a bright red heat. The product is drawn out in a molten state, allowed to cool and crushed. It is then boiled with water, which dissolves the soluble tungstate of soda while the oxides of iron, manganese, lime, etc., remain behind and are separated by filtration. The sodium tungstate is next treated with hydrochloric acid, when the insoluble tungstic acid is precipitated. This is filtered from the solution, dried and reduced to metal with carbon in graphite crucibles fired in gas-heated furnaces. The powder so produced contains about 98·5 per cent. of metallic tungsten.

Ferro-tungsten is made by the reduction of wolfram or scheelite, preferably the former, by means of carbon in the electric furnace. The ores used must be practically free from sulphur and phosphorus. The alloy produced requires refining, which is carried out in an arc furnace by melting under a slag of ferric oxide, lime and fluor spar. The ferric oxide reduces the carbon and silicon, the latter combining with the lime to form silicate of lime. The fluor spar is added as a flux.

Other uses.

Tungsten is used for making permanent magnets, for the valves of some makes of internal combustion engines, as contacts for spark plugs, tremblers and voltage regulators, etc., for targets and cathodes of Roentgen ray tubes, as a constituent of stellite and other alloys, as an alloy with aluminum in the mixture known as "partinium," as an alloy in dental and surgical instruments, in gramophone needles, and as a catalyser for the production of ammonia from atmospheric nitrogen and hydrogen. Tungstic acid and sodium tungstate are used in the production of colour resists for aniline black. The sodium salts are also said to be used to saturate materials, with the effect that if they catch fire they smoulder and do not blaze. The meta-tungstate is employed for the manufacture of tungsten-bronze. Tungstic acid is used in the preparation of magenta-bronze and saffron-bronze. The high melting point of tungsten combined with the toughness and fineness of the wire into which it may be drawn and its behaviour under the action of an electric current, make it the best material known for incandescent electric lamp filaments and millions of these are now made annually Unfortunately a comparatively minute amount of wolfram is consumed in this manner.

TUNGSTEN MINERALS IN GENERAL.

Tungsten has never been found as a native metal but always in combination with other elements. There are comparatively few of these compounds. The better known tungsten minerals are given in the following list:—

Ferberite, iron tungstate, $FeWO_4$.

Hübnerite, manganese tungstate, $MnWO_4$.
Wolframite, iron-manganese tungstate, $(FeMn)WO_4$.
Scheelite, calcium tungstate, $CaWO_4$.
Stolzite, lead tungstate, $PbWO_4$.
Raspite, lead tungstate, $PbWO_4$.
Cuprotungstite, hydrous copper tungstate, $CuWO_4,2H_2O$.
Tungstite, hydrous tungsten trioxide, WO_3,H_2O.
Ferritungstite, hydrous iron-tungsten oxide, $Fe_2O_3,WO_3,6H_2O$.

The iron and manganese tungstates form a good example of an isomorphous series. The two theoretical end products are ferberite, the tungstate of iron, and hübnerite, the tungstate of manganese. Mineralogists have attempted to show that the various mixtures of these two tungstates found in nature, bear a definite ratio as regards the proportion of the molecules of the two compounds present, but it has been demonstrated that the two may mix in any proportion and that the series is composed of an infinite number of members. It has been suggested therefore that arbitrary divisions shall be made as follows :—

Ferberite should be considered an iron tungstate, $(FeWO_4)$, contaminated by not more than 20 per cent. $Mn\ WO_4$, a proportion equivalent to 4·69 per cent. MnO, or 3·63 per cent. Mn, in the pure tungsten mineral.

Hübnerite should be considered a manganese tungstate, $(Mn\ WO_4)$, contaminated by not more than 20 per cent. $Fe\ WO_4$, a proportion equivalent to 4·74 per cent. FeO, or 3·69 per cent. Fe. Wolframite should cover the ground between the limits indicated above. That is, it should be considered a mixture of iron and manganese tungstates containing not less than 20 per cent. and not more than 80 per cent. of either.[1]

As the exact chemical determinations entailed by this classification have not been made in the case of the Tavoy mineral, the general term wolfram is used to cover all varieties in these pages. Certain Tavoy specimens which appeared to possess the characteristics of hübnerite were analysed, but were found to come within the wolframite limits of the above classification. It will probably be found that this holds good for most of the material from the district.

[1] Hess, United States Geological Survey. Bull., 652.

Modes of occurrence in Tavoy.

Wolfram and cassiterite occur in Tavoy as segregation deposits in muscovite granite; in pegmatite veins with quartz, felspar, mica, fluorite, scheelite, molybdenite and sulphides of iron, copper and lead, the last named being rare; in quartz veins with mica (practically always), fluorite (often), molybdenite (sometimes), pyrite (practically always), chalcopyrite (sometimes), pyrrhotite (in some cases), galena (rare), arsenopyrite (rare), zinc blende (rare), bismuth (rare), bismuthinite (rare) and topaz (in one case only); in greisens with mica and pyrite. Wolfram and cassiterite occur in residual, detrital, and talus deposits. Cassiterite occurs in alluvial and placer deposits.

It is stated in text books that the Tavoyan field is characterised by the universal presence of tourmaline and that columbite is a common mineral in it. These statements are not correct. Tourmaline has never been found with either wolfram or cassiterite up to the present time in Tavoy. Tourmaline pegmatites occur but they do not contain metallic minerals in Tavoy and do not belong to the same period as the mineral-bearing veins. One small specimen of columbite was discovered in a pegmatite in the north of the district in 1918. This rock contained neither wolfram nor cassiterite and the mineral is entirely absent from the vein association as far as we know.

In the following pages the more important vein minerals are described.

MINERALOGY OF TAVOY.

Important Vein Minerals.

Wolfram.

Wolfram is a black mineral rarely occurring with a good outward crystal form. Beautiful crystals have however been obtained from a drusy lode at Kanbauk.

It is not uncommon to find parts of both large and small imperfectly formed crystals embedded in quartz, though it is practically impossible to separate them from the matrix. In any large collection of roughly broken ore, pieces of wolfram showing one or more crystal faces can be picked out, and imperfect crystals with rounded edges are sometimes seen in concentrates from detrital deposits. But by far the largest quantity of wolfram occurs as irregular aggregates of the mineral showing no outward crystal forms, and varying in size from small pieces a few inches in diameter to great masses of several hundredweights. Intergrowths of quartz are always found in the larger pieces. Characteristic of the crystals are the corrugations and striations of the prismatic faces, parallel to their length.

The mineral also occurs in massive, lamellar, divergent or radiated, columnar and acicular forms. It is better to mention examples of each of these than to attempt a general description of them all.

(1) Massive wolfram. In its typical condition this is found in small veinlets of almost solid mineral penetrating sedimentary rocks or in the rather larger ones cutting through granite and greisen. The former type is well illustrated by specimens from Mr. T. Fowle's Yanmazu mine where stringers of nearly solid wolfram about ¾ of an inch in thickness occur. On fractured faces the coarsely crystalline structure is evident. Mica and a little quartz are the only other minerals.

The second case is illustrated by specimens from the Taungshuntaung mine of Messrs Ady, Giles and Hossein Amadanee. Here veinlets in greisen are 2½ inches thick, consisting of wolfram on the walls and cassiterite in the centre with irregular veinlets and small pieces of quartz. Polished surfaces show the coarsely crystalline structure of the mass and recall that of cooled molten metals. Weathered surfaces exhibit an irregular appearance due to the unequal resistance of individual crystals.

Weathered surfaces of a specimen of massive wolfram from the Ye subdivision of Amherst district have a roughened, rounded appearance similar to that displayed by certain iron and manganese ores under the same conditions.

(2) Lamellar forms. Thin lamellæ of wolfram are found in argillites near the veins in the Yewaing section of Crisp and Company's Pagaye property. Their surfaces often show iridescent colouring. This is also seen occasionally on the more massive forms, which are termed "rainbow wolfram" by miners.

(3) Divergent and radiated forms. These are the commonest types throughout the field and may consist of coarse individual growths up to an inch in thickness, down to quite small and closely packed fibres which recall the structure assumed by schorl. Especially characteristic are the various angles from which each group of individual fibres commences and the curving of the fibres which

is often shown. The wolfram from M. Sooratee's Winwa mine is the most fibrous that we are acquainted with.

(4) Columnar forms are merely a variation of the preceding, and seem to be a coarser development of the polysynthetic twinning which gives rise to the fibrous variety. Good examples come from Hermyingyi.

(5) We give the term "acicular" to those specimens of ore in which long and very thin individual wolfram crystals are scattered indiscriminately through the quartz matrix. The best examples come from Mr. T. Fowle's Yanmazu North mine.

For the benefit of prospectors it may be stated that the specific gravity of wolfram varies between that of hübnerite and that of ferberite, from 7·2 to 7·5, that its hardness is about 5 and that its streak is dark reddish-brown to dark brown. Though nearly always black in colour, Tavoy wolfram may assume a brownish appearance when stained by iron minerals, and, very rarely, dark grey varieties are met with. Especially characteristic is the very perfect cleavage of the mineral parallel to the long axis of the crystal. Rounded pieces of wolfram, which may be disguised by coatings of oxides of iron and manganese, always show this when broken open. There are other cleavages in the mineral but they are of no determinative value in the field. Finally, wolfram has a submetallic lustre, is opaque and brittle.

In thin sections under the microscope patches of a deep red colour are sometimes seen, set in the opaque ground-mass. Ferberite in extremely thin sections, probably not more than 0·0001 or 0·0002 inch thick, is said to be red, while hübnerite is typically reddish-brown, or even dark green in section.[1] How far the colour seen in some sections of Tavoy wolfram is due to original variations of composition in the same parts of the same section or how far it is due to changes brought about by leaching of the iron or manganese, or both, is not known.

Scheelite.

Calcium tungstate, $CaWO_4$. The presence of this mineral in Tavoy concentrates was first brought to notice in 1916 by a magnetic separating firm in London, who detected it in the tin residues from Pagaye mine. It was not discovered *in situ* for some time afterwards, when the first specimens were found by Mr. A. H. Morgan, General Manager

[1] Hess, *loc. cit.*, pp. 22 and 25.

of the mine, to whom we are indebted for specimens. These are two broken crystals of a beautiful translucent pale amethystine blue colour exhibiting the pyramidal faces. Both crystals are about 1 inch in length and it is curious to observe that certain faces are covered with a secondary crust of the same mineral, $\frac{1}{8}$ inch in thickness and of a lighter tint.

Since then other specimens have been found *in situ*, and small amounts of scheelite can be picked out of the coarse jig concentrates from time to time.

The first consist of irregular pieces of a creamy yellow variety occurring in a pegmatite with wolfram, brown cassiterite, pyrite and pale green and colourless fluorite; small flakes of molybdenite are intergrown with the green mica of the walls. The colourless fluorite contains hair-like inclusions of a black mineral which recalls some forms of bismuthinite and has not been determined.

The second, *i.e.*, the jig product, is either white, grey, straw-yellow to pale brown or pale translucent blue. Fragments of crystals and pieces intergrown with wolfram are common.

Scheelite also occurs in a wolfram-bearing lode on Mr. T. Fowle's Yanmazu North mine. Here it is usually of an opaque white colour stained and discoloured brown by iron compounds. Some fractured surfaces when examined at the proper angle show the cleavage planes. Polished specimens exhibit creamy yellow scheelite and felted masses of fine acicular wolfram. The latter is in no way intergrown with the scheelite, which appears to have been deposited later than the wolfram, and indeed than part of the quartz, as hexagonal-outlined sections of the latter can be found surrounded by scheelite, which also fills in the angular spaces between the long quartz crystals.

Opaque white scheelite is also known intergrown with massive wolfram, where it occupies spaces between the individual crystals. Specimens of this kind from the Zinba mine have been presented by Dr. J. Morrow Campbell. They also contain interspersed pyrite and quartz, while a scaly form of molybdenite is coated on the outside, nearest the wall of the vein.

Thin tablets of a pale greenish-yellow scheelite occur in a fine greisen which also contains wolfram, molybdenite, chalcopyrite, pyrite and bismuthinite from the same locality.

The larger pieces of scheelite, where they outcrop in veins, can readily be mistaken for quartz, and it is almost certain that it is distributed in minute quantities over a wider area of the Tavoy field than is generally supposed.[1] It readily alters into tungstite, which either forms on the surface or develops along minute cracks. As the above descriptions show it may either separate simultaneously with the quartz in the parent veins or later than the quartz matrix. It may also form as a secondary product due to the decomposition of wolfram in the presence of solutions carrying calcium salts.

When pure scheelite contains 80·6 per cent. of tungsten trioxide and 19·4 per cent. of lime. It has a specific gravity of about 6 and a hardness of 4·5-5, that is to say it is easily scratched by a knife. It has a vitreous lustre and is either opaque or translucent. It cleaves fairly well in four directions, possesses an uneven fracture and is brittle.

It is not an easy mineral to identify in the field without practice. Some of its similarities have already been mentioned; the mineral with which it is more likely to be confused than others is barite, the sulphate of barium, which has been found in Tavoy. Hess has summarised tests as follows:—

" Barite has cleavages in three directions, so perfect that if it is coarsely crystallized it may be cleft into blocks that show rhombic faces and that may almost immediately be distinguished from scheelite. Barite is not so lustrous as scheelite, and it has a lower specific gravity (4·3 to 4·6). It is much softer than scheelite (its hardness is 3), so that one means of identification is to scrape a smooth surface of it with the back of a knife blade. A powder is in this way much more easily made from barite than from scheelite. Barite commonly crystallizes in thin plates, a habit totally unlike that of scheelite. Some barite, however, is fine-grained and shows no cleavage and its surface is so rough that the scraping test is inconclusive. Under such circumstances the test for tungsten should be made and is conclusive " (Hess, pp. 30 and 31).

Scheelite is of no economic importance as an ore mineral in Tavoy owing to its occurrence in such insignificant quantities. It is in fact rather more troublesome than otherwise as in small amounts it gets into the separated tin ores and forms an undesirable impurity.

[1] A leaflet drawn up by the survey party and distributed through the field drawing attention to these facts resulted in the discovery of scheelite at several new localities.

Tungstite.

The hydrous tungsten oxide, or tungsten ochre, is the yellow mineral left by the decomposition of wolfram or scheelite. Most Tavoy veins contain sulphides; these readily decompose and yield acid solutions by which the wolfram is attacked. The final residue is the yellow tungstite and it is found in all veins carrying wolfram in those parts through which ground waters can circulate. The actual yellow tint of the mineral may vary a great deal from pale to orange. According to Morrow Campbell "Its structure is usually porous as if it is incapable of occupying the whole space of the original wolfram. The reticulation it usually displays in section under the microscope or even on polished surfaces shows very plainly how decomposition started from cracks and cleavage planes gradually extending inward. Examples of the process in progress are common but large masses of tungstite are rare on account of the facility with which it is dissolved by alkaline solutions when it passes away as soluble alkaline tungstate and is usually lost." Morrow Campbell goes on to state that "if such a solution however encounters acid water it is at once decomposed and hydrated tungstic oxide or tungstic acid, the mineral known as meymacite is found.[1] But T. L. Walker has shown that water is a normal constituent of tungstite and that Carnot's "meymacite" is not a new mineral[2] so that Morrow Campbell's meymacite must be regarded as tungstite. As he says "It is quite commonly found in cavities and exists in two forms:—(1) as sulphur yellow, moss-like tufts of radiating crystals, and, (2), as small but often well-developed amber coloured crystals commonly single, sometimes in groups."

Owing to its friability and the ease with which it decomposes tungstite is of no economic importance in Tavoy. It is universally distributed in the upper portions of veins, but is quickly carried away by the tropical rainfall.

Cuprotungstite.

The hydrous copper tungstate, which has the formula $CuWO_4$, $2H_2O$, is said to have a bright yellowish-green colour. It is a secondary mineral formed apparently by the alteration of scheelite. Its existence has not been definitely confirmed in Tavoy, though there is some reason to suppose that it may occur, as copper minerals are common enough in

[1] J. Morrow Campbell (9). The numerals refer to the bibliography, p. 9.
[2] Walker, T. L. "A review of the minerals tungstite and meymacite." *Amer. Jour. Sci.*, 4th ser., vol. 25, pp. 305-308, 1908.

some localities and are known to decompose readily. Maxwell Lefroy has mentioned the occurrence of "metallic green and yellow wolfram ochre stains or accretions on quartz—massive or crystalliform in cavities from which they were derived."[1]

Ferritungstite.

This mineral has not been identified in Tavoy but there is no reason why it should not occur. The following description is taken from Hess's work.[2]

"Ferritungstite, hydrous ferrous tungstate (Fe_2O_3. WO_3, $6H_2O$), is a light yellow mineral much paler than tungstite. It is friable or powdery and looks very much like iron stained clay. Under the microscope it is seen to be made up of small hexagonal plates. It has been found only as a product of the decay of wolframite, and, like tungstite, may be left in spaces from which wolframite has been weathered, and it may thus show the prospector that other tungsten minerals lie below the weathered outcrop."

Some of the light powdery varieties of the Tavoyan "tungstite" may prove to be ferritungstite on proper examination.

Cassiterite.

Tin oxide (SnO_2), nearly always accompanies wolfram in Tavoy veins, the two minerals are found together in the detrital deposits, and, of the two, cassiterite is found alone in the true river-sorted alluvial sands and gravels.

The mineral is unequally distributed throughout the district and veins in granite usually carry more tin-stone than do those in sedimentary rocks. There are however certain exceptions to this rule. It also occurs in true pegmatites. The mines producing most tin-stone are those at the northern end of the Central Range, *viz.*, Hermyingyi, Taungpila and Pa-in.

The mineral is found in a great variety of forms and colours. The commonest shades are browns and greyish-browns, but cassiterite of white, grey, pink, chocolate, ruby red and black tints also occurs. The fine granular varieties met with in alluvial deposits exhibit every shade of yellow, brown and red to black.

The cassiterite of the Pagaye pegmatites occurs usually as imperfectly formed pyramidal crystals of a light greyish-red colour and is often associated with green fluorite. Narrow veinlets in the south extension of the stockwork at the same mine are sometimes filled completely with dark greyish-black pyramidal cassiterite and a white mica.

[1] E. Maxwell Lefroy (20), p. 3.
[2] *Loc. cit.*, p. 34.

At Yanmazu, grey and dark grey crystals showing both pyramidal and stout prismatic forms are deposited on the mica walls of narrow veinlets.

Hermyingyi cassiterite is characterized by its peculiar light brown shades and coarse imperfect crystals.

Massive cassiterite, forming solid ore built up of intergrowing crystals, occurs as veinlets in greisen at the Pa-in mine. These veinlets vary from one inch to 6 inches in thickness and often yield masses up to 100 lbs. in weight. Large crystals of brown and black cassiterite are also found there and often a whole suite of colours is to be observed in an individual crystal.

The finest specimens come from Taungshuntaung, where black bi-pyramidal forms with a splendent lustre are found on mica rock with crystallized quartz.

The druses sometimes met with in the lodes at Kanbauk furnish beautiful and distinctive specimens of quartz crystals intergrown with wolfram and deeply implanted with small shining black crystals of cassiterite. Especially interesting is a specimen in the possession of Mr. W. Leslie of a tabular wolfram crystal broken across its short axis and held together by two crystals of cassiterite which have grown on the fracture. It is impossible to describe the endless mutations which cassiterite presents in Tavoy. The remarks already made relate to the mineral in its crystalline form and it remains to say that such crystals are always imperfect, very often intergrown with other individuals, and more often than not twinned either by contact or penetration. The knee-shaped doublet twins are very common.

The mineral is also found in irregular aggregates which may show a tendency towards botryoidal structure or have imperfect crystal forms and impressions on the surface. It then possesses a roughly radial structure with concentric bands and under the microscope shows irregular aggregate polarization. This form is very brittle.

Small slender prisms of shining black cassiterite terminated by very acute pyramid faces resembling the sharpened point of a lead pencil, occur at the Seinpyon mine near Natkyizin in the north of the district. They have been called "needle tin." The squatter prismatic forms terminated by the pyramid are also found there.

Especial mention must be made of the peculiar tinstone from Mr. Fitzherbert's Sinthe mine. It is found in the surface deposits of a hill-side overlying decomposed argillites. The ore is really a coarse, angular cassiterite but it is so rusted and penetrated by oxides of iron, that in bulk it resembles heaps of coarse rusty sand. When the surface soil is removed the underlying rock is seen to be penetrated in all directions with innumerable veinlets of a branching system. The maximum thickness of these is 12 inches but most of them are extremely thin and almost microscopic. One veinlet was sectioned and proved to be $\frac{1}{8}$ inch thick with clean walls. Under the microscope it showed fine cassiterite grains at the edge and a coarser grain inside. The centre of the veinlet was full of a brown and yellow iron mineral. A few laths of mica also occurred, otherwise there was no other mineral present. The matrix was a greenish-grey, vitrified argillite with irregular grains of quartz.

Cassiterite has also been found in laterites and lateritic gravels from various localities and is then masked by iron staining.

J. Morrow Campbell has described another variety of cassiterite obtained from Hermyingyi, Kalonta, and other places. He has termed it the "prismatic" form, though the term is not too well chosen, as it is liable to lead to confusion with the ordinary stout, prismatic crystal forms. "It is found in small prismatic crystals radiating from a central nucleus. They show aggregate polarization between crossed nicols. The existence of this form of cassiterite has not, as far as I am aware, been previously recorded. It has two modes of occurrence, (1) in bands parallel and alternating with quartz,—crustification—in veins, and (2) with the interspaces of prisms and groups filled with soft micaceous mineral. The first specimen of this I saw was picked up on an old alluvial dump and though it weighed about a pound had been rejected as worthless by Chinamen. It is so fragile that streak or hardness tests are difficult."[1]

Alluvial cassiterite or "stream tin."

The size of the grains of Tavoyan stream tin depends entirely on the distance it has travelled from its original home. In the upper parts of the valleys where little classification of the river deposits has taken place, and where there is still much unsorted true detrital

[1] Morrow Campbell (9), p. 21.

deposit, crystals of about the size of a large coffee bean with rounded edges can be picked out of the finer material.

Further down still, finer, rather angular material is found, while in the true alluvial sands and gravels the fine concentrated ore takes on a rounded form. Here it is associated with magnetite, ilmenite, topaz, garnet, zircon and sometimes with small amounts of monazite and gold.

Cassiterite crystallizes in the tetragonal system, it has an imperfect cleavage, a subconchoidal fracture and a grey streak. It has a hardness of 6½ and cannot be scratched with a knife. Its lustre is adamantine to splendent. Its specific gravity is 7.

It may be and is mistaken for many other minerals, and its density, hardness and the lustre of its crystal faces must be used to distinguish it from them. When such characters are masked, as they may be in the field, it is always safest to perform chemical tests. Though the contrary has been asserted, it is often impossible to distinguish small amounts of cassiterite in fine-grained mixed wolfram concentrates and the only reliable means of identification is a chemical test.

VEIN MINERALS ASSOCIATED WITH WOLFRAM AND CASSITERITE.

Native Metals.

Bismuth.

The bright silver-white and very brittle native bismuth has been found *in situ* at Kanbauk in one of the lower workings, where beautiful specimens of wolfram in long thin crystals separated by narrow bands of the vein quartz matrix occur. The edges of the crystals are lined with narrow films of native bismuth, which also penetrates into cracks in the wolfram and is scattered in the quartz between. The metal is very characteristic with its well-marked cleavage, metallic lustre and platy structure. Fresh surfaces tarnish rapidly in the atmosphere of Tavoy. Specimens of native bismuth, which appear to come from a vein, have been obtained at the London and Burmese Wolfram Co.'s Paungdaw mine, but the exact locality is not known.

Native bismuth also occurs in detrital deposits, in which irregular pellets are found surrounded by black decomposition crusts of hydrous oxide, or, if the decomposition has proceeded further, by a grey crust of other oxy-compounds in which a kernel of the native metal remains. Such occurrences are known at Kanbauk, where they are large enough to be of commercial importance, at Zinba, Putletto, Kalonta and other mines.

Native bismuth can be cut with a knife and is easily melted below a red heat.

Gold.

Gold is found in small quantities as small flakes and grains in most of the tin-bearing alluvials of the district. The metal is of course known from many tungsten bearing veins in other parts of the world, especially in the United States of America, though there it occurs more usually with scheelite than with wolfram. It cannot be asserted definitely that the Tavoyan gold is derived from the wolfram bearing veins, as up to the present time it has not been reported from them. Indeed the occurrence of gold in the thin quartz veins of Saba Taung near Tavoy town, seems rather to point to a separate derivation as these veins contain neither wolfram nor cassiterite as far as is known.

Sulphides and arsenides.

Molybdenite.

The sulphide of molybdenum, MoS_2, is found in granites which have undergone alteration in the vicinity of veins, in pegmatites, in greisens, in veins with wolfram or cassiterite, or both, and in veins in which it occurs alone with pyrite. It is a lustrous, lead grey, metallic-looking mineral usually occurring in small scales which can be split into thin leaves with the finger nail. Sometimes large pieces are found in short hexagonal prisms. In mixed veins it generally occurs close to the walls and is often intergrown with the mica which is almost always found in such positions. It is commoner in veins traversing granite than in those piercing sedimentary rocks. At Sonsin mine at the north end of the Mintha granite massif, there are veins which carry molybdenite without wolfram or cassiterite. The mineral tends to segregate at the walls and in the greisen adjoining them. Other localities where it is especially abundant are at the Burma Malaya Co.'s Wagon North mine, in certain lodes at Kadan Taung near Thingandon and at the Widnes mine of the High Speed Steel Alloys Mining Co. Ltd. Small parcels have been extracted from Sonsin and Wagon North but owing to primitive methods of mining and the impossibility of concentrating the crushed ore in the ordinary washing pan or sluice box, it is of little economic importance at present.

The mineral is easily confused with graphite but the mark it leaves on paper has more of a greenish tint than that left by graphite.

Molybdenite is readily attacked by acid solutions with the production of the oxide *molybdite,* which is a pale yellow soft mineral occurring in the spaces left by the molybdenite, as silky tufts or as an earthy powder.

Pyrite.

The yellow sulphide of iron, FeS_2, is common everywhere. Its cubic crystals and pale brass-yellow colour are so well known that it seems unnecessary to give any further tests to help the prospector to distinguish it. Yet it has been mistaken for chalcopyrite and for pyrrhotite. It is distinguished from the former by its greater hardness, its paler colour and from the latter by its colour. Pyrrhotite is of a pinchbeck-bronze tint and is also slightly magnetic. Pyrite is not only a very frequent mineral in the metalliferous veins, where it is generally found in lustrous cubes and growths of cubic combinations, but it also occurs in the pegmatites, in the granites and in the slates of the Mergui Series, especially when these are near the granite contacts. Massive pyrite and intergrowths of the mineral with chalcopyrite are also of common occurrence. The mineral is very easily decomposed and some varieties, probably because they contain marcasite, decompose more quickly than the others. When these changes take place ferrous sulphate and sulphuric acid are formed. It is believed that the sulphuric acid so liberated is to a large extent responsible for the removal of wolfram from the upper parts of veins through which ground water circulates.

Chalcopyrite.

The copper-iron sulphide, chalcopyrite, $CuFeS_2$, a bright brassy-yellow mineral which crystallizes in the tetragonal system is, after pyrite, the commonest sulphide ore in the district. It is distinguished from pyrite in the field by its colour and its softness, being easily scratched with a knife. On exposure to the air it readily tarnishes and then assumes the iridescent colours which give it the name of "peacock copper." The best specimens come from the Pagaye pegmatites, from the lower workings at Kanbauk and from Kadando, where it is found with pyrrhotite in a wolfram-bearing vein, but it was formed later than the wolfram as it fills cracks in that mineral. It also occurs at Egani and in small quantities at Hermyingyi.

Covellite.

The cuprous sulphide, covellite, CuS, is formed by the decomposition of chalcopyrite, and the dark indigo-blue films which often coat specimens of chalcopyrite from Pagaye are believed to consist of this mineral.

Galena.

The sulphide of lead, galena, PbS, is the commonest ore of lead and one of the rarer sulphide minerals of the wolfram veins. It has been noticed in small quantities at Hermyingyi, Pagaye and Kanbauk. It occurs with pyrite, chalcopyrite and fluorite in thin stringers and films at the Peneichaung granite quarries. The best specimens are from Seinpyon near Natkyizin, where fine granular forms exhibiting the brilliant facets of its cubical cleavage are obtained. A quartz vein carrying galena crops out in Mergui sediments on the road between Uthayan and Wumpo. Galena is recognised by its lead-grey colour, its perfect cubical cleavage and its weight. It is easily reduced on charcoal to metallic lead.

Zinc blende.

The sulphide of zinc, ZnS, sphalerite or "black jack," occurs sparingly as a vein mineral in Tavoy district. It is generally found as a very dark brown or black massive variety known as marmatite, which contains 10 per cent. or more of iron, possessing a pale brownish streak and a specific gravity of about 3·9. The best specimens come from the Rubber Mile mine near Kyaukmedaung. Blende also occurs at Kanbauk in a narrow vein intergrown with cellular pyrite and a little chalcopyrite, edged with dense vitreous quartz. It is not easy to distinguish in the matrix from wolfram, especially as it possesses a perfect cleavage. When separated however, its lower specific gravity is at once appreciated.

Stibnite.

The sulphide of antimony, stibnite, Sb_2S_3, has been found in Paungdaw and at Zinba in wolfram veins. The form it assumes is that of curved bands and fibres closely packed together. It has perfect cleavage and a brilliant metallic lustre which tarnishes somewhat on exposure to the air. It is quite soft and can be cut with a knife, and is distinguished from other sulphides by its easy fusibility. Massive groups of radiated and curved stibnite crystals have been found in the Mergui and Amherst districts. The radial cleavage surfaces of these specimens are furrowed with narrow cross lines and steps.

Bismuthinite.

The sulphide of bismuth, bismuthinite, Bi_2S_3, was first recognised in fine hairlike crystals. According to Dr. Morrow Campbell, "The sulphide of bismuth is somewhat more widely distributed [than the native metal], though not by any means common. It occurs in the same veins with wolfram, cassiterite and molybdenite, often in contact with the two former, also associated with them as a primary mineral in granite. It is always fibrous in structure, steel-grey in colour with high metallic lustre. Sometimes it is hair-like in separate fibres. It is often found in microscopic crystals throughout quartz to which it gives a smoky-black to black appearance. When exposed to the air it loses its lustre turning black then grey to green and finally pale yellow. The simplest test for bismuth is to place a fragment in a little cold hydrochloric acid not sufficient to dissolve it completely, wait a few minutes till action has ceased, pour the acid into a glass of water, it will turn milky and a heavy white precipitate will fall" [if bismuth is present].[1]

Bismuthinite has been found at Kalonta, Zinba, Paungdaw and Pagaye.

Pyrrhotite or magnetic pyrites.

Pyrrhotite is a sulphide of iron of doubtful composition though the best authorities agree that it conforms to the general formula Fe_nS_{n+1}. It is a rare mineral in Tavoy except in the Kadando vein where it occurs abundantly with pyrite, chalcopyrite and wolfram. It has a peculiar bronze colour when fresh but in the Tavoy climate it tarnishes in a few days to a dark metallic grey. In this condition it can easily be mistaken for other tarnished sulphides but its magnetic properties and the colour of a fresh fracture furnish discriminating tests.

Arsenopyrite.

The sulpharsenide of iron, FeAsS, arsenical pyrites or mispickel, is a rare mineral in Tavoy. It is common at the Tagu mines in Mergui where it is found in compact massive forms with irregular surfaces of a light steel grey colour. It has a hardness of 5½ and a specific gravity of 6. It is an important ore of arsenic in some parts of the world.

Carbonates.

Siderite.

The carbonate of iron, siderite, Fe_2CO_3, which is also known as chalybite, has been observed as a vein mineral only at Kanbauk, where it occurs as pale brown

[1] J. Morrow Campbell (9), p. 24.

platy forms in association with purple fluorite, wolfram, cassiterite and molybdenite.

Calcite.

The carbonate of calcium, calcite, $CaCO_3$, has been obtained as a vein mineral at Kanbauk only where it occurs very rarely in tabular forms under the same conditions as siderite. Both the carbonates are probably of secondary origin.

Cerussite.

White acicular crystals of cerussite, the carbonate of lead, $PbCO_3$, occur as a decomposition product on galena from the Natkyizin region. This mineral is of no economic importance in Tavoy.

Fluorite.

Fluorite or fluor spar, is the fluoride of calcium, CaF_2. Earlier writers have expressed the opinion that the mineral does not occur in Tavoy, but we have found that it has a wide distribution in small quantities. Amongst other localities the following may be mentioned, Pagaye, where green octahedra and colourless cubes occur in the pegmatites; Thingandon, as pale green, imperfectly formed crystals in the wolfram-bearing veins, and as amethystine films in the granite; Kanbauk, as purple and green cubes from bearing veins in the sedimentaries; Paungdaw, as green cubical pieces in bearing veins in granite, etc.

It is an easy mineral to distinguish in the field by reason of its colour, hardness (only 4), specific gravity (3·2) crystal form, and cleavage.

Certain Silicates.

Topaz.

Topaz $(AlF)_2\ SiO_4$. According to J. J. A. Page,[1] "there is a considerable amount of yellow topaz in some of the veins, and also in the concentrate procured by washing the alluvial deposits in various localities." With the exception of the Hermyingyi occurrence described later, we have failed to find topaz *in situ* anywhere in Tavoy. A small amount of water-clear topaz in grains and little, broken prismatic crystals with worn edges, is contained in the crude cassiterite concentrates from the dredge at Taungthonlon. We are also indebted to Mr. A. H. Morgan, who identified the mineral in minute quantities in the concentrates of the Kamaunghla valley. We have recognised the mineral occasionally when examining concentrates from other streams, but we have no hesitation in saying that topaz is a

[1] J. J. A. Page in discussion of Maxwell-Lefroy's paper (20), p. 113.

rare mineral in Tavoy, as far as our knowledge at the time of writing goes.

Topaz-fluorite rock at Hermyingyi.

In the southern portion of the Hermyingyi lease and close to its western boundary with the Hermyingale area a vein with a unique mineral association is worked. The Kanbanchaung flows across its strike. As the locality is very thickly wooded and mining operations have been insignificant, a complete account cannot be given, but the outcrop of the vein can be traced from the bottom of the valley for some distance up its steep southern slope. The country rock is decomposed argillite of the usual type. The vein itself is 10 or 12 inches in thickness, of dense, opaque, white quartz carrying altered mica, cubes of pyrite, wolfram, often in bladed crystals, and brown cassiterite. On the hanging wall side there is a band of topaz rock containing fluorite, about 12 inches in thickness, in contact with the vein but separated from it by a definite plane along which movement has taken place, as slickensiding is in evidence. The vein itself has also suffered various movements, as is proved by the character of the quartz, the contortion of the mica and the fracture and recementing seen in some of the large pyrite cubes. The country rock is a silicified argillite throughout which very numerous small crystals of pyrite are scattered. The topaz-fluorite rock is a loosely compacted, fine-grained aggregate of the two minerals. The topaz is usually white and either in granules or more or less imperfect crystals, in which the perfect basal cleavage and the vertical striations of the faces in the prism zone are well developed. The fluorite is colourless and semi-translucent as a rule, though pale brown and faint green tints are also seen in some hand specimens. The rock often shows a tendency towards banding in which one mineral is developed at the expense of the other. Certain bands, upwards of ¼ inch thick, are practically pure granular topaz. Where there has been more room for development larger crystals are the rule, the topaz prisms then being up to ¼ inch across and the colourless fluorite pieces larger. It would appear as if the topaz was the first mineral to crystallize and that the colourless fluorite filled in the interstices afterwards. Between the topaz-fluorite rock and the vein wall there is sometimes an edging of a greyish-green, fine-grained mica-rock, which contains small scattered crystals of brown cassiterite and bands of coarsely crystalline mica of much the same colour. Cassiterite and wolfram both occur rarely in the topaz-fluorite rock. Owing to the broken nature of the country rock, close timbering was essential in the small mine openings which had been made, and we were not able as a consequence to make as thorough an examination of this interesting occurrence as we should have liked.

Beryl.

Beryl, a silicate of aluminum and beryllium, $Be_3Al_2\ Si_6O_{18}$, has been found in the granite of Sinbo-Sinma in six sided prisms of a pale greenish colour. It has not been found as a vein mineral in Tavoy, but it is common in the wolfram veins of Byingyi in the Yamethin district. It is said to be one of the common minerals in the tungsten deposits of Queensland. Beryl has a hardness of 7·5 to 8 and a specific gravity of about 2·7. It is easily mistaken for apatite, from which it may be distinguished in the field by its superior hardness.

GENERAL DISTRIBUTION OF WOLFRAM AND CASSITERITE IN TAVOY DISTRICT.

Previous writers have remarked on the zone or belt-like nature of the area over which mineralization is known to have occurred in Tavoy. Thus J. J. A. Page has written :—" The general result of my exploration was that I demonstrated a strip or belt of country running from the west coast at Heinze Bay down into Mergui district in the vicinity of Tagu or Theindaw, roughly 10½ miles wide which I described as tin and wolfram-bearing. Outside this belt I decided that there were but poor chances of either mineral being found in commercially payable proportions. The western margin passes Onhbinkwin, Kanbauk, Egani, Talaingya, Pagaye, Meke and Tagu. The eastern passes Zinba, Hermyingyi, Myekhanbaw, Wagon, Heinda, Paungdaw, Kyaukton, Theindaw and Thabawleik." [J. J. A. Page in R. C. Beadon (1), p. 68.]

General statements of this nature are liable to be misinterpreted and a more exact definition is called for. In the first place, as we have shown elsewhere, the Tavoyan occurrences are merely a link in a long chain which stretches from the far north of the Southern Shan States down to the extreme southern point of Tenasserim as far as Burma is concerned, and beyond it, into Siam and the Malay States. Again, the western limit of the Tavoy region is an accidental

Wulfenite, molybdate of lead, $PbMoO_4$, has lately been discovered by Mr. A. W. Ross, General Manager of Hermyingyi, on that mine, as minute crystals closely resembling those typical of stolzite.

one,—the sea, and we know that granite reappears again in the string of islands which fringe the coast. The eastern or interior edge of the so-called belt is an arbitrary one, and it is merely giving a very doubtful hostage to the future, to assert that profitable deposits will never be found beyond the Siam frontier in the north of the district or east of the Ban chaung further south. These are the limits of exploration at the present time. The Tavoy field owes its shape to the situation and trend of the great granite masses which form so large a part of it, and wherever similar granite intrusions occur outside its present boundaries, there is a reasonable possibility of finding wolfram and cassiterite veins, provided that the portions of the parent rock which contained them originally have not been removed. The general distribution as it appears to-day is best appreciated by studying the geological map of the district, with reference to the locations of the larger mines. We consider it better to advise this course than to attempt any limitations in figures, for just as deposits may, and do, occur outside the belts which have been so described, for example the concessions of the Pe-Palauk-Pyicha region, or to go further afield, the cassiterite deposits of Lampi or Sullivan's Island, so it is equally easy to demarcate large tracts within such belts themselves, where careful search has failed to reveal any minerals of value, and regarding which there are strong reasons for thinking that they cannot occur.

The general strike trend of the granite is north and south or north-north-west and south-south-east approximately, and along the intrusions where marginal and crest aureoles exist and are favourable, mineral deposits of various kinds are found. The linear arrangement which has given rise to the belt hypothesis is due to this cause. As examples of it we mention the Medaw Kambay, Kanbauk, Taung-shun-taung, Pachaung, Kechaung and Egani mines, associated with the Coastal Range and extending 40 miles from north to south; and the Hermyingyi, Taungpila, Thingandon, Wagon, Putletto, Paungdaw districts stretching 20 miles from north to south as the crow flies, associated with the Central intrusion. It is exceptional to find any large part of the field where some such arrangement of this kind is not apparent. It is not asserted that any particular vein or vein system carries right through from one mine into the next, indeed this is very often known not to be the case; all we wish to emphasize is that the main vein strike approximates very closely to the trend of the granite masses.

CHAPTER IV.

STRUCTURES AND CHARACTERISTICS OF TUNGSTEN AND TIN ORE DEPOSITS IN TAVOY.

Leaving out of consideration alluvial cassiterite deposits and detrital deposits containing both cassiterite and wolfram, the occurrence of which is considered later, we propose to deal now with the distribution, form and structures of the original ore deposits.

Granites, aplites, pegmatites and greisens.

Cassiterite and wolfram as accessory minerals in granites.

The occurrence of cassiterite as an accessory mineral in some varieties of Tavoy granite was first discovered by Bleeck,[1] who records 0·15 per cent. of metallic tin in a granite porphyry from mile 21 on the Siam road. Since then its presence has been confirmed by others. That wolfram may occur in a similar situation was first definitely established by Morrow Campbell,[2] who writes :—" In many parts of the district I have observed, as original constituents of the granite, wolfram alone, cassiterite alone, and also both together in varying ratios, sometimes accompanied by bismuthite." A specimen of a fine-grained white granite from Zinba mine, now in the Geological Museum, Calcutta, contains a nest of small radiating wolfram crystals. Long rectangular black crystals seen in sections of the Bolintaung granite are probably wolfram.

Cassiterite and wolfram in aplites.

It is necessary to distinguish carefully between the true occurrences of cassiterite and wolfram as accessories in granite proper, and the far commoner finds of both minerals in the aplite veins, the fine-textured white rocks containing quartz, orthoclase felspar and a little muscovite mica, which sometimes penetrate the main granite masses and are later than their hosts. Weathered specimens of aplite from Kalonta exhibit spots of yellow tungstite left by the decomposition of wolfram.

[1] A. G. Bleeck (2), p. 59.
[2] J. Morrow Campbell (9), p. 3.

Wolfram and cassiterite in pegmatites.

In many parts of the world wolfram and cassiterite are known to occur in pegmatite veins with quartz, felspar, mica and other minerals. There is some reason to believe that many of the true quartz veins of Tavoy which contain wolfram and cassiterite, or both minerals, with mica and no felspar, represent a specialised variety of pegmatite formation. At Pagaye mine, at Osman Musti Khan's Sinbo Sinma mine and at other places, pegmatites, using the term in the ordinarily accepted sense, occur, in which wolfram exists in comparatively large quantities and has been profitably extracted. At the former mine the associated minerals are microcline felspar, mica, green fluorite, scheelite and cassiterite together with pyrite, chalcopyrite and covellite. A diagram showing the structure of the rock is given below.

Wolfram and cassiterite in greisens.

Both wolfram and cassiterite occur in greisens, narrow bands of quartz-mica rock formed by alteration of the granite adjoining quartz veins, and are sometimes present in sufficient quantities to make the greisen bands a profitable source of ore. Bands of greisen are sometimes observed traversing granite and containing little or no signs of any vein quartz. In such cases the mineralizing gases or solutions appear to have been injected through narrow films or cracks in the original rock. These occurrences occasionally contain wolfram and cassiterite and their destruction by atmospheric agencies may give rise to valuable surface deposits of both minerals even in the absence of quartz veins of any noteworthy size.

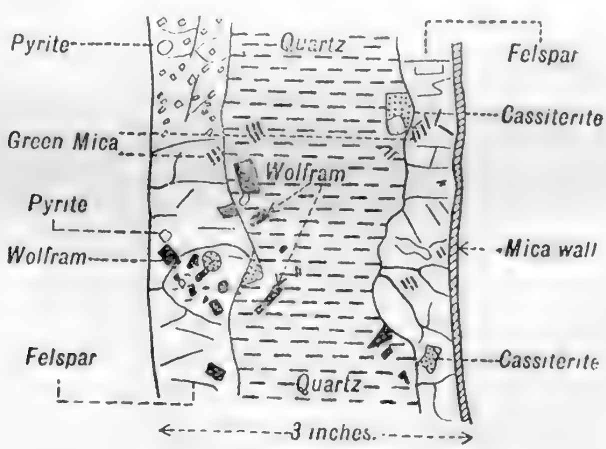

Diagram of a stringer in the Pagaye pegmatites.

Fissure veins.

General features.

The modes of occurrence of wolfram and cassiterite already described are, with the exception of the greisens and the Pagaye pegmatites, of more theoretical interest than economic importance. Leaving out of calculation the surface deposits, quartz veins furnish the great bulk of the concen rates produced in Tavoy. Mineral-bearing quartz veins are found either in the granite, penetrating its contact with the sedimentary rocks, or enclosed within the sedimentary rocks themselves at no great distance from the granite. A glance at the geological map will show that all producing mines are situated on the granite or are not far removed from it. Exceptional cases do occur of bearing veins which appear to be further away from the granite than this statement would seem to warrant, but investigation shows that in such instances there is reason to suspect the near presence of underlying granite not yet exposed by denudation.

Every major granite intrusion in the district has in some part or other its associated ore-bearing veins. Very often large expanses of granite are found where such do not exist now. The reasons for this are discussed later, but where favourable conditions remain and where exploration has taken place, there the veins occur.

It is only natural that a large number of veins, widely distributed over a vast area, formed intermittently by processes which may have varied slightly from place to place, subjected to more or less severe changes, dynamical and chemical, and denuded to different levels later, should exhibit changes of structure to-day. Yet there are certain generic characteristics apparent in them which may be classified as follows, with the reservation that exceptions to each case may exist.

(1) The veins are formed by the infilling of fissures;
(2) they often occur in parallel groups;
(3) they often form series of overlapping lenses;
(4) the lenses themselves are often irregular; they thin out and then thicken again, or split up and reunite;
(5) they generally possess clean and well-defined walls;
(6) alteration of the granite walls to greisen is practically universal;
(7) the quartz of which they are formed is usually dense, milky white and very compact;

(8) mica is nearly always present and sulphides very often;
(9) secondary movements of the fissures are common.

Length of veins.

According to Bleeck [1] "Individual veins, each one continuously varying in thickness, have been traced for considerable distances (a quarter of a mile or more) in the granite but only along the strike. Nothing as yet is known of the conditions to the dip." The writer is evidently referring to certain veins in the granite between Talaingyachaung and Byaukchaung.

Maxwell Lefroy[2] writes :—"The important question of lode continuity, horizontal or vertical, is one which has been severely neglected, so that not much information can be given. The longest outcrop hypotenuse the author has heard of, and has examined throughout, is upwards of 7,000 feet from the summit to close down to the base of a granite hill, 1,912 feet in height, which implies the dip angle to be 15° 50′ throughout the 7,000 feet of its south side and the base to be over 6,700 feet in length. Owing to the excessive pitch of the opposite side of the hill it was impossible to determine the existence or absence of a corresponding outcrop, though some of the fifteen lodes found on the southern slope must have their counterparts there, as the water courses at the foot contain much quartz and ore."

Morrow Campbell[3] states, "the most marked peculiarity of our veins is that they usually occur in groups parallel and close to one another, often very numerous and frequently of short length. We often find a second parallel series intersecting the first. Such deposits usually end abruptly along the strike, the ground outside not having been fissured or cracked. The longest vein in the district extends for several miles northward from the vicinity of Yewaing. It strikes about N. 10° W.-S. 10°E., practically parallel to the axis of the granite ridge. It is certainly one of the oldest veins in the district, has undergone several re-openings and contains wolfram with iron, copper, lead and zinc minerals." Dr. Morrow Campbell is here referring to the well known Kadando vein. Its limits in either direction are not known.

The length of a vein naturally depends on the length of the fracture which contains it, and it is subject to at least all the variations of that original fracture. Fractures parallel to the strike of the

[1] Bleeck (2), p. 63.
[2] Lefroy (20), p. 88.
[3] J. M. Campbell, (9), p. 5.

main granite intrusions are longer than those running across them, and the fractures of the granite itself are longer and better determined than those in the overlying covering of sedimentary strata.

The Tavoy field is not an old one. Mining of a sort commenced in 1909 and since then has been, with rare exceptions, carried on under a particularly pernicious tribute system. Exploration has in a great measure been left to the cooly, who, quite naturally, only concerns himself with rich mineralized patches. The denseness of the forests and the thickness of the soil cap have added to the difficulty, and mine plans are not compulsory until leases have been granted. It is only in the past three years that systematic working plans have been available, and these have reference to the larger mines alone. It is safe to say that the majority of the larger veins have not as yet been explored from end to end, and, when to these facts are added complications introduced by faulting and other geological anomalies, it will be seen that it is not easy to arrive at accurate data on this important subject.

There are several large and well-defined veins in the Paungdaw granite with strike extensions of at least 1,200 feet and possibly they continue very much further than this. In the Hermyingyi section of the field the outcrops of veins in granite have been traced for many hundreds of feet without their limits being determined exactly.

Again, bands or zones of mineralised country are sometimes met with which contain irregular veins throughout their length, though it may be impossible to trace any particular one for a great distance. For example, there are more or less continuous workings on the main "A" zone at Pagaye over a distance of 3,200 feet, and it is probable that this by no means limits the extensions of the zone.

From these large and well-formed veins on the one hand, to small insignificant stringers on the other, every gradation exists, and it is not uncommon to find examples of them all on a single mine. As a general rule veins are larger and longer in the granite than they are in the sedimentaries away from it.

Both wolfram and cassiterite show a tendency to deposit in thin stringers or leaders, and little veinlets, half an inch or so in thickness, are to be found which reproduce the internal structures of large veins. Such stringers are, for their size, often excessively rich in the metallic minerals and patches of ore occur in them which are practically solid, without the admixture of any other mineral. Instances occur at Yanmazu, Pagaye, Pa-in and other mines. When such veinlets are found in close association in soft ground they may form a valuable source of these ores. Much of the so-called "alluvial" concentrate won by sluicing residual or decomposed granite, is derived from the very numerous stringers and mineralized cracks penetrating the parent rock.

Strike and dip.

Details of the strikes and dips of the veins are given in the descriptive section dealing with the various mines, and all that need be repeated here is that the general strike is north and south to north-west, south-east, though there are many exceptions to the rule. Dips are usually high, though veins with low angles of dip are also known. It has been asserted by some writers that the dips of the Tavoyan veins are generally inwards, towards the centres of the granite intrusions from which they have arisen; as a matter of fact there is very little evidence that such is the case.

Composite veins.

Composite veins are not rare and are to be found on nearly all the larger mines. They seem to point to the fact that the fissure lines have continued as planes of weakness even after a preliminary filling of vein matter. Thus at Hermyingyi, near the Waterfall, there is a composite vein about 2½ to 3 feet in thickness, the major part of which consists of a hard, brittle quartz carrying wolfram. This is bounded on one side by a band of shattered and weathered soft quartz full of impressions left by pyrite crystals and containing poor wolfram values. The footwall of this part of the vein is slickensided. Again, in the Me-chaung section of the Tavoy Concessions Kyaukanya mine, there is a heavily jointed vein, the central and major part of which consists of a very pyritic and hard quartz. The boundary portions on each side of the centre are made up of quartz which does not contain any pyrite, but is full of small fragments of graphitic slate, which were evidently torn from both walls of the country rock. Both the vein and its walls show signs of much movement. These two examples, the first of a vein in granite, and the second of a vein in the sedimentary series, will suffice to illustrate the fairly common occurrences of composite veins.

Nature of the vein quartz.

Bleeck's general description of the gangue quartz of the veins is a good one. He writes as follows:[1]—"It is of a milky white and very compact appearance and has a vitreous lustre on the fractured

[1] A. G. Bleeck (2), p. 65.

surfaces. In some localities it is honeycombed and iron-stained along the outcrops, notably so at Kadwe. Very often the quartz shows numerous little cracks and veinlets containing red oxide of iron. Microscopically the quartz contains numerous vesicular inclusions. The extinction is undulatory."

In the larger veins the quartz is of a "blocky" nature and tends to separate into large roughly cubical masses. Along these partings and joint planes there are often black and brown films of iron and manganese oxides. Small irregular vugs and hollows sometimes occur, filled with the same compounds, remains of pyrite cubes and crystals of ferrous sulphate. Veins containing large geodes and crystals of quartz are very exceptional, but they do occur at Kanbauk. In some of the smaller veins which traverse granite the gangue quartz often assumes a more glassy appearance than it does in the larger ones.

Mica of the veins and greisens.

Mica is an almost invariably associated mineral in the veins. It occurs in small flakes, as thin bands along the walls and in crystal aggregates in the quartz itself. The commonest variety is muscovite in silvery white or yellowish flakes. Green chlorite is also common. According to Bleeck,[1] lithia chlorite has been observed, in which the presence of lithium can only be detected chemically. Reddish-brown micas, which often occur in the greisens, notably at Wagon South and in Paungdaw, may be lithium-bearing, but this group of minerals needs further chemical investigation. Thin bands of a green mica-rock are also found in greisen at various localities.

On the occurrence of wolfram in "shoots."

The erratic distribution of wolfram in its parent veins is an exceedingly well-known phenomenon, and Tavoy does not differ from other wolfram fields of the world in this respect. In the most extreme cases massive slugs of wolfram, up to a ton in weight, have been found in quartz veins, but any profit which has accrued to the miner from them has generally been lost in driving through barren ground to find the next one. In this connection it is our experience that veins in which small scattered crystals of wolfram occur, are generally more uniformly productive than those in which larger masses are found at irregular intervals. The question whether wolfram does or does not occur in "shoots" is one of considerable

[1] A. G. Bleeck (2), p. 68.

economic importance, and the mining engineers of the field were asked to give their views on the subject, as it was felt that they were in a better position to gather evidence of the required kind than any-one else. Their answers are given below:—

Mr. A. W. Ross, Hermyingyi.—"There are indications that wolfram and tin-stone occur in shoots in the veins but it is too little to call evidence."

Mr. H. N. Rees, Widnes.—"We have not done sufficient work to enable me to pass an opinion."

Mr. J. Finlayson, Kanbauk.—"I am of the opinion that wolfram does occur in well-marked vertical shoots at Kanbauk.

Mr. A. H. Morgan, Pagaye.—"The wolfram and tin-stone is unevenly distributed throughout the veins and the richer patches may be termed ore shoots, but they are not absolutely isolated, there are usually specks or small bunches of ore in between."

Mr. E. Maxwell-Lefroy, Tavoy Concessions.—"I have never remarked any shoots anywhere in the district. It is of course difficult to judge when one is on a shoot unless the mine is regularly laid out with adits one under the other and connecting winzes. Sporadic mineralization is essentially a feature of Tavoy veins and veinlets, I should think."

Mr. W. Crosley, Paungdaw.—"I am inclined to form the opinion based upon the extremely capricious occurrences of the mineral that shoots, so common in gold-bearing veins, are quite unknown in this district, or at any rate in my concession."

Mr. H. R. Mackilligin, Rubber Mile.—"There is no evidence to show that wolfram runs in shoots, in fact it seems probable that it occurs in irregular patches."

Mr. H. G. Mathews, Wagon and Pachaung.—"I have never seen anything which looked like a shoot on any of the veins. The wolfram occurs in bunches."

Mr. R. C. N. Twite, Sinbo-Sinma.—"My experience is that the ore, both tin and wolfram, does occur in irregular shoots and bunches and that in the majority of cases the vein is composed of base quartz between the shoots. I have also noticed that the bunches of ore are rich at the junction where a vein surrounds a horse."

Mr. N. P. Ghandi, Paungdaw and Padauk.—"I have not got sufficient data to pass an opinion, but am inclined to believe that wolfram occurs in shoots in the veins."

Mr. M. M. Sinclair, Egani.—"My experience on this property is that both wolfram and tin-stone occur in bunches as regards the greater bulk of them, but both minerals are also disseminated throughout the veins in small quantities."

Mr. A. G. Wood, Bolintaung.—"I am certainly of opinion that wolfram occurs in shoots in the veins. In all the cases which I have observed the ore is found in defined zones with barren bars between them, but these mineralized zones do not, individually, constitute any considerable length on the strike of the veins."

Mr. Malcolm K. Clarke, Heinda.—"In my experience of mining both for wolfram and tin-stone neither occur, to my knowledge, in shoots. I should be more inclined to call them rich patches or pockets. These certainly have been met with and do occur. Cases of this kind have been my experience here when certain adits have met with rich patches, extracting over $\frac{1}{4}$ of a ton of wolfram, while the intervening spaces of the reef carry the mineral in more or less small percentages and sometimes hardly at all. These pockets are not frequently met with, neither are they at regular intervals. Drives below and above on the same reef fail to meet the continuation of these rich pockets at distances where they should if shoots occurred. I therefore assume that wolfram does not occur in shoots in the veins themselves, but in pockets or rich patches apart from being distributed throughout the vein in greater or lesser quantities."

Outcrops of veins.

The outcrops of quartz veins are not well-defined in Tavoy and the prospector receives little help either from outstanding exposures or from hollows left by the decomposition of the veins themselves. Both in granite and in sedimentary rocks the veins break down under the influence of denudation at much the same rate as the enclosing rocks themselves, owing partly to their "blocky" character, and partly as a result of friability caused by the decomposition of soluble minerals. The thick soil cap and dense vegetation together form a very efficient mask, and it becomes impossible to know whether any particular small area does or does not contain veins until it has been trenched across the strike down to bed rock. On precipitous slopes such as are associated with the transverse drainage in places where streams breach the granite intrusions, wall-like outcrops of veins may be seen, in situations too steep to permit soil accumulation or the growth of trees, but even here they are hard to distinguish and very detailed examination is required. The larger veins sometimes betray their presence by dislocated blocks of quartz strewing a hill-side below them, and these may be traced back to the general position of their origin, but here again, the jungle growth renders an occurrence much less helpful to the prospector than it would be in more open country, for it cannot be detected from afar, and laborious search is necessitated. In a general way the best way to prospect any given area is to examine the stream beds first of all. The bare rock exposures may reveal veins; the presence of concentrates in the sands is an indication that they may occur; the existence of mineralised vein quartz is a sure sign which by judicious exploration can be made to lead back to the neighbourhood of the outcrop. The manner in which even the connected upper portions of veins bend and accommodate themselves to the slopes of the hill-sides is unusual and surprising, and, if not realised, is liable to lead to false deductions causing unnecessary trouble and expense later.

Tenor or mineral content of Tavoy veins.

Exact data regarding the metallic contents of Tavoy veins are difficult to obtain. It is regrettable to have to record that on many mines worked by the tribute system, detailed figures of production are not kept. Even where they are, at best they can only furnish an inaccurate and underestimated result. Again, the irregular and erratic distribution of wolfram and cassiterite in pegmatites and veins of associated origin is another misleading factor, and valuations approaching the truth can in reality only be determined on such ore deposits from the milling results of large scale stoping tests. The following figures are given with these reservations.

According to Mr. Maxwell-Lefroy:[1]—" A study of monthly outputs shows such contrasts as one mine working on lodes with 2·5 per cent. mineralization, *i.e.*, of recovered wolframite, giving a return of one ton of concentrate from 40 tons of quartz broken by eight or ten men, and low-grade concerns with only 1 per cent.

[1] E. Maxwell-Lefroy (20) pp. 12-13.

content which need from eighteen to twenty-four men to produce the same yield of concentrate." An example is given of mining operations conducted for eight months on narrow veins varying from 0·58 to 1·83 feet in thickness in which the recovery was 1·28 per cent. of quartz broken. These, of course, are tribute results gained under a system which wastes anything from 25 per cent. to 50 per cent. of the values. The same writer points out that the number of 1 per cent. propositions is relatively small compared with the high grade mines which earn large profits on from 2 per cent. to 3 per cent. ore.

H. D. Griffiths[1] writes:—"The writer has seen most of the important wolfram lodes of Burma, and from evidence gathered, and from the quantity of ore now being extracted, has come to the conclusion that the decomposed zones of the lodes carry high remunerative values. They also carry blanks or poor patches like all the similar deposits, but the richer portions are sufficiently good and extensive to make a good average. As an instance can be mentioned the case of a number of lodes having been mined to a depth exceeding sometimes 150 feet, and the ore being milled after a small amount of sorting had been done. The work extended over five years, 34,000 tons being milled for a return of 42 lbs. per ton (or 1·87 per cent.). The rejected dumps on testing proved to have a value of 11 lbs. per ton (or 0·49 per cent.), and were eventually crushed in the mill at a profit. The tailing, owing to shortage of water and imperfect concentration, assayed from 7 to 8 lbs. per ton. Some lodes in Burma will assuredly yield more than the value above quoted, and so far as is known few lodes have proved entirely barren. In another case that came under the notice of the writer, 1,000 tons of quartz, obtained by driving on five lodes, on being roughly sorted and hand-crushed, yielded 50·4 lbs. of wolframite per ton (2·25 per cent.).

Regarding Kanbauk, Mr. Griffiths[2] writes:—"Previous to the installation of a crushing plant, all the crushing was done by hand, such portions of the lodes only which carried wolfram in large quantities being treated, the remaining quartz being thrown out on the dumps. On completion of the crushing plant all the quartz mined, together with a large portion of the old dumps, was crushed, the only portions of the lodes left in the stopes being those showing

[1] H. D. Griffiths (12), p. 64.
[2] H. D. Griffiths (13), p. 213.

absolute blanks, so that the original returns of over 3 per cent. from picked ore have not been maintained. For reasons that need not be enumerated, but which were unavoidable, the latest mill returns have shown poor values, which, however, it is safe to predict will not continue. From careful consideration of the work which has been done, the conclusions arrived at are that about two-thirds of the lodes carry remunerative values, one-third representing the blanks or unprofitable values, and that the average yield has been $1\frac{1}{2}$ per cent., or 34 lbs. of wolframite per ton."

Mr. J. Thomas, Government Mining Engineer, kept careful data of the amount of ore mined and concentrate won on a small native-owned mine worked by tribute methods and employing 27 men, in the south of the district during the month of December 1917. These showed an average recovery of 2·25 per cent. For the month of January 1918, a similar investigation on the same mine gave a yield of 2·50 per cent. On another mine for the months of November to February (1918) inclusive, the average yield of all the veins was $2\frac{1}{2}$ per cent. From 50 observations made on the relation of the size of the vein to its richness, the figures given below were noted to be fairly regular on a small mine in Tavoy.

	Inches.
1 per cent. veins average width	12
2 " " " "	9
4 " " " "	8
5 " " " "	6 and under.

Tribute extractions from four veins in the Paungdaw granite region, representing several months' operations, were as follows:—

	Per cent.
Vein No. 1	0·75
" " 2	0·90
" " 3	1·00
" " 4	1·40

Driving for 200 feet on a $1\frac{1}{4}$ foot vein in argillites on the west bank of Tavoy river showed an average value by tribute methods of 1·90 per cent. and for 97 feet on another vein a return of 2·7 per cent. was registered. 40 feet of driving on a third vein of an average width of 9 inches yielded 1·10 per cent.

It is unfortunate that exact figures are not available regarding the percentage of wolfram in the large veins of granite regions like Paungdaw and Hermyingyi. The estimates of those best acquainted with them usually fix a minimum of 1·5 per cent., but in the absence of large scale stoping results, it is impossible to say at present by how much this figure is in some cases exceeded.

The cassiterite content of Tavoy concentrates.

A table is given below in which the approximate composition of the concentrates from 50 mines, all of which produced either 10 or more tons during the year 1918, is given. These mines produced nearly 96 per cent. of the district's total output in that year. Calculations have been made taking into account the individual production of each mine for the year 1918, and the final result is that the concentrates show an average composition of 54·32 per cent. WO_3, and 18·8 per cent. $Sn O_2$. This result does not differ much from the figures given by Mr. C. Sutton, President of the Tavoy Chamber of Mines, who has stated :—" From the outbreak of war to the end of 1918 we have exported 13,000 tons of concentrates, which I estimate will have carried about 55 per cent. WO_3, and 15 per cent Sn.[1]

These figures do not represent the true composition of the exported material, as a certain amount of mixed ore is separated before shipment. They must also be regarded as approximate for the following reasons :—

(1) Some small mine owners could not furnish assay data and in a few cases an arbitrary figure had to be taken, based on our general knowledge and the composition of concentrates from adjoining mines.

(2) The ratio of the wolfram and tin content varies with the season, and the tin content is always higher in the rains when water supplies enable ground-sluicing of the detrital deposits to be carried on intensively. In some cases it has been impossible to decide what proportion of the total production is represented by detrital won concentrates, compared with that won from veins.

The approximate percentage composition for 1918 must not be taken as a basis for computing the average amount of tin ore in any past or future year, for on various large mines its production is controllable within certain limits, and naturally increases when the world's market for the metal is good.

[1] Mining Journal, March 15th, 1919, p. 155.

Approximate composition of mixed concentrates in 1918.

Mine.	*Composition.*	
	WO_3 per cent.	Sn. per cent.
Anyapya	65	3
Bawabin	68	4
Byaukchaung (Rambux)	51·5	2·2
Byaukchaung	64	5
Crest	56	13
Darichaung	59·5	9·2
Egani	40	23
Heinda	72·5	0·1
Hermyingyi	42	28
Hteinthit	27	40
Kadantaung	65	2
Kadwe	68	1·2
Kalonta	42	28
Kanbauk	57	9·8
Kechaung	65	1
Kyaukanya	68	1·2
Medaw	70·9	0·1
Meke	57·7	18·9
Meke (Ni Toe's)	56	15
Myekhanbaw	26·5	47·3
Nwalabo	59·5	9·3
Pachaung	70·2	1·3
Padauk	62·9	0·6
Pagaye	62	11
Pagaye (Crisp's)	70·5	1

Approximate composition of mixed concentrates in 1918—contd.

Mine.	Composition.	
	WO_3 per cent.	Sn. per cent.
Pa-in	19	49·4
Paungdaw	68	1·7
Paungdaw, South	65	3
Putletto	59·4	8·6
Putletto (Syndicate)	60	4
Rubber Mile	47	22·9
Sheffield	47·3	16
Sinbo-sinma	55	15
Talaingya	62·6	2·5
Talaingya (Ho Kyin)	66·3	3·2
Talaingya (Kyi Pe)	60	5
Talaingya (Sein Thwe)	52	15
Taungbyaukchaung	66·8	0·2
Taungpila	29	40
Taungshun	26·9	39·2
Thingandon	68	1·2
Thitkado	47	21·7
Thitkatchaung	60	9
Wabyauk	19	49·3
Wagon	68	4
Wagon, North	52·4	16·7
Wagon, South	65·6	4
Widnes	64·5	3
Zinba (Sein Thwe)	68·7	0·5
Zinba	69·3	0·1

CHAPTER V.

THE ORDER OF DEPOSITION OF THE METALLIC VEIN MINERALS AND ITS ECONOMIC BEARING.

Examination of a very large number of mixed intergrowths of cassiterite and wolfram from Tavoy district have convinced us that in the great majority of cases the wolfram is older than the tin ore. Dr. Morrow Campbell states:—"I have examined carefully the mixed wolfram cassiterite ores from most of the mines of the district and in the vast majority of cases there is no shadow of doubt that wolfram was deposited before tin. I have seen many hundreds of samples of cassiterite filling the spaces between wolfram crystals, enclosing wolfram and carrying the impression of its striations, several where it has filled cracks in wolfram and two excellent examples of tin ore crystals actually formed on surfaces of wolfram."[1]

Molybdenite appears to have been the first ore mineral to be deposited, as it is often enclosed in wolfram, or intergrown with the mica at the edges of the veins. It was followed by wolfram, cassiterite, bismuth, bismuthinite and then the majority of the sulphides like pyrite, chalcopyrite, arsenopyrite, pyrrhotite, galena and blende. Pyrite belongs to several stages of the crystallization processes and is not always confined to its place in the general order given above. Flourite was probably one of the latest minerals to be formed. It is usually found in crystals coating other minerals. It should be pointed out that all these compounds do not occur in every vein; the sulphides of lead, bismuth and zinc are rarely found, but the order given is the best that can be made out from specimens which we have seen, and it may of course be modified by future discoveries, though we do not think that is likely. Dr. Morrow Campbell has listed most of the following examples from the district and we have noted similar occurrences and added others.

Molybdenite enclosed in wolfram, wolfram inside a quartz crystal, cassiterite enclosed in wolfram, cassiterite enclosed in bismutite derived from bismuthinite, cassiterite enclosed in mica, mica in wolfram and cassiterite, quartz enclosed in scheelite, quartz

[1] J. Morrow Campbell (1), p. 17.

enclosed in siderite, chalcopyrite and pyrrhotite piercing wolfram, chalcopyrite in pyrrhotite, blende in chalcopyrite and in pyrrhotite, galena and blende on wolfram, fluorite on wolfram, quartz and cassiterite, bismuthinite in fluorite, native bismuth in wolfram, double terminated quartz crystals with one end in cassiterite. Some of these intergrowths are not easily interpreted and mistakes may easily be made if numerous specimens are not available for examination; it is interesting to note that chemical evidence is available which show that lumps of wolfram, with no visible cassiterite may carry estimable quantities of tin.[1]

Dr. W. R. Jones believes that in general wolfram was deposited at lower temperatures than tin ore. He has stated that the purest wolfram concentrates, that is those which have no cassiterite or only traces of it, are found in veins in sedimentary rocks farthest removed from the granite contact. This fact, to which however there are a few exceptions, he believes supports a suggestion made in 1915, that the probable reason why Lower Burma carries more wolfram in proportion to tin-ore than Malaya does, is that the lower part of the Malay Peninsula has suffered greater denudation than Lower Burma and he has added that in Mergui, which is between the Tavoyan and the Malayan mines, the proportion of tin-ore to wolfram is greater than in the Tavoy district, and less than in Malaya. It is admitted that there are individual exceptions, but they are believed to support the temperature zone denudation theory, which has however only to be taken in a broad and general way. If this theory is correct it follows that mining operations in Lower Burma to-day are being conducted in the outcrops and upper horizons of veins which have for the most part been denuded away in Malaya, and that at depth there are in Burma deposits more after the nature of those occurring *in situ* in Malaya and which have been the source of its famous tin-fields. Dr. Jones does not suggest that wolfram will in all cases give place below certain depths to tin-ore; nor that an increase in depth must necessarily mean a higher temperature zone, but he believes that the majority of the mines in Tavoy are probably at a zone several hundreds of feet above the part where the temperature was too high for the deposition of wolfram as the predominant ore.[2]

[1] W. R. Jones, Mining Mag., Vol. XXII, No. 4, p. 245.
[2] W. R. Jones (15), pp. 41-42.

This theory has been criticised severely by Dr. Morrow Campbell, whose views regarding the relative order of deposition of cassiterite and wolfram in mixed intergrowths are much like ours, but in fairness to Dr. Jones it must be pointed out that he referred more to the order of deposition as the mineralizers travelled and not so much to the order of deposition in the parts of a vein where both occurred together. He holds that in an intermediate zone, under suitable temperature conditions, both wolfram and cassiterite would be deposited more or less simultaneously and an occasional specimen showing cassiterite in wolfram in no way detracts from his view that cassiterite deposits at higher temperatures than wolfram does. According to Dr. Campbell :—" In general in such tin-wolfram areas on the contact, the ratio of cassiterite to wolfram is greater in veins in the sedimentary rocks than in those in the granite below. When in granite the ratio of tin to wolfram appears to fall as we move down from the vicinity of the contact."[1]

Our experience is the reverse of this. As a general rule we find that cassiterite is present in relatively larger amounts in veins traversing the granite, than in others which pierce sedimentary rocks. The highest grade wolfram concentrates, *i.e.*, those which contain the greatest percentages of WO_3, come from mines working in veins at high horizons in the sediments, the richest tinny concentrates from veins in granite, though there are exceptions to both statements. We are not aware of the existence of any evidence regarding a change in the relative ratio of the two minerals at various levels in the granite.

With regard to the intermediate character of the ore from Mergui, it is true that, in the aggregate, that district produces a greater proportion of cassiterite than Tavoy, but most of it comes from wolfram-free tourmaline pegmatites—a type absent from the Tavoyan field. In the wolfram-cassiterite quartz veins themselves the proportion of cassiterite to wolfram is lower than in many Tavoyan veins.

It is impossible for geologists unacquainted with the Malayan tin fields to pass an opinion on the validity of Dr. Jones' theory. We note that no physiographical evidence has been brought forward to prove conclusively the contention that the Peninsula has suffered greater denudation than Lower Burma. The existence of the

[1] J. Morrow Campbell (9), pp. 18—20.

cappings of schists and phyllites over the Malayan granites, even if they are less in number and not so extensive as those in Tavoy, is insufficient ground on which to base so far-reaching a theory. In view of the local differences of composition in mixed concentrates from closely related geological horizons in Burma itself, we prefer to regard the cause as one connected with inherent variations of composition in the original magma.

THE PERSISTENCE OF WOLFRAM IN DEPTH.

There is little field evidence in Tavoy to furnish data regarding the persistence of wolfram in depth. All that can be said is that the deepest exploratory workings in granite have proved both the veins and the two minerals wolfram and cassiterite which they were commenced to find, but they do not go more than 400 feet below the horizon of the granite contact. Veins worked for a few fathoms in the soft rocks below the level of their outcrops, and detrital deposits, have furnished by far the greater part of the concentrates which the district has produced up to the present, and deep level mining has hardly commenced. But as Dr. W. R. Jones has pointed out, "it does not require artificial crosscuts to establish (the presence of wolfram), for Nature has provided us, on some mines, with many in the form of deep valleys, and has definitely proved, in the exposed lodes, that wolfram does occur in workable amounts, at depths of several hundreds of feet below the great majority of the present workings."[1] Dr. Morrow Campbell, on the other hand, does not believe that because the outcrop of a vein is seen to be continuous from the summit to the base of a granite hill several hundred feet high, it persists for an equal vertical depth, for the slope of the hillside is usually practically parallel to and not far below the original granite periphery, the overlying sediments and only a very little granite having been removed by denudation. This is doubtless true in some cases. In others it is not, and if there is anything in the old miners' rule regarding the relationship between the strike extension and the depth to which a vein extends, some of the wider and well-defined veins, say in regions like Paungdaw, ought to persist to very considerable depths. Dr. Campbell is

[1] W. R. Jones (15), p. 43.

very pessimistic on this subject. He divides the veins into three groups as follows:—

(1) those entirely in the metamorphic rocks,
(2) those partly in these and partly in granite,
(3) or those entirely in granite.

Regarding the first group he writes,—"In no mine of this type where ore-bearing veins are found over 500 feet up vertically above the granite does the ore persist as far down as the contact."[1]

Our own knowledge of Tavoy mines leads us to conclude that in no mine of this type have the veins as yet been followed down to the granite contact by mining operations. This is certainly not the case in the example quoted by Dr. Campbell.

Hermyingyi is given as an example of the second group. Our view is that sufficient development work has not yet been conducted at Hermyingyi to warrant a final conclusion that the average amount of ore in respect of both number and width of veins diminishes in depth, or that the average tenor of the vein stuff above the contact is consideraby higher than it is below.

With regard to the third case, veins which are entirely in granite have naturally had their upper portions in the sedimentary rocks removed by denudation, if they ever extended up into them. If there are examples in the Talaingya valley which are worthless in the metamorphic rocks and payable in the granite, this surely is evidence of value increasing with depth.

Dr. Campbell concludes.—"Persistence to a depth of 1,000 feet has not yet been proved in any Tavoy vein and, while possible in only a few cases, is improbable. In the great majority of the veins already opened up values disappear at small depth. With a few exceptions very little profit has been yielded by veins at a depth of 200 feet. Unfortunately it must be admitted that not only experience in the mines but deductions from the phenomena of the occurrence of the ores compel us to regard the mineralized zone in the Tavoy district as being of small vertical extent."[2]

It is something that Dr. Campbell admits the possibility of a few veins in Tavoy persisting to 1,000 feet in depth. In the great majority of veins opened up "values" may have disappeared at small depth, but this is not the fault of the vein. Coolies gouging

[1] J. Morrow Campbell (10), p. 346.
[2] J. Morrow Campbell (10), p. 346.

out a vein from its outcrop, or following it in shallow drives underground, can only continue doing so in the decomposed rock zone. It is self-evident to anyone acquainted with Tavoy that it is impossible to work a vein in hard undecomposed granite by the tribute system alone as it exists there, and once the easily won ore is removed, exploitation ceases and the vein is said to have "petered out," or become too low grade to pay. The latter statement is of course quite correct under prevailing conditions.

After all, the existence or non-existence of wolfram at depth is a matter which can only be settled by the experiment of driving into the veins and examining them. We are not aware of any reasons which would lead us to advise that such an experiment is not worth carrying out. The theoretical arguments are rather in its favour. There is a mine in Burma, which reproduces the Tavoy granite conditions almost exactly, and it has been found profitable there to mine wolfram and cassiterite at depths some hundreds of feet below anything yet attempted in Tavoy. This also should give encouragement. In our opinion the question of the permanence of wolfram is of minor importance to that of devising means of exploiting narrow veins in hard granite with the labour supply available, and to extract it by a more modern method than the knapping hammer and cradle.

The world-wide association of wolfram with granite rocks is remarkable. These rocks usually, if not always, contain free silica and are of the lighter coloured varieties. The ores of tungsten and tin also appear to be connected only with the upper and outer parts of the intrusions, for, as we have pointed out earlier, it is possible, when a considerable thickness of the granite has been removed, for the veins to disappear altogether. What the inner limit of vein extension, expressed in terms of feet, may be, we have no means of ascertaining at present, though the problem is not an insoluble one. In this connection, it is of interest to know to what depths profitable deposits of wolfram have been worked in other countries, with the reservation of course, that it by no means follows that all Tavoy deposits will maintain similar values to equal depths. When all has been said each case must be judged on its own merits.

At East Pool in Cornwall wolfram was most plentiful in the Great Lode from the 140 to the 196 fathom level, that is from 840 to 1,176 feet and it has been worked to the 300 fathom level or

1,800 feet. Most of the wolfram from this mine comes from the Middle Lode, which is worked to the 240 fathom level. At the South Crofty mine the distribution of wolfram is irregular; it is most abundant in the middle levels and cannot be depended on below 245 fathoms (1,470 feet). The best lode is not payable below 205 fathoms (1,230 feet), at which the average yield of tin ore and wolfram is 23 lbs. per ton. In the eastern section of the same mine development is being carried on down to the 310 fathom level (1,860 feet). At this bottom level the North Lode is 2 feet wide and carries 40 lbs. per ton.[1]

According to Hess, Grey and Winters conclude that the wolfram deposits in the aplites of Yenberrie, Northern Territory, Australia, give promise of a considerable persistence in depth.

At White Oaks, N. Mexico, hübnerite has been found at a depth of 1,350 feet. In the Boulder field of Colorado, no ferberite ores have been found at a depth greater than 900 feet, but the question of depth cannot be considered as settled for the field. According to George, the ferberite in these deposits is distributed along the veins in bunches and pockets or rarely shoots, and up to the present nothing has occurred to suggest that the downward distribution is less regular than the lateral. In fact a considerable number of the best ore bodies have had greater vertical than lateral dimensions.

Hess points out that the minerals associated with wolfram are those usually considered characteristic of deposits formed at considerable depths below the surface, and that it is thought that pegmatites were extruded from great depths. He concludes that most tungsten deposits doubtless extend to depths as great as those reached by deposits containing other metals. "Many tungsten veins, like veins carrying deposits of gold, silver, tin, copper, and other metals, will give out at shallow depths, and only the exceptional mine may be expected to yield ore of good quality in commercially valuable quantities to great depths. Probably not one in five hundred gold-bearing veins carries commercially valuable ore below a depth of 100 feet. Possibly tungsten veins may carry ore at depths greater than those reached by workable gold veins, but this possibility has not yet been demonstrated by actual developments

[1] Dewey and Bromehead, "Tungsten and Manganese Ores," Geological Survey of Great Britain, 1917, pp. 20-21.

In a general way the depths that are reached by gold-bearing veins are indicated by the length of their outcrops, but tungsten deposits whose outcrops are comparatively small seem to reach relatively greater depths, especially those that have pegmatitic characteristics.[1]

THE DECOMPOSITION OF WOLFRAM.

Very erroneous ideas are prevalent in literature regarding the behaviour of the natural tungstates of iron and manganese on exposure to the action of water or air. Thus, W. H. Emmons classes tungsten as a metal that dissolves very slowly when its ores are exposed at or near the surface and subjected to the action of water and air. He considers them as stable ores comparable, say with cassiterite, for he places both tin and tungsten in the same division of his classification, along with gold (in part), bismuth, chromium and molybdenum.[2]

R. H. Rastall writes :—"The outstanding feature of the tungsten minerals is their great stability and resistance to any kind of chemical or mechanical alteration. Hence, like cassiterite and gold, they are particularly prone to occur in both residual and alluvial deposits. In many of the published descriptions, and especially in the technical journals, a good deal of confusion is found to exist between the residual deposits, where the material is still more or less in place, and the true alluvial or transported deposits. From their stability and high density it also follows that the tungsten minerals are specially liable to occur as placers and other forms of transported deposits. The same properties also lead to a natural concentration in such deposits, especially in the lowermost layers, resting on the bed rock, and in natural riffles. In this respect both wolfram and scheelite behave like stream-tin, gold and platinum. In fact, the properties of wolfram are so like those of cassiterite that their separation by mechanical processes is very difficult, and it was not until the introduction of magnetic separation that this difficulty was overcome."[3]

A large portion of the wolfram produced in Tavoy is won by hydraulic methods from residual and detrital deposits, but there

[1] Hess, *loc. cit.*, pp. 62-63.
[2] W. H. Emmons, *Min. Sci. Press*, March 31st 1917.
[3] R. H. Rastall. "The Genesis of Tungsten Ores," *Geol. Mag.*, N. S. Dec. VI, Vol. V, 1918, pp. 367-368.

are no true wolfram placers or anything resembling them, if the word be used to mean stream-borne and watersorted alluvium. Wolfram does occur at the foot of slopes where the eluvial deposits of the hill sides merge into the true placers of the valley bottoms, but long before the clays, sands and gravel deposits have been sorted out and classified by running water, the wolfram has disappeared, though it comes from the same veins as the tin ore, in which it occurs almost invariably in considerably greater quantities. The only wolfram found in the alluvial deposits proper is tightly enclosed in quartz, to which it owes its preservation, as the solutions from the decomposing soil, or the river water itself, cannot penetrate to it. Such a stability is clearly an accidental one.

The rapidity with which wolfram disappears is remarkable, and is accounted for by its perfect cleavage, resulting in its disintegration on movement and the production of a comminuted form eminently suited for chemical decomposition.

Again, observations on weathered outcrops of veins prove that wolfram is readily leached. Sometimes nothing is left but the empty spaces once occupied by the crystals, at other times these are filled with oxides of iron and manganese, or with a bloom of yellow tungstite. The ready oxidation of the sulphide associates of the wolfram produce acid solutions which attack the mineral, while the mechanical effect of their removal opens up a path for deeper-seated chemical action.

Dr. W. R. Jones has maintained that in Siam and the Malay States as well as Lower Burma, all countries possessing a moist, tropical climate, it is common to find wolfram so weathered that only deposits of the oxides and hydroxides of manganese and of iron remain. In some cases the product left after the weathering is almost a pure manganese mineral, in others it is limonite, in still others only the mineral tungstite. The character of the decomposition he believes depends on :—

(*a*) the original composition of the wolfram and

(*b*) the composition of the water acting on it.

He gives an analysis of a manganese deposit taken from a wolfram vein. It occurred as a patch in the vein and gave place on both sides to slightly altered wolfram assaying over 70 per cent. WO_3. The analysis, by H. R. Pepper, was as follows[1] :—

MnO	90·38
WO_3	4·20
Al_2O_3	4·00
SiO_2	1·80
TOTAL	100·38

At the head of a narrow valley on a certain mine in Tavoy, where the detrital deposits have been sampled as systematically and carefully as this kind of work can be done, the concentrates from the ground assay 55·7 per cent. WO_3 and 15·4 per cent. Sn. The veins which are shedding the minerals yield a concentrate by mining containing 61·5 per cent. WO_3 and 4·8 per cent. Sn. The valley is steep and about 500 yards long. Approximately half way down its length, the detrital from the slopes, tested in a number of places, averages 41·6 per cent. WO_3 and 23 per cent. Sn. Close to where the valley joins the main stream, the composition changes to 40·5 per cent. WO_3 and 26·5 per cent. Sn. 200 yards down the main stream sampling gives a concentrate with 30·2 per cent. WO_3 and 35·8 per cent. Sn. 150 yards further down stream the composition is 15·4 per cent. WO_3 and 51·6 per cent. Sn. Further still down stream, actual working produced some tons of concentrate of a composition 6 per cent. WO_3 and 64 per cent. Sn.

The following analyses of general representative samples from various parts of the Hermyingyi Mine are also instructive :—

No.	Sample.	WO_3 per cent.	Sn. per cent.
1	General sample of concentrate from veins worked in No. 419 Adit., Big Hill. All these veins are in sedimentary rocks.	57·20	13·50
2	General sample of concentrate from sluicing detrital slope deposits derived from veins in sedimentary rocks.	42·60	27·80
3	Similar to No. 2, except that the veins are in granite.	50·45	20·50
4	General sample from an old talus deposit at foot of slope.	31·45	41·40
5	General sample from the stuff overlying the old talus deposit of No. 4 and doubtless much more recent and subjected to more intense weathering.	11·50	59·80

[1] W. R. Jones (16), p. 320.

According to Dr. Morrow Campbell, as well as the acid decomposition of wolfram, an alkaline decomposition also takes place. This is brought about by the action of alkaline carbonates which are present in ground water, and dissolve out tungstic oxide. Scheelite is said to break up more readily than wolfram with all natural solvents, and pearly scales of gypsum, the result of its decomposition with sulphuric acid, have been observed in intimate association with the residual tungstite.[1]

R. W. Gannett has carried out laboratory experiments to determine the effects of various solutions, such as are found in ground water, on tungsten minerals, and to determine the natural reagents which precipitate the metal from solutions. The minerals used in the tests were scheelite, ferberite, wolframite and hübnerite, and the following conclusions are given amongst his results :—

(1) Carbonate solutions had no apparent effect on any of the tungsten minerals.

(2) Alkali hydroxide solutions had no effect on scheelite, but dissolved tungsten from wolframite.

(3) Sulphuric acid alone, and in combination with sulphates of lime, soda, manganese, and ferrous iron, dissolved portions of all the minerals.

(4) Humic acids are inactive.

(5) Except by sodium hydroxide, scheelite is more readily attacked than ferberite or wolframite.

(6) Calcium tungstate is precipitated from solutions by lime salts when slightly acid, but the precipitation of tungsten is incomplete.

(7) Acids partially precipitate the tungsten as tungstic acid.

(8) Ferrous tungstate is not precipitated in acid solution, but is precipitated in slightly alkaline solution ; the reaction is nearly complete.

"The evidence of the experiments, on the whole, is that tungsten minerals are somewhat soluble. The field evidence seems to point to the same conclusion."[2]

In these paragraphs we have attempted to describe the results of ordinary processes of weathering on tungsten ores in a tropical climate with a very heavy rainfall. Whether identical or nearly-

[1] J. Morrow Campbell (9), pp. 25—29.

[2] R. W. Gannett. "Experiments relating to the Enrichment of Tungsten Ores," *Econ. Geol.*, Vol. XIV, No. 1, 1919, pp. 68—78.

related changes are undergone by the natural tungstates in other climates or when accompanied by other series of mineral associations,—one in which easily decomposed sulphide ores are absent being prominent in our minds—we must leave for those better acquainted with them than ourselves to decide. We are inclined to think that the sulphides of molybdenum and bismuth are also oxidised, dissolved and leached away on their passage through a soil cap from their parent veins towards the valley deposits in moist tropical climates. We conclude by pleading for a stricter use of the word "alluvial" in descriptions of these and similar processes, than is the case in most modern literature, for it does not appear correct to us to assign residual desert deposits, or detrital deposits of hill slopes, which may have been to some extent moved, but not definitely arranged, by water, to this class.

SECONDARY ENRICHMENT.

Although it is possible to imagine theoretical conditions under which tungsten ores in the upper part of a vein should be dissolved to form solutions which, percolating downwards, might have their tungsten contents precipitated in a lower region, the fact remains that in Burma there are no zones of any economic importance in wolfram mines, which have been enriched by solution and reprecipitation in any way comparable to those of, say, copper and silver in other parts of the world.

According to Gannett, after tungsten is dissolved it is very easily precipitated by ferric salts, but this precipitate is colloidal and difficult to filter. If such a precipitate should form in nature, it might be carried long distances and be widely distributed through the rocks without being lodged in a definite deposit. In such a case the original source of the tungsten would become impoverished. Precipitated ferric tungstate or the hydrated tungstic oxide, which is often seen in Tavoy, are both compounds that it is practically impossible to recover by ordinary concentrating devices in any case. Secondary scheelite is not unknown in the district, but it is a mineralogical curiosity and possesses no economic importance.

PROSPECTING FOR WOLFRAM VEINS.

The granites of Tavoy and indeed of all other parts of the province where we have examined wolfram and cassiterite-bearing veins in association with them, have a very uniform composition and appearance. They are hard, white or greyish, rather fine-grained rocks when fresh, characterized by an abundance of quartz and light coloured mica. The dark coloured micas are not so abundant in their peripheral portions and iron ores of any kind are rare. We believe that all the isolated expanses of granite are probably connected underground, and that they were formed by the same processes in the same period in time. The question arises why large areas of the granite show no signs of mineralization, and that in spite of careful search, no mineral-bearing veins have been found in them. The geological map of Tavoy shows that all the producing mines of the district are situated on or near a granite contact; that the larger ones are located in positions where the granite bands are narrowed; that Hermyingyi, the biggest mine of all, is on a comparatively small granite exposure of its own. It may be that the absence of wolfram and cassiterite from certain areas is due to the absence of the elements tungsten and tin in those portions of the original magma which gave rise to these particular outcrops of the granite. The matter is a highly speculative one, but it seems to us more reasonable to suppose that the original magma which gave rise to a range of mountains, stretching at least from the Southern Shan States to the islands of Banca and Billiton, varied somewhat in composition from place to place, than that it was of a perfectly uniform composition throughout. At the same time the size of a granite outcrop reveals in many cases the relative amount of denudation which the original intrusion has undergone. The intrusions narrow towards their summits and broaden out downwards. The wide expanses of granite have suffered severely from denudation and they contain no minerals of economic value because the veins, if they ever existed, have been entirely removed. The depths to which the veins of any particular mine in granite will extend downwards then depends partly on the amount of erosion to which it has been subjected. The prospector is advised to concentrate his attention on the acidic portions of the granite; by this we mean the fine-grained white varieties with much pale mica and free quartz, rather than the coarser kinds which contain a good deal of dark biotite, like the material from the southern portion of the Coastal Range; to pick out the narrower exposures and in particular to examine most carefully the contacts where isolated patches of sedimentary rocks still remain to prove that denudation has just reached the granite itself.

CHAPTER VI.

PRODUCTION IN BURMA AND ITS RELATION TO THE WORLD'S OUTPUT.

The modern demand for wolfram arose about 1903, as a consequence of the development of high speed tool steel manufacture; before that year the mineral was regarded as an impurity by tin smelters in England, but after 1903 the price quickly responded to the growing requirements and the output of tungsten minerals from various countries in the world began to increase. In 1910, when mining commenced in Tavoy, the world's production was about 6,000 tons of 60 per cent. WO_3 concentrates and the participating countries were the United States, Portugal and Queensland, with smaller amounts from the Argentine, Bolivia and New South Wales. By the year 1911, wolfram mining was thoroughly established in Tavoy, and an output of over 1,300 tons made Burma the leading tungsten-producing country in the world, a position she maintained until 1916, when the boom in the Americas caused the production of the United States and of Bolivia to exceed hers. Tables are given showing the output of wolfram and cassiterite from Tavoy and from Burma from 1910 to 1918.

In 1914, out of a world's production of some 8,000 tons, Burma alone produced 2,300. By this time other countries had entered the list—Japan, Siam, the Malay States and Billiton in Asia, the Northern Territory of Australia, Tasmania, New Zealand and Peru, while the European countries, including Germany and Austria, contributed their small quotas. Although Germany had no important domestic supplies and possessed none in any of her foreign territories, in 1913 she has been credited with the control of two-thirds of the world's output.[1] Thus she treated nearly 6,000 tons of 60 per cent. concentrates. The British steel makers generally obtained their supplies of finished tungsten products from the German manufacturers and it is no secret that August 1914 found Britain with but a few months stock in hand. In 1915 steps were taken by the Imperial Government to increase the output

[1] F. H. Hess. "Political and Commercial Geology Series No, 1. The Tungsten Resources of the World." *Eng. and Min. Jour.*, November 1st, 1919.

of tungsten minerals as much as possible; all wolfram or scheelite produced in the Empire was earmarked for despatch to the United Kingdom, and all shipments reaching British ports were taken over by the Government at a fixed rate of 55 shillings per unit of WO_3 on a basis of 65 per cent. ore, and were distributed to manufacturers through brokers appointed for the purpose. The price was raised at a later date to 60 shillings per unit.

It should be explained that the tungsten minerals are sold on the basis of their tungstic acid or WO_3 content, the best concentrates containing from 65—70 per cent. The price of the ore per ton thus depends on the number of units of WO_3 present. Over the years 1897 to 1914 the price fluctuated between a minimum of 9 shillings per unit and a maximum of 51 shillings.

In September 1915 it was intimated in Tavoy that a large increase in the output of wolfram was necessary for munitions purposes. Mr. W. B. Brander, C.B.E., was placed in charge of the district with special powers to help on this end. He was assisted by a number of other officers of the administrative and technical services. At a later date an Advisory Board was formed. Coolies were imported in large numbers from China, India and the F. M. S. A Protector of Chinese labour was deputed to the district. An elaborate programme of road construction to help transportation was undertaken. A bank was opened to facilitate exchange and monetary transactions. Geological and mining officers toured the mines and gave free advice to anyone in need of it. A Government assay office was installed and a systematic geological survey of the district commenced and in due course concluded. Numbers of firms with capital and skilled engineers at their disposal took up concessions and the general result was the largely increased output registered from Burma. This rose from 1,688 tons in 1913, to 4,480 tons in 1917, and from the beginning of the war year to the end of 1918, no less than 17,642 tons of a total value of £2,323,000 were exported. Of this tonnage of wolfram concentrates over 14,000 came from the Tavoy field.

The American output, under the stimulation of an uncontrolled price, which reached a maximum of 93 dollars a unit, or six times the price offered in the Empire, in 1916 rose to over 5,900 metric tons of 60 per cent. concentrates, and there was a corresponding increase in all other producing countries, so that the world's production of about 8,000 tons in 1914, rose to 12,000 in 1915, 23,000 in

Production of tungsten-ore in the Indian Empire, during 1909 to 1913.*

—	1909.		1910.		1911.		1912.		1913.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value	Quantity.	Value.	Quantity.	Value.
	Tons.	£	Tons.	£	Tons.	£	Tons	£	Tons.	£
Burma—										
Mergui	7	560(*a*)	..	..	103	8,525	217·8	16,993	205·5	17,092
Tavoy	..	..	362	36,150	1,165	88,204	1,393·4	93,407	1,399	104,800
Southern Shan States	..	..	33	2,636	40	3,260	60·1	4,808	83·7	8,561
Central Provinces—										
Nagpur	·2	19 (*b*)	·9	87	..	..	·2	22	..	..
TOTAL	7·2	579	395·9	38,873	1,308	99,989	1,6[illegible]·5	115,200	1,688·2	127,762

* This contains some cassiterite.

(*a*) Estimated at £80 a ton.

(*b*) Estimated at £4¾ a cwt.

Production of tungsten-ore in the Indian Empire, during 1914 to 1918.*

—	1914.		1915.		1916†		1917†		1918†	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Tons.	£	Tons.	£	Tons.	£	Tons.	£	Tons.	£
Bihar and Orissa—										
Singhbhum	..	..	..	..	8	640	20	1,333	2·5	498
Burma—										
Mergui	194	16,647	232·3	29,554	340	46,014	368	49,541	376·6	52,477
Tavoy	1,976·6	152,333	2,032·9	235,827	3,034	410,586	3,697·5	508,794	3,636·1	610,832
Southern Shan States	138·4	8,993	330·7	24,802	185	18,500	307	39,910	287	41,615
Thaton	17	570	49·4	6,589	91·5	15,079	107·5	15,366	96·5	14,312
Kyaukse	..	..	..	..	..	..	..	..	·1	17
Central Provinces—										
Nagpur	..	..	..	..	1·3	220	..	..	..	..
Rajputana—										
Marwar	..	..	..	..	32·7	6,358	42	8,130	37·4	7,565
TOTAL	2,326	178,543	2,645·3	296,772	3,692·5	497,397	4,542	623,074	4,436·2	727,316

* This contains some cassiterite.
† Burma figures taken from "Note on the Mineral Production of Burma for 1916, 1917 and 1918" with readjustments for the Southern Shan States.

Production of tin and tin-ore in the Indian Empire, during the years 1909-13.

—	Mergui.		Tavoy.		Southern Shan States.		Hazaribagh.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Cwts.	£	Cwts.	£	Cwts.	£	Cwts.	£
1909—								
Tin	..	..	..	..	..	..	..	..
Tin-ore	1,665	9,611	7	34	..	..	..	..
1910—								
Tin	1,507	10,935	..	..	..	..	3	26
Tin-ore	1,767	7,589	6	28	..	..	..	..
1911—								
Tin	1,764	15,543	..	..	..	..	3	27
Tin-ore	1,141	6,101	802	3,260	..	..	..	..
1912—								
Tin	2,756	28,224	1,258	7,966	..	..	..	..
Tin-ore	2,261	9,781	30	165	1,202	4,808	..	..
1913—								
Tin	2,336	24,419	1,314	8,279	..	..	..	..
Tin-ore	1,717	7,703	21	122	1,675	5,861	..	

Production of tin and tin-ore in the Indian Empire, during the years 1914-18.

—	Mergui.		Tavoy.		Amherst.		Thaton.		Southern Shan States.		Hazaribagh.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity	Value.
	Cwts.	£	Cwts.	£	Cwts.	£	Cwts.	£	Cwts.	£	Cwts.	£
1914—												
Tin . .	1,963	16,235	..	..	..	..	..	..	..	..	1	16
Tin-ore . .	1,861	9,263	767	3,696	..	..	..	..	2,767	8,993	..	..
1915—												
Tin . .	2,553·5	20,534	·6	4	..	..	..	..	..	..	0·7	6
Tin-ore .	1,762·25	8,678	253	956	..	..	..	..	6,613·9	24,802	..	..
1916—												
Tin . .	2,257·19	19,802	..	..	..	..	..	..	..	..	..	...
Tin-ore .	1,897	10,531	1,644	8,192	10	16	900	3,598	4,862	16,965	..	..
1917—												
Tin . .	2,817·9	27,962	..	..	..	..	..	..	..	..	..	..
Tin-ore . .	1,761	10,930	1,762	11,015	33	176	1,677	3,972	8,088	40,440	..	..
1918—												
Tin . .	2,013·6	28·123	..	..	..	..	..	..	..	..	..	..
Tin-ore . .	1,471·2	12·432	4,052·7	31,056	1,317·5	8,767	1,141	2,959	7,609	51,361	..	..

1916, 28,000 in 1917 and 35,000 in 1918. In 1917, China, which had been an insignificant producer before that time, brought 1,500 tons into the market, rising in 1918 to over 10,000 tons, or more than the whole world's output for any one year before 1915.

As F. L. Hess has pointed out, the world's known large tungsten fields are grouped in the great mountain masses which parallel the shores of the Pacific Ocean and in 1918 fully 92 per cent. of the world's tungsten came from the Pacific shores. Of the remainder 5 per cent. had its origin in Portugal and Spain, while the small deposits of England, Germany, etc., produced less than 3 per cent. of the total.[1]

WOLFRAM DEPOSITS IN OTHER PARTS OF BURMA.

As is pointed out elsewhere, wolfram and cassiterite have been found at intervals over a distance of 750 miles in Burma, always in direct association with the granite ranges which stretch from the Shan States to the extreme south of the province. The occurrences of the Kyaukse, Yamethin, Karenni, Thaton, Amherst, Tavoy and Mergui districts have already been described by us.[2]

WOLFRAM DEPOSITS IN OTHER PARTS OF INDIA PROPER.

The occurrences of wolfram and cassiterite which have been discovered in other parts of India outside Burma, are not of great economic importance. L. L. Fermor[3] has described wolfram-bearing quartz veins at Kalimati in the Singhbhum district of Bihar, from which about 36 tons of wolfram were won in the years 1916-1918. Some years ago, a series of small wolfram-bearing veins were discovered at Agargaon in the Nagpur district of the Central Provinces, interbedded with mica schists and tourmaline schists of Dharwar age, but the total amount of wolfram obtained from them was only some 3 or 4 tons.[4] Over 100 tons of wolfram were produced from the Degana mine in the Marwar State of Rajputana during the years 1916-1918. The mineral occurs in quartz veins with coarse mica, ilmenite and fluorite. The country rock is granite.

[1] F. H. Hess, *loc. cit.*, p. 715.
[2] Coggin Brown and Heron (8), pp. 101—121.
[3] L. L. Fermor. *Jour. As. Soc., Bengal*, New Series, Vol. XV, No. 4, p. 188.
[4] L. L. Fermor. "Occurrence of Wolfram in Nagpur District, Central Provinces." *Rec., Geol., Surv. Ind.*, Vol. XXXVI, Pt. 4, pp. 301—311, 1907-08.
L. L. Fermor. "Mineral Resources of the Central Provinces," *Rec., Geol., Surv. Ind.*, Vol. L, Pt. 4, pp. 296—297, 1919.

Mining operations are considerably hampered owing to lack of water.

Cassiterite occurs occasionally in the mica pegmatites of Bihar and Orissa, but is of more scientific interest than economic importance.

DESCRIPTIONS OF TAVOY MINES.

In the following pages the mines are grouped in accordance with the geological structure of the country, that is to say with the particular granite intrusion to which they owe their origin. Such a method is regarded as more suitable than a purely geographical or alphabetical one would be. Every mine which has produced more than 10 tons of concentrates in any one year since it was opened is referred to, and brief references are made to smaller prospects which possess any points of peculiar interest.

Some idea of the activity which has taken place in Tavoy may be gathered from the following table, which gives the total number of applications received by Government for licenses or leases to work mineral lands in the district for the past 10 years:—

1908	1
1909	21
1910	665
1911	515
1912	172
1913	220
1914	92
1915	151
1916	506
1917	365
1918	271

In the following table the producing mines of the years 1916, 1917 and 1918 are tabulated according to their outputs:—

Production per annum.	Number of mines.			Percentage of total production.	
	1916.	1917.	1918.	1917.	1918.
Under 5 tons	58	74	70	2·8	2·5
Over 5 and under 10 tons	18	18	8	3·2	1·5
Over 10 and under 50 tons	19	25	38	16·0	24·7
Over 50 and under 100 tons	7	9	6	17·5	11·8
Over 100 tons	5	6	7	60·5	59·4
TOTAL	107	132	129	...	...

1916.

Pagaye produced 151 tons.
Paungdaw produced 184 tons.
Kanbauk produced 311 tons.
Widnes produced 424 tons.
Hermyingyi produced 765 tons.

1917.

Taungpila produced 114 tons.
Paungdaw produced 185 tons.
Pagaye produced 186 tons.
Kanbauk produced 357 tons.

1917—*contd.*

Widnes produced 357 tons.
Hermyingyi produced 1,051 tons.

1918.

Taungpila produced 127 tons.
Kalonta produced 140 tons.
Paungdaw produced 169 tons.
Pagaye produced 215 tons.
Widnes produced 360 tons.
Kanbauk produced 383 tons.
Hermyingyi produced 868 tons.

Mines of the Coastal Range.

The greater part of the Tavoyan coast line is formed by a high granite ridge which rises from the sea a few miles to the north of Ye in the Amherst district. It is breached by the Ye river, crosses the Malwedaung range, forming the northern boundary of the district, at an elevation of about 2,800 feet and then continues south.

Medaw Kanbay.—The wolfram mine of Medaw Kanbay, the property of Maung Ni Toe, is situated on its eastern flank a few miles north of the point where it is breached by the narrow tideway known as the Heinze Basin. This mine was opened in the year 1915 and the output from the commencement up to date has been as follows :—

	Tons.
1915	28
1916	29
1917	58
1918	62

The concentrate is a high grade wolfram practically free from cassiterite. It comes from a peculiar flat quartz vein which crops out at intervals around the periphery of a group of hillocks, and varies in thickness from 1½ to 3 feet. It is often divided horizontally into two or three portions by thin layers of the country rock, which is an argillite of the ordinary type. Granite occurs in the high range to the westward and is said to have been met with in the deeper exploratory shafts below the vein. There is some evidence that the vein begins to dip towards the south in the most recent workings, and that it may be found to conform more to the general type as they extend. There are also a few small normal veins on other sections of the mine. The mine is worked entirely by primitive hand methods.

A few miles to the south of Medaw Kanbay, a wolfram-bearing quartz vein was located in a mangrove swamp within tidal limits in 1918, and although this caused a rush of prospectors to the neighbourhood it is doubtful if the discovery is of any economic interest.

Kanbauk.—The Kanbauk mine of the Kanbauk (Burma) Wolfram Mines, Limited, is the most important one of the Coastal Range section, and is situated near the southern end of the Heinze Basin. Alluvial cassiterite deposits have been worked sporadically on the leased area and in the district around it from an unknown antiquity, but the introduction of modern European methods only dates from the year 1910, when a prospecting license over an area of 7 square miles was granted to Col. Radcliff. In 1913 the property was incorporated by Radcliff & Co., Ltd. Later a mining lease for a period of 30 years was granted and in 1917 the company was reconstructed under its present title with an issued capital of Rs. 21,000.000 in shares of Rs. 15 each and Rs. 7,50,000 in convertible debentures.

Since the commencement of operations the outputs have been as follows :—

Year.	Mine ore.	Sluicing.	TOTAL.
	Tons.	Tons.	Tons.
1911	...	...	250
1912	206·75	...	206·75
1913	254·75	...	254·75
1914	86·75	37·00	123·75
1915	70·50	101·75	172·25
1916	55·85	249·50	305·50
1917	91·18	266·51	357·69
1918	104·25	272·47	376·72

The approximate average composition of the concentrates for the past few years has been roughly WO_3 57 per cent. Sn. 10 per cent. and Bi. 1·5 per cent.

The mining camp lies at an elevation of 100 feet in the narrow valley of the Yin Ye Chaung which leads from the south towards the Heinze Basin. On the east and south it is surrounded by high granite walls while on the west rises Kanbauk hill proper, built up of sedimentary rocks of the Mergui Series. The actual contact is visible in places along the eastern side of the valley but is usually hidden under the deep alluvial and detrital deposits which fill it. The mineral-bearing veins are entirely confined to the western side of the valley and therefore to the sedimentary series though there are no bearing veins in it near the contact. These rocks consist of fine-grained argillites interbedded with more or less sandy layers, occasionally passing into sandstone, though the lines of demarcation between the different varieties are not always definite. These rocks have a north and south strike and dip at a fairly high angle towards the east, that is to say, towards the granite. Between the sedimentary series and the granite there is a broad band of decomposed material referred to locally as the "black rock" whose origin has been the subject of some controversy. It is exposed in the lowest mine workings and in cuts made by sluicing operations. The latest specimens which have been obtained prove that it is a large basic dyke genetically related to the basic dykes met with in the Coastal granite nearer the sea in this vicinity and in other places. A peculiarity of this rock is that it carries tungsten. The samples examined so far contain quantities varying from a trace to $1\frac{1}{2}$ per cent. of WO_3 yet no concentrate can be obtained by crushing and concentrating in the ordinary way. The presence of the element is only determined by chemical analysis and the form in which it occurs has still to be discovered.

Limestones also occur with the argillites and sandstones but their exact relationships are still obscure.

The main mineralized zone has a trend length of some 1,500 feet, a width of about 800 feet and at least 20 distinct veins are known to occur. At Kanbauk proper the main series strikes approximately east and west and dips south at about 60°. The same directions prevail in the case of a second series at Kanbauk West. But at Thingankyun, a section of the mine to the south of Kanbauk proper, the dip is towards the north at an average angle of 45° while the strike remains the same. A few cross veins have also been met with in the deeper workings. Veins of the ordinary massive quartz, with sporadic occurrences of wolfram and cassiterite in them are common, but special mention must be made of the veins of drusy quartz, which are of very exceptional occurrence in the district. In these crystallization seems to have set in from the walls with the result of a mass of more or less imperfectly formed quartz crystals, growing horizontally towards the centre. The metallic minerals have tended to deposit between the bases of the crystals and the mica walls, and in druses amongst the crystals themselves. As will be demonstrated in a later chapter these veins are probably of hydrothermal origin.

At Kanbauk there is definite evidence of the occurrence of wolfram in shoots, which are often well demarcated, although the mineral also occurs disseminated elsewhere in the veins. The wolfram of the Kanbauk veins is coarser than usual and its crystalline habit is typical. The veins themselves vary from 3 to 24 inches, with an average of about 10 inches, in thickness. Thus they follow the general rule that veins in the sediments are thinner than those in granite. They also follow another general rule and form thin overlapping lenses, the duplication taking place in a left-handed direction. At least one flatter vein cuts the more steeply inclined ones in Kanbauk proper. It is said to be richer than the others and to go straight through them without displacement. Evidences of deposition of wolfram on the vein walls are common. Sometimes the mineral has to be broken away when the vein quartz is removed, often it is wedged in between the wall and the terminations of quartz crystals. At other times it is splashed irregularly in small crystalline aggregates in the matrix.

Associated minerals are pyrite, chalcopyrite, galena, marmatite and native bismuth. Fluorite and siderite have been found.

Mining and milling.—The veins are systematically opened up and stoped by a series of drives from 60 to 100 feet apart vertically. Two main low level adits have been driven which give a maximum of backs of about 400 feet. Temple-Ingersoll electric rock drills are used in the harder country rock. The ore is trammed to gravity inclines and thence to the mill, which was erected in 1914 and consists of 10 heads of stamps of 1,100 lbs. dropping 8 inches, with a screen aperture of $\frac{1}{2}$ inch. There are four Wilfley tables of Nos. 5 and 6 types. The installation is driven by a Pelton wheel when water is available and by a 32 b.h.p. Hornsby engine, assisted by a 12 h.p. portable engine and boiler, at other periods.

The Kanbauk valley is filled with detrital, alluvial and possibly lacustrine deposits in part, which in the centre are over 100 feet in maximum depth below the present surface. The old valley probably follows the general course of the modern one in its upper reaches, and deposition was doubtless aided to a considerable extent by the regional subsidence of the land, proved by observations on the adjacent sea coast and by the fact that the rocky floor of the central part of the valley is below the present level of the sea. The present valley surface is approximately 1,500—1,800 feet from east to west across at its wider parts. At the western edge true talus deposits predominate but as these are followed out towards the centre, the evidences of water action become more apparent and river sorted alluvial wash intermingles with the others. Certain sections of clayey material characterised by the occasional presence of large rounded boulders are believed to represent silts laid down in the comparatively stagnant waters of a lagoon formed by temporary damming, by floating trees carrying masses of earth and subsoil attached to their roots. This is a common enough phenomenon in Tavoyan floods at the present time.

The thickest sections of these deposits are exhibited in a large cut made by sluicing. Here the shallow talus deposit can be traced down the hill side, and at the bottom, where the slope begins to change, a great depth is attained at once. The material is exceedingly stony, and boulders, often of great size, are interspersed through the clayey mass, but further down, as the surface becomes flatter, a distinct banding can be observed below the uppermost layer. In the deepest part of the cut, the ground is blacker and finer; there are thin sandy bands and stones are fewer in number. They are mainly decomposed argillites. The band is 20 feet thick, with its bottom layer unexposed and passes up into a brown clay at least 20 feet thick with great numbers of stones. This in its turn passes up into reddish surface stuff of normal stony character. While the larger stones are roughly rounded the smaller ones show comparatively few signs of violent attrition. Large pieces of quartz and whole sections of mineral-bearing veins occur in the clays.

In the Elevator Cut further out towards the centre of the valley, the prevalent material is a brown clay containing stones of all sizes laid at all angles with little or no sign of stratification. The stones, which are only roughly rounded, are slates and sandy quartzites with vein quartz boulders and rare pieces of granite. Laterally and further to the east the brown clay passes into a mottled reddish-brown and yellowish material and white fine clay with groups of boulders at irregular intervals. It includes a few curved stringers of granulated quartz which are displaced and broken by later settlement. There are also blue and black patches and layers of pure white kaolin in this material, which in its turn is surmounted by a thin layer of ordinary surface detritus. On weathering the mottled silt assumes a uniform brownish-white appearance. Bands of it have in places undergone lateritisation and in extreme cases form masses of hard black ironstone. Further east still and close to the bed of the present stream, the upper layers of the deposit are not so stony but the stones themselves are rounded and quartz is commoner.

The complexities of the structural geology of the Kanbauk valley deposits are too many to consider here, especially as much of the available evidence is derived from bore holes made by the percussive drill, but it may be pointed out that they are very much disturbed, that patches of Mergui rocks appear to occur with alluvium underlying them, that there are vertical subterranean cliffs of argillites with alluvium banked up against them, and that the bedded alluvium has been folded into vertical and inverted positions. Apart from the rapidly changing conditions during the time of deposition, which include soil creep, and river and lake action, possibly with the occurrence of land slides by which blocks of Mergui rock bodily overrode the older alluvium in places, profound disturbances have been brought about later both by recent or sub-recent faulting and by the solution of the calcareous portions of the underlying floor, resulting in collapse of patches of the deposits.

The whole of these valley deposits carry wolfram and cassiterite and they have been tested systematically by means of pits and bore holes. According to H. D. Griffiths, at the end of 1917, "the area proved exceeds 173 acres, and a conservative computation gives 8 million cubic yards capable of being worked at a profit."[1]

The wolfram content of the concentrate obtained by the treatment of these deposits decreases as the distance from the western hill slopes increases, but the cassiterite contents increase at the same time, until in the middle of the valley a rich cassiterite concentrate is found. In the article quoted Mr. Griffiths states that

[1] H. D. Griffiths, (13), p. 215.

the computed average value in wolfram or cassiterite was 1¾ lbs. per cubic yard, while the acutal return made by sluicing over 350,000 cubic yards of this material was 3·31 lbs. The exploitation of these unique deposits is undertaken on a large scale by an electrically driven plant designed by the late Mr. C. M. Lyons, O.B.E., the General Manager of the mine, who for many years advocated and practised scientific mining in Tavoy and who gradually evolved methods which now result in Kanbauk possessing the largest hydraulic mining installation in the Indian Empire.

The following summary of the methods used in working these surface deposits has been given recently by R. Coleridge Beadon :—

"Water is brought to the mine by two steel flumes, capacity 25 and 35 cubic feet per second respectively, and of a total length of about 3 miles.

The working pressure varies from 125 to 150 lbs. per square inch, while the equipment includes four 8-inch and two 12-inch monitors with nozzles ranging from 2 to 4 inches.

Two hydraulic elevators are used to elevate the gravel to heights of 50 and 45 feet respectively, but the former is now being replaced by a 12-inch gravel pump mounted on a pontoon and driven by a Pelton wheel ; this pump will lift a total height of 80 feet and enable deeper ground to be worked.

The water and gravel is passed over grizzlies with one inch spaces, the stones being passed down a steel chute to the end of the boxes where they join the main flow in the tail race.

Two main sets of boxes are used. Each contains three compartments 12 feet wide and 130 feet long.

They are cleaned up about once a month by sluicing them out with a fire hose and elevating the concentrates to the cleaning box with a 6-inch hydraulic elevator.

As the concentrate contains large amounts of magnetite it has to be passed through the magnetic separator.

As the streams diminish rapidly when the rains cease, water is stored in a reservoir, 2,200 feet above the mine, by means of a "rock-fill" dam 650 feet long and 51 feet high. The dam consists of a reinforced concrete face with a backing of hand-laid dry stone work, and has proved very satisfactory.

The capacity of the reservoir is 500,000,000 gallons and this together with the natural flow of the stream will enable 1,000 H. P.

to be developed during the greater part of the year, though at present only the first unit of 500 H. P. has been installed.

The water is piped direct to the mine 3 miles away and will operate an impulse turbine under a working head of 2,000 feet. The turbine is directly connected to a 375 k.w., D. C., generator at 750 r.p.m. and 500 volts.

The power will be used to operate a pump dredging plant, the mill, and workshops, and the electric drills and separator."

The first pontoon carries a 12-inch gravel pump connected to a 180 B. H. P. motor and a 12-inch turbine pump also directly connected to a 220 B. H. P. motor, this will supply 3,400 gallons per minute to a monitor under a pressure of 70 lbs. per square inch.

Direct current was selected because a large speed variation of the motors to suit the varying pumping heads is required, also as the transmission lines are short there was no great advantage to be obtained by the use of alternating current.[1]

Placer deposits of cassiterite occur on the flatter ground near the shores of the Heinze Basin, and although production from them has been insignificant in recent years there are large areas of ancient workings. The deposits of Booth's Grant and adjoining areas are now being tested systematically by boring.

Taung-shun-taung.—Four miles west of Kanbauk and on the eastern flank of the range is the Taung-shun-taung mine, owned by a syndicate of Mr. R. Ady and several others. The most noteworthy feature of this mine is the occurrence of flat veins similar to that at Medaw Kanbay. Detrital deposits are worked during the rains. Although the original prospecting license was given out earlier, the mine only commenced operations in 1916 and the output since then has been as follows:—

	Tons.
1916	21
1917	26
1918	29

The average content of metallic tin in these concentrates is about 35 per cent.

[1] R. C. Beadon (1), pp. 60-61.

Pachaung.—South of Kanbauk, the Coastal Range rises rapidly and attains its maximum elevation in the peak Paungchon Taung, 3,805 feet above the sea. Approximately midway between Kanbauk and this peak is the Pachaung Mine of the Wagon-Pachaung Wolfram Mines, Ltd., lying slightly to the east of the main ridge on a narrow spur of sedimentary rocks which wrap over on to the higher slopes of the granite behind. The first prospecting license over Pachaung was taken out by C. Su Don in 1910. In 1914 a lease was granted to the Wagon-Pachaung Wolfram Mines, Ltd., for a period of 30 years. The area covered by the lease is 2,162 acres. Since that date the production has been as follows:—

	Tons.
1912	31
1913	28
1914	40
1915	15
1916	52
1917	70
1918	48

There are a number of veins which are as a rule thin and range up to a maximum of 2 feet in thickness. The general strike is north-east and south-west with dips of 25° to 60° to the north-west, but there is another series with an approximate east and west strike and a northerly dip. Some of the veins are very distorted, especially those which strike east and west. In places they stand practically vertical, while within a few feet they lie almost flat. The smaller veins are richer in wolfram than the larger ones; in the latter the mineral sometimes occurs at the edges, separated from the country rock by a layer of mica, but generally it is found in bunches in the middle of the quartz.

Kechaung.—The Pachaung veins are worked on the northern slopes of an extremely steep ridge which divides the drainage of two small tributaries of the Tavoy river. On the southern slopes of the same ridge, the extensions of the same veins are worked in the Kechaung concession of Quah Cheng Guan. According to Mr. Page the ridge itself is probably but 70 or 80 feet thick through within 50 feet of its summit. The boundary line between the two mines runs along the knife-edged top of the ridge. It is obvious that the remarks already made regarding Pachaung apply with equal force to Kechaung, where if anything the crushing and distortion of the veins is more severe. This mine was first opened in 1910 and its output since then has been as follows :—

	Tons.
1910	2
1911	45
1912	35
1913	38
1914	64
1915	28
1916	30
1917	37
1918	31

A mining lease over 220 acres was granted from 1914 for a period of 30 years.

Both mines are worked by hand methods only and both produce a very clean wolfram concentrate. The average tin (metallic) content in the Kechaung ore for the year 1917 was only about 1 per cent.

Egani.—To the south-west of the Paungchon Taung, but again on the sedimentary series, is the Egani mine of the Egani Tavoy Mining Co., Ltd. The workings are situated in and about a hill known as the Baw Taung, rising about 555 feet above sea level some 2½ miles west of Tavoy river at Tanyed-in. The first prospecting license was granted in 1911. Since then the output has been as follows :—

	Tons.
1911	13
1912	20½
1913	13
1914	19
1915	*nil.*
1916	7
1917	16
1918	17

A mining lease of 1,185 acres was granted from 1914 for a period of 30 years to Messrs. Foucar & Co., Ltd., of Rangoon.

The Baw Taung has been subjected to considerable movement and a large fault seems to have completely cut off the southern extensions of the veins. The fault itself has a strike of north 10° east and dips towards the west at 75°. For a zone extending over a width of 60 feet in the region of the fault the rocks are said to be shattered and altered.

The strikes and dip of the veins are given in the following list :—

B vein strikes	31°	north of west	and dips vertically.	
C	,,	33°	,,	,, 70° to the north-east.
D	,,	37°	,,	,, 70° to south-west.
E	,,	43°	,,	,, 70° to south-west.
F	,,	31°	,,	,, 70° to south-west.
H	,,	24°	,,	,, 80° to north-east.
K	,,	30°	,,	,, 80° to north-east.

Minor faults have been met with in the workings but they need not be described here. The veins tend to be thin and the greater amount of the ore, both wolfram and cassiterite, occurs in bunches. Parts of some of the veins contain felspar and are thus pegmatites. The associated vein minerals are sulphides of iron and copper with fluor spar. The veins are being systematically opened up and a small prospecting stamp battery driven by steam has been erected.

The alluvial deposits at Egani contain cassiterite and are now being tested. The ordinary detrital concentrates are high in tin values which sometimes rise to 25 per cent. of metallic tin.

From the latitude of Egani the Coastal Range continues more or less directly south to Tavoy Point where it disappears under the sea, re-appearing again in Tavoy Island and other islands of the Mergui Archipelago further south still. No mineral veins of any economic importance have been found in it, though a wolfram-bearing quartz vein is known to occur high up in the granite range opposite the village of Thebon, and another in a low hill of sediments in the Tawshe rubber garden, both of which places are within a few miles of Tavoy.

It is a matter for speculation why more veins have not been found in the southern extension of the Coastal Range. It has certainly received attention from prospectors, as it is the most accessible of all the granite intrusions of the district and is bordered by the thickly populated portion of the Tavoy plain along its entire length. We offer the suggestion that it has been denuded below the limit in which veins are likely to occur, an idea which may be confirmed by the relative abundance of black biotite mica in it, as compared with the white muscovite granites which we know form the bearing portions of the intrusions elsewhere.

The Frontier Range.

The range which separates the Tavoy district from the Kingdom of Siam rises to heights of over 3,000 feet in the latitude of the

Heinze Basin and consists of intrusive granite of the ordinary type. Wolfram was discovered in it in the open season of 1916 by native prospectors and, although the region was most difficult of access, numerous concessions were applied for in 1917 and great hopes were entertained that a large extension of the main mineral-bearing zone of the district had been discovered. Extensive prospecting has however shown that the actual bearing area is small and is confined to the two concessions of Messrs. Steel Bros. & Co., Ltd., and Maung Sein Khine. They are situated near the contact of the granite and the Mergui sediments above the bend which the Zinba stream makes to the south-west.

Steel Bros. Zinba.—This concession was granted to The Burma Minerals, Ltd., in 1916 and at a later date it was sold to Messrs. Steel Bros. & Co., Ltd. In 1917 it produced 25 tons of concentrates and in 1918 77 tons. It contains several thin veins which are believed to be of pegmatitic origin and to strike north and south, though this observation is uncertain. A good deal of the production, which is won entirely by hand labour, comes from the detrital deposits. The concentrates are practically tin free, the average content being about ¼ per cent. of metallic tin. Molybdenite, bismuthinite, oxidised bismuth compounds and fluorite also occur.

According to Dr. Morrow Campbell the order of deposition is molybdenite, bismuthinite, fluor spar and quartz, commencing with the first; the minerals have been observed in thin bands in this order commencing from the outer granite wall of the vein. In other veins there are intimate intergrowths of molybdenite and bismuthinite and both are sometimes found in the form of rounded pebbles completely enclosed in quartz. Antimonite has also been found in small quantities. Hair-like crystals of bismuthinite enclosed in quartz crystals are known and interesting greisens containing wolfram, scheelite, molybdenite, bismuthinite, chalcopyrite and pyrite. In one place Dr. Campbell discovered a tourmaline pegmatite on the wall of a wolfram-bearing vein, while the same authority reports a very large quantity of tourmaline in large quartz veins right on the Siamese frontier at an altitude of about 3,300 feet. There are remains of a former covering of sedimentary rocks at about 2,700 feet above sea level on the spur west of the mine, and within a mile of the frontier, so that the evidence is strong that the bearing veins occur near a dome as well as near a marginal contact.

Maung Sein Khine's Zinba.—This mine adjoins Steel Bros. on the east and reaches up to the frontier. The workings are near the boundary with Steel Bros. and are really part of the same deposit. In 1917 it produced 4 cwts., and in 1918, 13 tons. There is a small prospect to the south of Sein Khine's mine known as Ethe chaung and licensed to Khoo Zun Ni. It produced over 2 tons in 1917 and 2 tons in 1918.

The Kaleinaung Intrusion.

This is a long narrow lobe of the Frontier Range intrusion and its eastern boundary follows the north and south portion of the course of the Zinba chaung. Various prospecting licenses have been taken up in and around it for a number of years but up to date it has yielded nothing of importance. From an area known as Pawaye near its eastern boundary and close to the stream itself, Messrs. Booth and Milne extracted 3 tons of concentrates in 1918. Their area formed part of a larger one originally belonging to Shwe Goe, who extracted a somewhat larger quantity from it.

The Bolintaung-Byaukchaung Range.

This is built up of a lobe of granite from one to three miles wide which runs in a north-westerly direction for seven miles from the Bolintaung peak, joining the main Sinbo-Sinma massif. The latter, although one of the largest expanses of granite in the district, contains only one or two mines and is now reserved for a cinchona plantation. The Bolintaung range is breached by the Talaingya river. Practically the whole of it is covered with mining areas and on the south the surrounding country too is given out in small concessions, none of which produce any large quantities of ore. They are, with few exceptions, small native-owned concessions worked on hand to mouth principles.

Bolintaung.—One of the important exceptions, where development is being undertaken systematically, is Messrs. Bulloch Bros.' Bolintaung area, which lies on the eastern side of the main steep intrusion, which is here about a mile across and culminates in a peak 1,000 feet above sea level. It forms part of a large area which in the early days of the field was held by The Burma Malaya Co., Ltd., and in which Mr. Page recorded 7 veins varying from ½ to 2 feet in thickness in 1912 or 1913. The following data are from notes supplied by Mr. Arthur G. Wood, Mining Engineer to Messrs. Bulloch Bros. & Co., Ltd.

The general strike of the Bolintaung veins is a north and south one with a variation to the east of north of from 4° to 22°. The dip is usually to the east and is high, from 77° to 87° with the horizontal. There are however cases of veins in certain sections of the property which vary greatly from the general direction. Thus in North Camp section two veins have strikes of N. 80° W. and N. 89° W. and high dips to the north. These veins are about 1 foot and 2 feet thick respectively. Speaking generally these cross veins are of hard, vitreous white quartz and, with one exception, are not productive. The average width of the normal veins is from 2 to 3 feet. Mr. Wood states that in the case of the North Vein, which varies in width from 2½ to 4½ feet and strikes N. 14° E., some of the richest ore from the opencut workings was extracted at points in the vicinity of the intersection of the cross veins. Altogether six veins were being developed in 1918.

Byaukchaung.—The largest mine on this intrusion north of the Talaingya stream is Byaukchaung, the property of Tavoy Concessions, Ltd.[1] It was opened in 1911 and is now held under a mining lease of 616 acres granted for a period of 30 years from 1917. It has produced as follows:—

	Tons.
1911	10
1912	31
1913	63
1914	71
1915	44
1916	90
1917	72
1918	47

The concentrate is a high grade wolfram product averaging about 5 per cent. metallic tin and 64 per cent. WO_3. There are a few veins on this mine but they have never proved profitable to work. On Monitor Hill there are two in granite varying from 2 to 5 feet in width, of short extensions, vertical dip, and striking N.E.-S.W. On the Ninhla hill a narrow quartz vein with greisen walls strikes N. 20° E. and S. 20° W. and has a vertical dip. The longest vein on the Dapho hill strikes N. 10° E., S. 10° W., but it is not a well-defined fissure The chief characteristic of Byaukchaung is the extensive metamorphism and extreme minera-

[1] Now Burma Finance and Mining Co., Ltd

lisation of the granite. The concentrates are won by sluicing the decomposed ground *in situ* and they come from innumerable short stringers and greisen bands which penetrate the granite at all angles and in all directions and have consequently enriched the surface deposits wherever the granite occurs. Instead of forming fissure veins as is usually the case, the mineralising agents seem to have permeated the whole rock and it is interesting to note that this has taken place only in the immediate vicinity of the contact.

The greater part of the output of this concern is obtained in the rainy season when water is abundant, though the long flume line now under construction will enable water to be delivered to the working places for a longer period during the dry weather than has been the case formerly. A small pumping installation driven by a semi-Deisel oil engine is also used to supply water for sluicing during the dry season.

The granite ranges in the Byaukchaung lease rise to over 2,000 feet above sea level.

Kalonta.—The Kalonta mine of Tavoy Concessions, Ltd.,[1] lies on a small granite boss of its own, two miles further east up the valley of the Talaingya from the main intrusion. The smaller and larger intrusions are probably connected underground as there is great similarity in structure, appearance and in the changes which both the Byaukchaung and Kalonta granites have suffered both as a result of mineralisation and of atmospheric decomposition. Both vein mining and surface operations are carried out at Kalonta, the veins outcropping in a greisenised granite hill known as Adit Hill. The hills surrounding it are all capped with argillites and it is evident that the structural conditions are again very favourable, in that the original outer layers of the boss are left and that it has undergone but little denudation.

The original prospecting license was granted in 1910 and a mining lease over 1,092 acres followed in 1917, for a period of 30 years. Output has been as follows :—

	Tons.
1911	21
1912	8
1913	26
1914	25
1915	40
1916	90
1917	91
1918	140

[1] Now Burma Finance and Mining Co., Ltd.

The average composition of Kalonta concentrates is about 42 per cent. WO_3 and 28 per cent. Sn.

On Adit Hill there are 10 veins which are worked, varying in thickness from 8 inches to more than 2 feet. They are all in granite or greisen with well-defined walls. There is very little evidence of faulting. Strike extensions vary from 650 feet to over 1,000 feet and directions from 12° to 22° east of north, west of south; the average bearing is 15° east of north, west of south and the dips are all towards the west at angles varying from 59° to 70°. On the East Extension hill there is a thin vein of unknown length which bears 10° east of north and west of south with a dip of 70° towards the west, that is to say, towards the centre of the main intrusion.

Fitzherbert's Sinthe.—About 3 miles to the west of the Bolintaung peak, the Sinthe tin mine is situated, not far from the east bank of the Tavoy river. Operations are confined to ground-sluicing the soil and decomposed overburden which is two or three feet thick, and lies above soft argillites and quartzites of the Mergui series on a steep hill side; these rocks are penetrated in all directions by thin quartz stringers, often of almost microscopic dimensions, but rich in cassiterite. The concentrate produced is a high grade tin ore which does not contain wolfram. Working can only be carried on in the wet season when storm water is available. Twenty-two tons of tin-stone were won by this method in the rainy months of 1918. The proximity of the Bolintaung granite evidently has a bearing on the origin of this peculiar deposit.

Other Small Mines.—Other small mines in this neighbourhood include Sein Daing's Talaingya and Dauklauk, E Zin's Talaingya, the Bombay Tavoy Mining Co.'s Talaingya and Ong Hoe Kyin's Talaingya.

The Kyaukanya Peneichaung Intrusions.

South of Bolintaung the granite disappears under its sedimentary covering but it comes to the surface again a few miles further to the south, along the same direction of strike, in the hill to the east of Kyaukanya known as Kadantaung, again near Byindaung, then in the valley of the Maungmeshaung near Kadando and finally in the Peneichaung hill of Crisp's concession. A glance at the geological map will show that all these places are more or less on a line which runs parallel to the axis of the main granite intrusion of the

Central Range, and that an extension of the line south-south-west passes through the well-known Pagaye Mine.

The whole of this belt of country is covered with mining concessions and although the great majority of the occurrences are small and do not lend themselves to large scale development, they have found an outlet for the activities of small owners, employed the floating population of the neighbouring portions of the Tavoy plain and produced a large quantity of concentrates in the aggregate over a number of years.

Fitzherbert's Kadantaung.—A typical example is Fitzherbert's Kadantaung which was sold to that owner by C. Su Don, to whom it was originally granted in 1910; a mining lease for a period of 30 years dating from 1914 has issued in 1917. It has produced as follows:—

	Tons.
1911 } 1912 }	19
1913	9½
1914	7½
1915	2
1916	6½
1917	8
1918	16

In the main working place the mineralised zone is about 800 feet across and it contains at least 11 veins varying in thickness from a few inches to three feet. They strike approximately north 40° west, south 40° east and dip at high angles to the north-east. The country rock is granite and the veins are erratic and low grade. Ground-sluicing is carried on the rains. The veins carry down into the hard granite but here as elsewhere under similar conditions they are unworkable by local tribute methods.

Tavoy Concession's Kyaukanya.—Adjoining Fitzherbert's Kadantaung on the south is the Kyaukanya property of Tavoy Concessions, Ltd.[1] The original prospecting license was issued in 1911, followed by a mining lease for a period of 30 years. Production has been as follows:—

	Tons.
1913	23
1914	39
1915	32
1916	18
1917	9
1918	10½

[1] Now Burma Finance and Mining Co. Ltd.

The most important group of workings is situated about the head of the Byindaung chaung where the country rock consists chiefly of argillites of the Mergui series containing a mineralised zone which may be as much as 500 feet wide. The zone is penetrated by a series of thin quartz veins carrying wolfram and varying in thickness from 1 to 8 inches. One better developed vein attains a thickness of 2 feet. It is known as the "Tank Lod·." The general strike is east 15° north, west 15° south and the dip from 30° to 50° towards the north. There are indications of a cross series striking a few degrees west of north and east of south. Mr. Page in an early report on the mine wrote:—"I have however seen an almost horizontal vein which intersected one of each of the other two sets of veins. The steep veins are all sufficiently rich to be working, but the horizontal vein appeared to be barren." The ore channel has been worked entirely on the tribute system. The veins are followed by open cuts and short adits in the dry season while the overburden and rotten rock is sluiced in the rains.

The great Kadando vein extends into the eastern portion of the lease, where it averages two feet in thickness, strikes north 10° west, south 15° east, dips towards the east at 75° and carries wolfram, pyrite, chalcopyrite and pyrrhotite.

Kyaukanya ore averages about 68 per cent. WO_3 and 1 per cent. to 2 per cent. Sn.

Tavoy Concession's Kadwe.—This mine adjoins the same firm's Kyaukanya lease on the south. The first prospecting license was issued in 1909 and a mining lease for a period of 30 years followed. The output has been as follows:—

	Tons.
1913	54
1914	126
1915	107
1916	44
1917	22
1918	11

The concentrates average about the same composition as those from Kyaukanya.

A system of bearing veins originally cropped out at the summ't of Kadwe hill in argillites of the Mergui Series and in the earlier days of the mine these were worked by deep open cuts. Thay varied in thickness from a few inches to about two feet and had strikes varying from north 30° west, south 30° east to north 10°

east, south 10° west, with dips of 60° to 68° towards the east. The upper portion of the hill is now practically exhausted. In 1915 a series of cross-cuts had been driven into the hillside at various levels to intersect the veins, which were then driven on. The more important of these, starting from the bottom, were numbered 35, 33, 15, 14-A and 11. The vertical distances between them were as follows; between 35 and 33 about 180 feet, between 33 and 15 about 176 feet; between 15 and 14-A about 25 feet; and between 14-A and 11 about 20 feet. The veins in the upper levels proved profitable to work for a time but as deeper levels were opened up the enterprise became unremunerative and all underground work was abandoned. Small quantities of concentrates continue to be won by ground-sluicing the top of the hill. The necessary water is lifted a height of 700 feet through a pipe line about a mile long by a steam-driven pump on the Maungmeshaung stream.

The Kadando vein.—This vein crosses the eastern portion of the Kadwe lease into Kyaukanya. It is well exposed on the Hermyingyi road about a mile above the Maungmeshaung bridge, where it leaves the Kadwe lease and enters Crisp's concession. In Kadwe it varies from 3 to 5 feet in width, has a vertical dip and strikes a few degrees either east or west of north in different places. It has been traced for many thousands of feet and is the longest known vein of the district. It is remarkable for the large amount of sulphides it carries in addition to wolfram.

Crisp's Concession.—On the south side of the Maungmeshaung stream, Crisp's Concession stretches along the Peneichaung hills from Yewaing to Pagaye, a distance of nearly five miles. Originally taken out in 1910, this property is now under a 30-years' mining lease which dates from 1914. It has an area of 1,561 acres. Its production has been as follows:—

	Tons.
1911	46
1912	27
1913	20
1914	22
1915	23
1916	56
1917	77
1918	76

Wolfram-bearing veins occur in many sections of the property such as Hoon chaung, Kadando, Taungthit, Yebok, Aungdaung, Peneichaung, Kyaukpyin, Yekanzin and Kamaung. With the exception of the Peneichaung veins, which are in granite, they are all in a sedimentary country rock. The general strike is the normal one for the region and dips are usually high. In the dry season the concentrates are won from open-cuts and tribute adits in soft ground. In the rains ground-sluicing is practised. In 1916 a working option was taken over the property by the Bombay Burma Trading Corporation and experiments were made in pump-sluicing and milling. These were abandoned when the Corporation surrendered its option in 1918. Large masses of wolfram, some of which attain a weight of 3 cwts, have been recovered from the detrital deposits at the base of the Thitpyintaung hill.

Excellent sections of the undecomposed Peneichaung granite can be seen in the Kyaukpyin quarry, where wide bands show extensive greisenisation and contain pyrite, chalcopyrite, and galena, with thin films of a violet fluorspar. This is the granite which contains the Peneichaung wolfram-quartz lodes at a higher elevation.

Crisp's Concession also has a number of peculiar barren, crystalline quartz veins, made up of myriads of small, opalescent quartz crystals, more or less imperfectly formed and set at all angles. They are not associated with the wolfram-bearing veins proper and were perhaps formed at a later period and represent a phase of hydrothermal activity.

Rangoon Mining Co.'s Pagaye.—This mine lies to the south of Crisp's on the southern side of the Pauktaing stream. It is the oldest mine in the district and was discovered by Mr. J. J. A. Page of the Geological Survey of India in April 1909. The prospecting license dates from 1911. In 1916 a mining lease for a period of 30 years was issued. Its production has been as follows:—

	Tons.
February 1910 to August 1910	105
August 1910 to August 1911	324
„ 1911 to „ 1912	264
„ 1912 to „ 1913	148
„ 1913 to „ 1914	118
„ 1914 to „ 1915	68
„ 1915 to „ 1916	110
„ 1916 to „ 1917	178
„ 1917 to „ 1918	202

The mine is the property of the Rangoon Mining Co., Ltd., and paid handsome dividends in the early days of its existence. In 1915 the management passed to Mr. J. W. Donaldson Aiken on a partnership basis. In August 1916 this was transferred to the Bombay Burma Trading Corporation, Ltd., who still hold an option to purchase it. The Rangoon Mining Co. has an authorised capital of Rs. 3,50,000, of which Rs. 2,10,000 are issued.

The main mineralised zone, or, as it is known on the mine, the "A" system, has a known strike extension of over 3,000 feet and its limits have not been determined. It runs in a north 38° westerly direction. Parallel to it and some 500 feet away on the south side of the stream there is another zone, while a third series cuts across the first one striking north 38° easterly. The general vein strike within the first two zones is 42° west of north and east of south and the dip 80° to the north-east. The cross veins strike 38° east of north, west of south and dip at 80° to the north-west. The exact strike of any one particular vein is impossible to determine because the system consists of a mass of veins which coalesce and branch in all directions. These are the remarkable Pagaye pegmatites whose mineralogical features have been described in another chapter. According to Mr. A. H. Morgan, the General Mining Manager of the Corporation, to whom we are indebted for much information, variations in the strike are due to these divergencies, and actual measurements give in an extreme case a strike 17° west of north and others between this extreme and the mean. Mr. Morgan points out that the cross veins are more constant in width and bearing, that they appear to have been formed simultaneously with the main veins and that no differences are observable at the intersections. "The wolfram and tin-stone are unevenly distributed throughout the veins and the richer patches may be termed ore shoots, but they are not absolutely isolated as there are usually specks or small bunches of ore in between." It now appears certain that the Pagaye pegmatites come to the surface as we know it, split up into almost innumerable stringers which are often extremely rich—sometimes solid wolfram or cassiterite or both. Scheelite also occurs in them and the edges are always bordered with mica. As they descend through the argillites they coalesce and widen. In the hard rock of the lowest workings they broaden out to 6 feet and seem to promise still greater widths at lower depths. Felspar appears in greater quantity with depth and very often there is a peculiar banded arrangement with the felspar on the sides of the vein and the quartz in the middle, as contrasted with the more usual chessboard pattern.

In 1911 a mill was erected. It has been enlarged and altered from the original design and since an air compressor and machine drills were introduced has run continuously. It consists of a rock breaker, three pairs of rolls (22, 18 and 8 inches), three jigs, two rotating screens and two Wilfley tables. It is driven by a 40 H. P. Campbell oil engine.

The compressor is an Ingersoll Duplex machine of 300 cubic feet per minute capacity, driven by a 55 H. P. Petter's semi-Diesel oil engine.

Another machine installation consists of two high speed Bellis and Morcom steam engines of 50 H. P. each (supplied from two water tube boilers by Thompson of Castlemaine) direct coupled to a 10 inch centrifugal pump. These are used in the treatment of the high level detrital deposits of the slopes on both sides of the valley. It is interesting to note that there is a vertical difference of height of 400 feet between the lowest and highest underground workings on the "A" system.

In 1918 a concentrating pan similar to the type used at the Burma Ruby Mines and the Kimberley diamond field was erected. The pan is 10 feet in diameter and has attached to it a grizzly, a rotary screen and picking tables. It is driven by a 20 H. P. Hornsby-Akroyd oil engine which also propels a 3-inch centrifugal pump which supplies water in sufficient quantity to meet the requirements of the whole plant. The pan has a capacity of 100 cubic yards a day and it is claimed that it saves a larger proportion of fine concentrates and does the same work with about a third of the amount of water required by an average sluice box.

Further down the valley there is an alluvial flat containing a bed of cassiterite-bearing gravel. A plant has recently been erected to deal with this. The ground is opened up in a "paddock" and the pay dirt raised in trams to sluice boxes. Two rotary screens and a haulage winch complete the machinery, the whole being driven by a 22 H. P. Hornsby oil engine.

The following assays may be taken as typical of Pagaye concentrates :—

	Per cent.	Per cent.
Detrital concentrate	80 wolfram.	18 cassiterite.
Vein ,, ...	86 ,,	10 ,,
Alluvial ,, ...	15 ,,	69 ,,

Fowle's Yanmazu.—About a mile and a half to the east of the granite exposure in the Peneichaung hill (Crisp's Concession), the Yanmazu lease of Mr. T. Fowle is situated. Originally granted as a licensed area for prospecting in 1912, it is now held under a mining lease covering 293 acres for a period of 30 years from 1914. Its production has been as follows:—

	Tons.
1912 } 1913 }	4
1914	1
1915	6
1916	9
1917	31
1918	7

The workings are situated on the slopes of a hill built up of argillites of the Mergui Series and most of the production comes from a series of thin quartz veinlets carrying both wolfram and cassiterite, which strike north 18° west, south 18° east and have a vertical dip. There are also a few longer veins which strike further to the west of north. In 1917 the mine was worked by the Rangoon Wolfram Co., Ltd., who adopted open-cut methods on a large scale.

Detrital deposits occur on the hill slope below the vein zone and there are old tin streaming works in the valley of the Pauktaing at the foot of the hill.

Fowle's Yanmazu North.—The main vein system of Yanmazu crosses over the Pauktaing into the next concession of Yanmazu North, where however it has failed to yield much ore. Of more interest is a large vein in another part of the same area which has the distinction of having furnished the first specimens of scheelite found *in situ* in the district. It is about 2 feet in thickness, strikes approximately 20°—25° west of north-east of south and has a high dip towards the west. It consists of a very dense and hard quartz containing acicular wolfram together with some scheelite. The wolfram is fine and very evenly distributed in the vein-stuff. The scheelite is white to light yellow and occurs between the quartz crystals which make up part of the vein.

The Sinbo-Sinma Massif.

There is a certain amount of mineralisation about the border of this great granite massif some five to seven miles north of Hermyingyi, though the occurrences are of more theoretical than economic importance. About 4 tons of concentrates rich in cassiterite have been obtained during 1916, 1917 and 1918 from a prospect worked by Osman Musti Khan. The veins occur to the north of peak 3,550 in the vicinity of a small patch of Mergui sediments and they strike a few degrees west of north and east of south. The concession was called Sinbo-Sinma.

Ma Sein Daing's Sinbo-Sinma.—Further to the south and nearer the edge of the granite lies Ma Sein Daing's Sinbo-Sinma mine which produced 11 tons in 1918 and 10 tons during the two preceding years. Here there are at least five veins in granite with a general strike of 20° to 30° north of west and south of east, two of which dip southwards at angles of 65° and 70° and three of which dip northwards at the same angles. The veins are irregular and often thin. Horses of decomposed granite are often met with. On the eastern side of the main ridge there is, according to Mr. R. C. N. Twite, a very well-defined vein (Lode No. 1 East), which increases in width as it is followed into the hill side. At an elevation of 3,100 feet above sea level the vein is solid quartz but towards its outcrop it gradually splits up into a number of quartz stringers from 2 to 4 inches in width.

Myekhanbaw.—Still further south, and on the granite margin in a southward pointing lobe of the Sinbo-Sinma massif, is the Myekhanbaw mine, the property of Messrs. Steel Bros. & Co., Ltd., who purchased it from Mr. A. E. Wallenberg. The prospecting license dates from 1910, but before that time the area was held by Chew Lu Yin. Production has been as follows :—

	Tons.
1915	13
1916	7
1917	18
1918	31

The concentrates contain 47 per cent. of metallic tin. The Myekhanbaw neighbourhood is to be considered more as a source of tin-stone than of wolfram. Ancient alluvial tin workings are numerous, especially along the Seinpyon chaung. According to the local Karens these operations were conducted by Siamese Shans. There are numerous small veins and stringers on the area and it is from their disintegration that the detrital deposits have received their values. The part of Nalotaung on which the workings are situated is made up of a peculiar porphyritic granite, probably a chilled margin showing fluidal structures in a plastic cooling magma, with a capping of black and white fine-grained quartzite. The deposits are worked by monitors.

The contact of the Sinbo-Sinma granite with the Mergui Series follows a course parallel to the Htantalon chaung for some distance, and a number of veins, usually with a strike east of north and west of south, are known in the stream valley. They are worked in the concessions of Mahomed Adam, Ma Chein and Ung Kyi Pe.

The Hermyingyi Intrusions.

In the five miles of hilly country built up of rocks of the Mergui Series, separating the southern edge of the Sinbo-Sinma mass from the northern end of the Central Range, there are at least five small separate granite exposures which break through the overlying covering.

Ma Chein's Thitkado.—The workings of Ma Chein's Thitkado mine are situated on two of these. The original prospecting license was issued in 1911, followed by a mining lease in 1915. Output has been as follows :—

	Tons.
1913	7½
1914	6
1915	17
1916	11
1917	7
1918	35

The concentrates average 25 per cent. of tin oxide.

The workings are divided into three districts, *viz.:*—Kadan Taung, Taung Thit and Myai-ni Taung.

On the Kadan Taung, according to Mr. J. Thomas, Government Mining Engineer, two veins strike east-north-east and west south-west and dip about 30° to the south-south-east. Other small veins are known on the Taung Thit section, but both this and the Kadan Taung are more important by reason of their detrital deposits than of the veins themselves. The Myai-ni Taung district is, according to the same authority, the most promising section of the mine and the four parallel though thin veins which it carries are regarded as the continuation of the northern Hermyingyi group. They have been proved over a strike extension of 400 feet. The

Kanbin chaung vein, which is 12 inches thick, also crosses from the Hermyingyi property. It strikes north-west and south-east and dips at 80° to the south-west.

A vein about 12 inches thick, striking north-north-east and south-south-west, is also known to occur in association with the most northerly exposure of granite in this region.

Hermyingyi.—By far the most important of this group of small granite bosses is the southernmost, on which the Hermyingyi mine of the Hermyingyi Mining Co.[1], is situated. In 1909 Mr. Page recorded the existence of wolfram in roughly parallel veins from 10 inches to 5 feet in width in the granite of this locality, and in 1910 a concession was applied for by Mr. Baldwin on behalf of Tavoy Concessions, Ltd. This was granted in 1911. In 1917 a lease for a period of 30 years dating from 1913 over an area of 1,782 acres was granted to the company.

Since the commencement of operations the output has been as follows :—

Year.	Tons.
1910	0·9
1911	86·3
1912	177·8
1913	189·4
1914	432·12
1915	640·29
1916	755·41
1917	1038·0
1918	868

The approximate average composition of the concentrate for the past few years has been—Vein ore 46 per cent. WO_3 and 24 per cent. Sn. Detrital ore 38 per cent. WO_3, and 32 per cent. Sn.

The axis of the granite exposure is about 1,500 yards in length and runs approximately north-north-west and south-south-east. Its greatest width is 450 yards, but it narrows to considerably less than this at either end. It is breached by a small stream known as the Maungmeshaung chaung practically at right angles to its axis, and is thus divided into two hilly sections known as Tin Hill and Big Hill respectively, separated by the narrow valley of the stream. Both sections exhibit granite capped on the highest points and

[1] Now Burma Finance and Mining Co., Ltd.

covered partially on the slopes by sediments. On the top of both hills, the sedimentary covering is now about 200 or 300 feet thick and there is no doubt that it once extended right across. On the western margin the granite appears to emerge from the overlying rocks at a high angle while on the eastern margin the angle is much lower.

About 60 different veins have been worked. They occur in groups which have a general north and south trend and a steep easterly dip. They may be grouped as follows :—

The general strike of the veins in Big Hill is north-north-east, south-south-west with an easterly dip. On Tin Hill the general strike is north and south with an easterly dip. The exact strikes and dips of a number of the larger veins is given below :—

New Reef	Strike . . .	27° E. of N.	dipping	68°E.	Big Hill
No. 2 ,,	,, ...	28° E. of N.	,,	55°E.	,,
No. 3 ,,	,, ...	22° E. of N.	,,	65°E.	,,
55 Reef	,, ...	25° E. of N.	,,	75°E.	,,
419 ,,	,, ...	17° E. of N.	,,	68°E.	,,
No. 1 ,,	,, ...	20° E. of N.	,,	78°E.	,,
B ,,	,, ...	11° W. of N.	,,	86°E.	Tin Hill.
C ,,	,, ...	1° E. of N.	,,	87°E.	,,
Ba Eik Reef	,, ...	6° E. of N.	,,	86°E.	,,
Tha Baw ,,	,, ...	10° W. of N.	,,	83°E.	,,

Many of these veins are strongly developed and have been traced on the surface for distances of 500 to 1,100 feet. Like most other veins in the district they tend to vary considerably in thickness and in places to form long, drawn out, overlapping lenses. They continue through from the sedimentary rocks to the granite and carry both wolfram and cassiterite to the lowest point yet reached, some 400 feet below the contact. Faulting is prevalent and complicated and its general scheme will not be apparent until more underground development has been done. At present all that can be said is that the faults appear to throw in both directions without any special rule. Certain small fissures of more recent date than the main veins are said to cut them at an acute angle, the faults striking about 10°—15° more to the east or west as the case may be. The displacements caused vary from a few inches to two feet and there seems to be no enrichment of metallic ores at these points, though this is not always so. The small fissure veins themselves also carry values.

Owing to the softness of the rocks in the decomposed zone, underground production work has been carried on to a great extent without the aid of machinery, though an air compressor with an equipment of machine drills is used in the development work now being undertaken on Big Hill. Here, below the limit of alteration, both granite and sedimentaries are exceedingly hard.

Bands of greisen form borders to the veins in the granite and both granite and greisen from the altered zone rapidly break down on exposure to the air. The granite is an exceptionally white and fine-grained rock and is practically devoid of black micas or of iron ores. It is decomposed to a greater depth on Tin Hill than on Big Hill. The veins, with one or two notable exceptions, do not carry through from one section to the other and were perhaps formed in different fissure systems. The vein quartz is of the opaque, white, massive variety as a rule; glassy quartz and good crystalline structures are rare. All the veins carry mica. In the deeper parts of the veins galena, pyrite, chalcopyrite, molybdenite and zinc blende are found with wolfram and cassiterite. In the upper portions the sulphides have been leached away and the wolfram is often partially changed into tungstite. Molybdenite is commonest in the Waterfall vein. Oxidised compounds of bismuth, derived from the sulphide, are found in the hill-side detrital deposits on the eastern end of Big Hill. Fluorite is not uncommon in small quantities.

Evidences of movement such as slickensides, crushed quartz and contorted micas are often seen. In the Kanban chaung section of the mine there is an extraordinary occurrence of a fluorite-topaz rock bordering a wolfram-molybdenite-cassiterite vein in sediments. It is described in detail in another chapter (p. 58).

The detrital deposits of the hill sides are of great extent and value and are extensively worked in the rainy season by water which is led on to them by an elaborate and lengthy system of water races and flumes. In the bottom of the valley there occurs a thick deposit of clay, pebble and boulder beds partly, in our opinion, of detrital origin and partly the result of torrential stream action. This is worked by means of a monitor. An old river terrace with rich wolfram and cassiterite-bearing gravels has recently been uncovered at a height of 75 feet above the present level of the Maungmeshaung chaung. It owes its preservation to an overburden of 20 to 40 feet of eluvial deposit which appears to have slipped down from the hillside above it.

THE CENTRAL RANGE PROPER AND PAUNGDAW.

This intrusion commences as a rounded mass of granite, three quarters of a mile wide, about a mile to the south-south-east of Hermyingyi. Its western boundary runs south for seven miles and then swings around to the south-south-east. The eastern boundary follows approximately the same direction for 12 miles and then turns more to the east. As a consequence, the width of the granite belt, which is only ½ mile across at its constricted portion, is at least 6 miles, 20 miles further south. The total length of the intrusion is at least 32 miles so that its average breadth is small in comparison with its length. At its southern extremity the western boundary swings eastwards to meet the eastern one. The intrusion forms the high ridge visible from Tavoy and bears the peaks Pya Taung 3,575 feet), Khat Taung (3,545 feet), Nwalabo (5,063 feet) and the high massif of Southern Paungdaw which has one peak of 5,133 feet above sea level. Both sides of the intrusion are steep and precipitous in places. With the exception of Southern Paungdaw, that is to say the portion lying south of Lat. 14°, which is still imperfectly prospected and little known, practically the whole of the intrusion and its surrounding contact zones are covered by grants of ground held under prospecting licenses or mining leases. Especially characteristic of the southern portions are the isolated patches of sedimentary rocks which lie on the upper surface of the granite forming the last remnants of its former covering which still resist denudation. The intrusion is breached by the Pauktaing stream and fine sections of the granite are seen in its gorge. This carries the main easterly road and telegraph line connecting Tavoy with Siam.

(a)—MINES OF THE NORTHERN SECTION.

The northern section of the intrusion, which we define arbitrarily as the portion lying north of the Pauktaing valley, contains the Taungpila and Thingandon groups of mines.

Taungpila.—The most important of the former is Quah Cheng Guan's Taungpila, which was opened in 1912. The mining lease over 199 acres for a period of 30 years dates from 1915. The mine has produced as follows :—

	Tons.
1912	$28\frac{1}{2}$
1913	34
1914	22
1915	70
1916	65
1917	115
1918	127

The average percentage of metallic tin is approximately 40 per cent.

There are at least four veins of major importance, varying in thickness from one to two feet and over. They strike approximately north-north-west, south-south-east and have high dips. They carry good values and are very micaceous in places. Originally work was done in open-cuts on the outcrops but as these became exhausted the veins were followed downhill and opened up by cross-cuts and drives. All the concentrates are won by hand and no machinery is used. In the rainy season sluicing is carried on in the detritals of the surface and on the dumps from the underground operations. The beds of the streams at the bottom of the hill in which the veins occur also carried gravels which were profitable to work.

Taungpila No. 1 and No. 2.—North of the mine just described lies the Tavoy Wolfram Co.'s Taungpila No. 1, while to the south is the same concern's Taungpila No. 2. Both are held under mining leases which date from 1915-16. The prospecting license of No. 1 (Ma Safia's) was issued in 1912 and No. 2 (Ung Kyi Pe's Pa-in) in 1913.

Their production has been as follows :—

Taungpila No. 1 (Ma Safia's).	Tons.	Taungpila No. 2 (Ung Kyi Pe's).	Tons.
1913	20	1913	1
1914	$8\frac{1}{2}$	1914	4
1915	6	1915	2
1916	9	1916	15
1917	6	1917	14
1918	[illegible]	1918	33

On both these mines the geological conditions approach very closely those of Quah Cheng Guan's Taungpila, that is to say they are in granite close to its contact with the argillites. The veins, which as far as is known to-day, are not so numerous nor so strongly developed as those on that mine, yet possess the same approximate strike and general characteristics, cassiterite greisens bordering them being a common feature. All the concentrates are rich in tinstone. Hand mining and ground sluicing are carried on.

Hteinthit.—To the south of Taungpila No. 2, and still following the granite contact, is the Hteinthit mine of Mr. G. N. Marks. Though unimportant as a producer, this property is very interesting from a geological point of view. Its production for the past few years is given below:—

	Tons.
1915	6
1916	8
1917	4
1918	12

The concentrates contain a high percentage of cassiterite and are won by sluicing and from a few small veins.

The granite contact runs from north to south of the area approximately along the course of the Hteinthit stream, dividing the concession into two parts; the western two-thirds are in the Mergui sedimentary series, the eastern portion is in granite. On the western hill there are two narrow veins, eight inches and five inches in thickness, in greatly disturbed argillites. The veins themselves are twisted so that the strikes vary from east 10° north, west 10° south to east 30° south, west 30° north. The dip is towards the north at 60°. Slickensiding of the walls is common and the larger vein is cut off by a cross vein which meets it at approximately 90°. These veins are well mineralised, the recovered content being about 2 per cent., of which 60·70 per cent. is cassiterite in the larger vein. On the other side of the valley three veins are known in granite. They strike north 10° west, south 10° east and have a high dip towards the east. They contain wolfram and no tinstone. We are indebted to Mr. E. Maxwell Lefroy for these data.

Sheffield.—Sheffield mine lies to the south of the Hteinthit concession. It has a large surface area and stretches right acruss the intrusion, thus including both its eastern and western contacts. It was held at first under a prospecting license by Kyon Nga, from whom it was purchased in 1916 by the High Speed Steel Alloys Mining Co., Ltd. It has produced as follows:—

	Tons.
1915	31
1916	48
1917	20
1918	17

The average content of metallic tin in the detrital concentrates is about 25 per cent. The content from the vein concentrates is about a quarter of this amount.

The mine is divided into three sections:—(1) East Kalataung, (2) West Kalataung and (3) Thingandon. The latter includes the sluicing grounds in the Hteinthit valley. Both the others contain a number of thin veins in granite and in sediments. The general vein strike is north and south with slight variations in either direction. The dips are high and towards both the east and the west.

Tavoy Concessions'[1] *Thingandon.*—This mine adjoins the south-western corner of the Hteinthit area. Operations were commenced in 1910 when a prospecting license, followed later by a mining lease, was granted. The following table gives the outputs which have been obtained:—

	Tons.
1913	27
1914	56
1915	38
1916	44
1917	23
1918	22

Although many of the veins are in granite the tin content of the concentrates is a low one, the average composition being 68 per cent. WO_3 and 1 per cent. to 2 per cent. of metallic tin.

On the Hlanki Taung section of the mine, the name given to the portion north of the main road, which runs right across the lease, there are several veins from 6 inches to 2½ feet in width, striking from north and south to north 30° east, south 30° west and dipping easterly at 70°. The upper portion of the Hlanki Taung hill is granite but the lower slopes have a covering of Mergui sedimentaries. A large vein crops out in granite at the 6th furlong of the 19th mile on the road side. It is here 3 to 4 feet thick and

[1] Now Burma Finance and Mining Co., Ltd.

conforms to the general strike and dip directions. It carries good values in wolfram for a vertical distance of some 400 feet above the road, but below this level an exploratory drive yielded only a little molybdenite. On the South Hill section, the part to the south of the road, the veins are thinner and strike from 5° to 40° west of north, east of south, the general dip being about 65° towards the east. The veins themselves are in granite, but the sediments come in on the lower flanks of the hill.

Wagon North, Thitkatchaung, and Rubber Mile.—These mines are situated on the Kyaukmedaung ridge, which crosses the main Siam road at mile 25, and from that point runs northwards for some four miles through the concessions, and more or less parallel to the main Central Range. The crest of the ridge is about 2,000 feet above sea level and it is built up of typical sedimentary rocks in which slates and argillites predominate. In the Rubber Mile area, a small patch of altered granite comes to the surface and it is probable that the mineral-bearing veins owe their origin to this underlying granite, which may be connected underground with the main mass some two miles away. The workings of Wagon North are on the steep western scarp and those of the other two mines on its eastern side.

Wagon North, as it is known to-day, was granted under prospecting license to the Rangoon Mining Co., Ltd., in 1918, but at a later date became the property of the Burma Malaya Mines, Ltd., on whose behalf it is now worked by the Rangoon Wolfram Co., Ltd. Production has been as follows :—

	Tons
1916	6
1917	13
1918	19

The Rubber Mile mine was originally held by Mr. S. Crawshaw. It is now worked by the Rangoon Wolfram Co., Ltd., under a prospecting license granted in 1916. Production has been as follows :—

	Tons.
1915	23
1916	38
1917	52
1918	40

The Thitkatchaung is a stream which flows through both the concessions already named. It has given its name to the Thitkatchaung mine, also the property of the Rangoon Wolfram Co., Ltd., at the present time. Production has been as follows:—

	Tons.
1916	11
1917	25
1918	38

The veins of all these properties are short lenses, entirely in sedimentary country rock, and they have not proved of sufficient length nor value to open up in a systematic manner below horizons which are easily accessible from the surface. Information concerning them is therefore somewhat meagre.

At the Rubber Mile the general strike is about north 30° east and south 30° west and the dip averages about 75° towards the south-east, with a tendency to increase towards the vertical at depth. Faulting is not common, although the veins are often contorted. Veins often split into two or more branches which may or may not come together again. Mr. Mackilligin, the General Manager of the Company, writes:—" Lenses in close proximity to one another, having the same strike but not the same line of strike, and which may or may not overlap, are not uncommon. They often appear to be the faulted portion of the same vein and the line of fissure can often be traced for considerable distances after the vein itself has pinched out." Owing to the homogeneous nature of the altered sediments in the upper horizons which are worked, it is often exceedingly difficult to measure the dislocations produced by these fault planes or, in extreme cases, to see signs of any dislocation at all beyond the presence of the fracture. Mr. Mackilligin adds—" One vein showed two distinct dip faults, the more important a heave of 15 feet and a vertical displacement of probably about 80 feet. The strike of the vein was north 35° east and it dipped towards the south-east at 83°. The fault had a strike of north 30° west, south 30° east, and its head was nearly vertical."

The general strike at Wagon North is about north 20° east, south 20° west and the dip is about 80° towards the east. At Thitkatchaung the general strike is between north 20° east and north 58° east, the deviation from the north increasing as one works northwards in the concession. Dips are westerly near the surface but on the veins which have been traced down, they have changed either to a vertical or eastern dip at depth.

It remains to add that this group of veins is exceptionally micaceous and that sulphides are the common associated minerals with the wolfram. The Wagon North veins carry some molybdenite.

In the bed of the Wagon stream which flows through the Burma Malaya Wagon North lease there are detrital and alluvial deposits carrying wolfram and cassiterite. These are now being opened up by a monitor and gravel pump.

(*b*)—Mines of the Southern section.

Wagon South.—South of the Siam road, between miles 20 and 21, lies the Rangoon Wolfram Co.'s Wagon South. Originally the property of Tenasserim Concessions, Ltd., this mine commenced operations in 1911. It is now under a mining lease for a period of 30 years dating from 1917 over an area of 305 acres. It has produced the following quantities of concentrates :—

	Tons.
1911-1912	13
1914	5
1915	4
1916	10
1917	40
1918	20

The mine contains one large vein and several others of lesser importance. They are all in granite, which is excessively decomposed near the surface, and the general vein strike is north 40° east and south 40° west. The dip is towards the south-east at about 80°. A certain amount of bearing detrital ground exists and is sluiced in the rains when water is available.

Wagon.—The Wagon mine of the Wagon Pachaung Wolfram Mines, Ltd., adjoins Wagon South on the south and east. The property originally belonged to C. Su Don, but was purchased from him by the present concern in 1913. The company is incorporated in the Straits with its head office in Penang and had an issued capital of 200,000 dollars at the time of formation. Production has been as follows :—

	Tons.
1913	43
1914	87
1915	47
1916	71
1917	49
1918	77

The concentrate from the veins is practically tin free. The average is about 4 per cent. Sn. in the detrital concentrates.

The eastern contact of the granite runs right through the area, so that the western end is made up of granite and the eastern of sedimentary rocks. Veins occur in both sections, but the most important ones are in the sedimentaries of the Yebutaung where the strike is north-east, south-west and the dip about 45° to the north-west. These veins and the smaller ones on Show Shwe Taung carry large quantities of mica and pyrite as well as wolfram.

Most of the output from the western end of the mine is obtained by hydraulicing the surface deposits and soft decomposed granite which underlies them, the values being derived from thin veins, stringers and greisen bands. The length of piping used is about a mile with a head of 230 feet. Unfortunately water is only available for about five months during the year.

Heinda.—Four miles south of Rubber Mile and about one mile to the east of the main granite boundary is the peak Chauk-to-wo Taung, 2,256 feet above the sea. The Heinda mine of Messrs. Steel Bros. & Co., Ltd., is situated on this mountain. A prospecting license was originally granted over the area in 1916, which has changed hands several times before it came into the possession of the present owners.

All the workings are on a flat vein which crops out on the north-eastern, southern and south-western flanks. According to the manager, Mr. Malcolm K. Clarke, the general strike is north 20° east, south 20° west and the dip is 30° towards the east, but as the vein rolls considerably, variations are liable to occur. The vein itself is in sedimentary rocks and has an average width of 8 inches, but it is pinched in places to a thickness of 2 inches. Rich patches of wolfram are of common occurrence in it and the concentrates are practically tin free.

Output.	Tons.
1916	10
1917	40
1918	47

(c)—Paungdaw.

The southern and most important group of mines in this section is known as the Paungdaw group. The most northern one, the Putletto Mining Syndicate's Putletto, is usually regarded separately, but to avoid a multiplicity of terms it is preferable to place it in the Paungdaw group, to which it naturally belongs.

Putletto.—The prospecting license was taken out in 1911 and the mine has produced as follows :—

	Tons.
[1] 1913	39
[1] 1914	36
1915	*nil.*
1916	43
1917	91
1918	98½

The average amount of cassiterite in the concentrate is about 7 per cent.

The mine lies on a spur of Oktu Taung, adjacent to that on which Messrs. Steel Bros.' Putletto mine is situated. Both spurs are formed by lobes of the main Paungdaw boss. This particular one, however, is broader and more dome-like than the other one, and its sides pass beneath the flanking sediments at lower angles, so that the junction of the granite and its overlying cover has, in plan, a somewhat sinuous course, as the variations of the ground relief affect it more than is the case with a more vertical plane of contact. It also has a patch of Mergui rocks remaining undenuded from its highest portion. Some 30 veins are known, with a remarkably regular strike to the north and south, or to a few degrees east of north and west of south. They all dip easterly at 60°—65°. Many of them are over one foot in width, and there is one of four feet, one of five feet, and one of four to eight feet in thickness. Though not fully traced out, several veins appear to have a longer strike extension than is usual and workings over 100 feet below the outcrops show that they carry to that depth without diminution in size or value. All except one are in granite and two or three are said to pass from granite into sediments with a slight thickening in the latter, but they have not been followed for more than a short distance from the contact. Pyrite is the common associated vein mineral, and, in two of the veins, Nos. 3 and 7, the cassiterite content is high. Manganese oxides are common in the weathered portions of the veins and rhodonite has been found in small amounts.

[1] These totals include the production of the adjoining Putletto mine of Messrs. Steel Bros. & Co., Ltd., as well, because during these two years the two properties were worked as one mine under one owner.

Steel Bros.' Putletto.—This mine adjoins the one just described, on the south-east. It was opened in 1911 and has produced the following amounts of concentrate :—

	Tons.
1913[1]	39
1914[1]	36
1915	*nil.*
1916	14
1917	15
1918	40

The average content of metallic tin is about 6 per cent.

The workings are situated on the extremity of a high and narrow granite ridge, a north-eastward trending spur of Oktu Taung, with precipitous slopes descending to the ravines of the Putletto and Oktu chaungs on either side. These ravines are occupied by sediments of the Mergui Series with apparently almost vertical contact surfaces against the granite, and the spur itself runs out from below the capping of sediments on Oktu Taung, with an outlying patch of them near its outer end. About 20 veins of good size and value have been located, but they are discontinuous and much disturbed ; for this reason and because of the hardness of the enclosing granite, underground mining was suspended temporarily and operations confined to open-cutting and ground-sluicing. One of the veins, the "Scar Lode," is in some places 10 feet broad and one of the widest bearing-veins in the district. The general strike is from north and south to north-east, south-west, but both strike and dip are irregular. Outside the granite margin there are one or two veins in sedimentary rocks, but they have not been worked to any extent.

Widnes.—South of the Putletto mine just described lies Widnes mine, the property of the High Speed Steel Alloys Mining Co., Ltd., by whom it was purchased from Quah Cheng Guan in 1916. Its production has been as follows :—

	Tons.
1915	283
1916	424
1917	358
1918	380

[1] Includes the production of the Putletto Mining Syndicate's mine as well.

The concentrates from the veins carry 1 per cent. to 3 per cent. of metallic tin while the detrital material probably averages about 5 per cent.

The eastern portion of the lease is built up of granite emerging from under a sedimentary capping on Oktu Taung, at elevations of 2,500 to 2,700 feet, deeply dissected by the narrow ravines of the Oktu and Wazwinchaungs and their tributaries and standing high above the main sedimentary area further east, where the altitude attained by the Mergui rocks in the vicinity is not much more than 1,000 feet. The outer margin of the granite is comparatively straight, the inner one is sinuous and complicated, for the reasons already advanced in the case of the Putletto Mining Syndicate's mine. The Widnes granite is part of a broad dome-shaped intrusion from which but little material has been removed by denudation. This is proved by the presence of thin residual cappings of argillites which still remain *in situ* here and there. It is more comparable in structure with the Hermyingyi type of intrusion, than with those narrower and steeper-sided occurrences which rise to a higher level, but in which the veins themselves tend to be shorter, more disturbed and discontinuous.

Up to the advent of the Company the property was worked entirely by ancestral Chinese methods and great credit is due to Dr. W. R. Jones, the general manager, Mr. H. N. Rees, the mine manager, and those associated with them, in keeping up a high level of production during the war, and, at the same time, succeeding in carrying out development work which has had far-reaching effects. The mine is divided into four sections known as Anauktaung, Aletaung, Shamataung and Kalataung. On the Anauktaung at least seventeen veins are known. Their general strike is north 15° east and south 15° west and the dip about 62° to the eastward. These veins are partly in granite and partly in the overlying sediments, though some of them do not persist beyond the granite contact. A main tunnel, No. 1, was put in at right angles to the strike of this series of veins and about 200 feet vertically below their outcrops. Another main tunnel, No. 3, enters the series 60 feet below No. 1. A large number of veins, all carrying good values, have been cut and most of them have been driven on, while rises and winzes have prepared the ground for stoping. The compressed air used for driving the machine drills comes from a small

Ingersoll machine driven by an oil engine. An aerial ropeway connects Anauktaung with the mill.

On the Aletaung section there are at least five veins in granite, varying from 3 to 5 feet in thickness, which have been traced for over 1,000 feet each in strike extension. Their general strike is north 11° east, south 11° west and the dip about 65° easterly. These veins are being developed by drives from their northern ends at about 60 feet vertical intervals. The section is connected to the mill by a tramway.

On the Shamataung section two veins are being developed by drives 280 feet vertically below their outcrops, while a number of veins on the Kalataung are to receive attention in the near future.

The residual surface deposits are hydrauliced by a number of monitors working under heads of 300 to 400 feet. These operations can only be carried on during the rainy season when an abundant water supply is available.

The mill contains the latest machinery for crushing, concentration and recovery from slimes. Power is supplied by a 50 h. p. semi-Diesel engine. At the time of writing, May 1919, the mill was nearly completed but crushing had not commenced.

Pyrite is the commonest associated vein mineral and the portions of the veins within the oxidised zone are stained black and brown by the decomposition of this and other minerals. The vein quartz is of a solid, vitreous variety tending to separate into great, cubical blocks. Small, imperfect vugs and hollows filled with black iron and manganese oxidation products, decomposing pyrite crystals and traces of sulphate of iron are common.

The decomposition of the Aletaung granite has been exceptionally profound and the rock *in situ* is often quite soft to over 100 feet from the surface. When fresh it is a tough, white variety with more muscovite than biotite but, when oxidation sets in, it becomes red and mottled red and white. Seams and films of kaolin up to ¼ of an inch in thickness then often pierce it. The veins themselves are always bordered with well developed greisen bands and thin zones of green mica-rock traverse the greisen. Occasionally the granite has been greisenised in patches and irregular masses which do not contain vein quartz, and it is difficult to resist the conclusion that this is due to some form of gas action, in the latter stages of its formation. On Anauktaung also the sedimentary capping carried a three-foot band of greisen, parallel to the flat dome of the granite and separated from it by a few feet of normal argillites. The evidence that the Widnes veins "make and break," or, as it is more usually termed, "consist of a series of long, overlapping lenses," is irrefutable and excellent examples of this structure are to be seen on the mine.

Steel Bros.' Paungdaw.—Adjoining Widnes on the south is the Paungdaw mine of Messrs. Steel Bros. & Co., Ltd., which was purchased by the firm from the former owners, Messrs. Martin and de Paulsen, in 1916. It has produced as follows :—

	Tons.
1915	100
1916	184
1917	185
1918	169

The concentrates contain only about 1 per cent. of metallic tin.

The main eastern boundary of the granite crosses the north-eastern corner of the concession. The rest is made up of granite with patches of residual sediments on Thayetngok Taung in the south-western corner and a thin layer on Ashetaung. At least 10 important veins are worked. They are all approximately parallel. strike north 18° west, south 18° east and dip at high angles to the east. The larger veins were commenced as open cuts and then continued as underhand stopes. Development work consists of a deep level crosscut which it is proposed to carry right through the Ashetaung in hard granite, and various exploratory winzes sunk on the more important veins. The compressed air plant comprises a 45 h. p. Campbell oil engine driving a Sentinel compressor. The veins of this mine appear to have suffered more from faults and other movements during and after the consolidation of the granite than is usually the case in the Paungdaw region. Horizontal fractures occur too, which show themselves as steps on the steep eastern side of the granite ridge overlooking the valley. There is much evidence of shearing and squeezing movements in the veins themselves and a great development of greisen. Pyrite occurs in large quantities in the deeper portions and is responsible for the staining of the quartz nearer the surface. Green fluorite has been found in small amounts. The surface deposits were of considerable extent and have yielded large quantities of concentrates ; they are treated by ground-sluicing methods, water being brought for this purpose from streams some distance away by ditches, flumes and a syphon.

Tata's Darichaung.—The Darichaung mine of Messrs. Tata Sons, Ltd., is situated south of Steel Bros.' Paungdaw. Mining operations commenced in 1916, and the output has been as follows :—

	Tons.
1916	4
1917	22
1918	32

The vein ore contains very little tin and the detrital concentrates carry about 5 per cent. of cassiterite. There are a number of thin veins in the area which strike north 15° east, south 15° west and dip from 50° to 80° towards the east. The country rock is granite, and in the rainy season ground-sluicing is carried on in its decomposed portions. The veins carry mica and have greisen walls.

Steel Bros.' Crest.—The Crest mine of Messrs. Steel Bros. & Co., Ltd., lies to the west of the one which has just been described. A broad tongue of sediments crosses it from north to south, otherwise it is entirely in granite. It was opened in 1916, and has produced the following amounts of concentrate :—

	Tons.
1916	25
1917	37
1918	43

The concentrates average about 12 per cent. of metallic tin. There are a number of thin veins near the contact in the eastern portion of the area which possess the strike and dip characteristic of this region, but most of the output has come from the surface deposits, which are treated with water raised from a small dam by a Worthington pump driven by a 16 h. p. Petter oil engine. The high granite peak, Nwalabo (5,063 feet above sea level), lies in the extreme south-western corner of the Crest concession and prospecting has recently been carried on around it. Many quartz veins were found on all the slopes examined but only those on one ridge were at all promising. Here, at an elevation of 4,400 feet above sea level, two veins about 2½ and 1½ feet in thickness were opened up along their outcrops and yielded some wolfram. These workings are the highest in the whole district.

London Burmese Co.'s Paungdaw.—The Paungdaw mine of the London and Burmese Wolfram Co., Ltd., is the last to be described in this region. It lies to the south of Tata's and Steel Bros.' areas and was taken over by the late Miss Dawson of Bangalore in 1912. Its production has been as follows :—

	Tons.
1913	93
1914	113
1915	73
1916	75
1917	76
1918	49

There are two districts in the concession which produce wolfram. *viz.*, Pathan Hill and Maung Pok Hill. In Pathan Hill and its vicinity the mean strike is north 60° west, south 60° east, with a dip of about 60° to the north-north-east. It is to be noted however that several of the veins, and especially Nos. 1 and 9 have, for short distances, strikes differing several degrees from this. These veins at the bottom of the hill are in hard argillites and have thicknesses of from $1\frac{1}{2}$ to $3\frac{1}{2}$ feet, but further up and nearer the surface they have split up and formed numerous smaller veins varying from 4 to 10 inches in thickness. Some of these thinner veins have been followed for several hundreds of feet and occasionally right through the hill to the other side, but most of them have a tendency to thin out and disappear after reaching the heart of the hill. The vertical distance between the highest and lowest workings in this hill is 280 feet. Faults of any magnitude are unknown, and the small ones which do occur are normal.

The Maung Pok Hill is of granite and attains an elevation of some 4,000 feet above sea level. On the south face, about 900 feet below the summit, numerous veins crop out, while a few small ones are found at points higher than these. They are either vertical or dip very steeply, up to 85° to the east, the strike being north and south. There are no notable departures from this rule. The thickness of the veins varies from two inches to one foot six inches, but they all possess the property of diminishing in width and value as they are followed into the hill until they practically disappear. This occurs at a distance of about 80 feet from the portals of the drives. On the north side of the hill there is a considerable change. The veins strike nearer east and west. They are either vertical or dip at varying angles in both directions. A few instances are given to illustrate these changes :—

Vein.	Thickness.	Strike.	Dip.
a	8 inches.	N. 76°E. S. 76°W.	S.
b	14 „	N. 75°W. S. 75°E.	Vertical.
c	3 feet.	N. 70°W. S. 70°E.	S. high.
d	18 inches.	N. 85°W. S. 85°E.	S. high.
e	12 „	N.E.—S.W.	30° N.-W.

All these veins carry good values, indeed the veins of the north Maung Pok section yield better values than the others and hold out more promise for systematic mining. Ground-sluicing is carried on in all sections during the rains.

Anyapya.—This mine is held under a lease by Quah Cheng Tock. It is the only working mine on the western side of the Paungdaw capping and has veins both in granite and in the overlying sedimentaries, in two different sections of the workings. Though small and rather irregular, they carry good values. Methods of working are primitive and underground mining has hardly been attempted. A long water-race and flume has recently been constructed to ground-sluice the detritals. The difficulty of transport to the camp has always been a drawback to this area.

The Meke Area.—Three miles beyond the edge of the Central Intrusion, but associated with a small exposure of granite in the Meke chaung, are the mines of the Meke area. These are leased by Maung Ni Toe and Lim Kyi Yan, respectively.

Ni Toe's Meke.—This mine was opened in 1911 and has produced as follows :—

	Tons
1911	65
1912	90
1913	30
1914	40
1915	40
1916	70
1917	70
1918	69

The vein concentrates only contain a little tin ore. In the case of the material won from the detrital deposits the content is about 15 per cent. Sn.

A large number of small veins are worked entirely by native methods over a group of low hills built up of Mergui argillites and slates. The general strike is north and south with rather low dips to the east. Extensive surface deposits exist, which are treated in the rains.

Lim Kyi Yan's Meke.—The second mine of the Meke area lies a short distance to the east of the one just described. It is the property of Lim Kyi Yan and is under a mining lease sanctioned in 1915. It has produced as follows :—

	Tons.
1916	31
1917	24
1918	19

The veins and country rock have much the same characteristics as those of Maung Ni Toe's property except that the concentrates contain a larger percentage of cassiterite. The mixed concentrates contain about 18 per cent. of metallic tin, but in addition to this the concentrates from the extreme eastern end of the concession are practically pure tin ore. Three tons of this material were produced in 1918 in addition to the 19 tons of mixed concentrates mentioned above.

The Pe Area.—The Pe granite, which appears on the map to be in line with the southward extension of the Central Intrusion, continues across the Tavoy border a great distance into the Mergui district. It is probably a portion of the Mintha granite, from which it is separated by a narrow band of Mergui sedimentaries along the valley of the Pe chaung.

The band of sedimentary rock is merely a thin covering over the underlying granite through which the latter appears in several places, and it is on it and in its vicinity that wolfram-bearing quartz veins were discovered about 1915.

The isolation of the region has, to a certain extent, prevented its quick development, and in 1918 there were only two producing mines of any importance in it. The concentrates from both of them are practically free from tin.

Tata's Padauk.—The general strike of the veins is west 20°—25° north, east 20°—25° south, and the dip 75°—80° towards the north-north-east. A group of nine bearing-veins possess this general direction, but there are at least other two which carry very good values. One of these strikes north 32° east, south 32° west and dips at 45°—50° to the south-east, while the other, which also carries iron ores, strikes north 30° east, south 30° west and has a dip which is almost vertical. The veins tend to separate into lenses of short extent; they are all in granite in the neighbourhood of a sedimentary capping. Production :—

	Tons.
1917	24
1918	29

Su Don's Pe.—Close to Tata Sons' Padauk mine is C. Su Don's Pe area, on which similar geological conditions prevail. Production :—

	Tons.
1917	19
1918	9

CHAPTER VII.

MINING METHODS.

The Tribute System.

Wolfram was rediscovered in Tavoy in 1908 and the modern history of the field may be said to date from 1909. Up to the end of 1910 some 408 tons of high grade concentrates had been produced, and no less than 687 applications had been received by the local authorities from persons desirous of taking up land for prospecting purposes.

Mining methods in those days were of a very primitive character and the industry still suffers because their evils have never been entirely eradicated. This is to some extent the fault of the mine-owners, but it is also a result of the very large numbers of veins which exist, the wide area over which they are scattered, and the permanent shortage of labour.

The first discoveries were made by Burmans and Karens and these races were the first to collect the ores from the outcrops. They were followed speedily by Chinese, whose "crude methods exasperate equally with their bland unwillingness to improve on them."[1] A gang of Chinese works under a contractor who is paid according to the amount of clean high grade concentrate he brings in, and sometimes a footage rate for underground driving or cross-cutting in addition. Rates naturally vary with the position of the mine and with the richness of the particular vein. When Lefroy wrote in 1915 the figure fluctuated "round one shilling per viss of clean concentrates, equivalent to £32 per ton, less from 3 per cent. to 8 per cent. for water and sand. The standard viss is 3·60 lbs., or 555·5 viss to the long ton, though Tavoy methods prevail in this, for many concessions call 3·5 lbs. a viss, making 640 to the long ton."

During the period of the war these rates increased and Re. 1 to Rs. 1-8, or one shilling and four pence to two shillings per viss, or even more, was given.

[1] Lefroy, (20) p. 7.

That it may not be considered overdrawn, it is considered preferable to describe the system of the Chinese tributor in the words of a private mining engineer connected with Tavoy rather than in those of an official. Mr. H. D. Griffiths writes as follows:—"Wolfram having thus been struck, the Chinaman is generally allowed to work on it at his own sweet will, provided he hands over all the wolfram obtained, for which he is paid at a fixed rate per ton. His work may be of any kind, with the usual result that when he works open-cut he generally takes no precaution for the prevention of accidents and creates regular death-traps. If he decides to start an adit he makes it of such dimensions as will best suit him, and if he at all timbers any weak spot, he generally does so in a cheap and inadequate fashion. He will not undertake to do a specified kind of work unless he gets paid footage in addition to being paid for the ore. In most cases, therefore, he is allowed to work as he likes. When he comes to some poor or unprofitable portion he moves his chattels to some other spot, and the chance of proving the value of that vein is lost. If he gets on to ground that cannot be brought down by the pick, he immediately abandons the work. . . . . . With the exception of perhaps one property, where primitive development has been attempted, the work is really only 'fossicking.' On a wide zone, with veins close together, a few adits may be put across the formations and only in the oxidised portion, for as soon as the work gets a little hard, or the pyritic zone is approached, operations are abandoned. In the course of this cross-cutting the different quartz stringers are encountered, and any wolfram obtained is sorted out and placed in bags. If a rich leader is cut, a little driving in both directions may be undertaken; but this will be stopped as soon as the pocket of ore is exhausted. Another adit will then be commenced "on spec" a few feet to the right or left and generally a few feet above. The result is the crowding of small adits within a restricted area."[1]

The Chinese tribute adits are generally 3 to 4 feet wide and 5½ to 6 feet high, and are thus too small to permit of anything but single-handed drilling. All quartz which shows wolfram is picked out and bagged at the face for later treatment, while gangue and country rock are dumped at the portal. As most of the adits are on steep hillsides and the country possesses a very heavy rainfall

[1] H. D. Griffiths., (11) p. 446.

the adits in the decomposed zone collapse during the monsoon season while the lower ones are blocked by land-slides from above.

Special arrangements exist with regard to tools, candles and explosives on different mines. In some cases they are found by the mine owners, in others the labourers purchase them themselves.

Ore concentration methods are of the crudest kind, the quartz being crushed by hammers on a flat stone and the powdered stuff washed in a cradle or pan. It follows that most of the fines are wasted, as only high grade concentrates are wanted by the companies. To quote an independent engineer again :—" The sequence of operations is wasteful in the extreme, for at least 90 per cent. of lode rock is dumped without more than cursory examination ; much fine ore flies away under the hammer and the loss in dressing is known to be high, as much as 28 per cent. in one mine, and 40 per cent. combined dump and cradle loss on another."[1]

As late as 1916, we computed that 90 per cent. of the output of vein wolfram from Tavoy was won by this ruinous system, which results in losses under at least three heads, *viz.*:—

(1) Low grade ore left in the mine, often under such conditions that it may never be recovered profitably.

(2) Low grade ore thrown away on dumps, usually so scattered that it may not pay to collect it later for milling.

(3) Losses in crushing and dressing.

Yet allowances must be made for pioneering operations in a difficult field, which throughout its history has never been fully equipped as regards labour, and which during the critical period of the war *had* to produce wolfram by any and every means. It is also admitted that there are concessions containing thin veins, often at considerable distances apart, so poor as to dispel any hope of their ever being treated in any other way ; but it is also evident that large mining firms whose operations are directed by specialists will not continue to disregard the future, to avoid any semblance of conservation and to permit avoidable waste of the mineral resources of the country any longer than is necessary. During the past two or three years there have been many changes for the better, and it is now the exception rather than the rule to find any large mine in which the Chinese cooly is allowed to do entirely as he pleases. Tribute is still widely practised but it is controlled to a degree hither

[1] Lefroy (20) p. 13.

to unknown. This is to some extent due to the slow, but none the less sure, exhaustion of easily won wolfram-bearing quartz from the softer parts of the veins in the uppermost decomposed zone, for there must come a day in the life-history of every vein-mining field when the harder and deeper-seated portions of the deposits have to be exploited if the industry is to continue. The earlier Tavoy tribute system cannot adapt itself to this change and consequently fails. It is not proposed to describe here the deep level exploratory work which is now being carried on with the aid of machine drills driven by compressed air; attention has been directed to it in the descriptive section of the report. The leases under which mining areas are held from the Government insist that ore deposits shall be worked and developed in a skilful and workmanlike manner and upon the most approved principles. Both mining leases and mining rules, under the Indian Mines Act, provide for the preparation of large scale mine plans and sections, and for them to be kept up-to-date. The Mines Act Rules have also improved the indigenous methods of mining by making it unlawful to carry on dangerous operations. Finally, the importation of coolies in large numbers both by Government and by private firms has eased the labour shortage to some extent.

Concentrating Mills.

Mills for the concentration of wolfram or mixed wolfram and cassiterite ores have been erected at Kanbauk, Pagaye, Widnes and Paungdaw, while others are in contemplation for other mines. Unfortunately, the latter two were only completed about June 1919, and no results are available as to their performances at the time of writing.

Kanbauk Mill.—The mine ore is crushed in a stamp battery of 10 stamps of 1,100 lbs., dropping 8 inches, and the screen aperture is $\frac{1}{4}$ inch. There are 4 Wilfley tables of Nos. 5 and 6 types. The installation is driven by a 32 B. H. P. Hornsby-Akroyd engine, assisted by a 12 H. P. portable engine and boiler. In 1916 the crushing operations resulted as follows :—

Hours run, 259·5 hours per month or 35·4 per cent. only.
Mine ore crushed, 6,075·6 tons.
Mullock crushed, 1,600·4 tons. (Value $\frac{1}{4}$ per cent.)
Total ore crushed, 7,676 tons.
Stamp duty 5·8 tons.

Mill concentrates (58 per cent. of WO_3) 43·7 tons.
,, ,, (70 ,, ,,) 25·35 tons.
Hand picked (71 per cent. of WO_3) 8·02 tons.
Average return of mine ore, 19 lbs. per ton.
Average assay of tailings, 7·1 lbs. per ton. (70 per cent ore.)

Up to 1917 the working of the mill was handicapped for want of water during the dry seasons, and through fuel and power difficulties. Mr. Griffiths has pointed out "that an improvement on these figures is still possible and that a system of jigging followed by concentration on tables will probably be adopted, by this means, it is hoped the losses will be confined entirely to a much smaller percentage in the shape of slime. The tailing has proved to contain only fine ore and slime which could only be concentrated with difficulty and the quantity of which could only be ascertained by the wet method. The losses indicated comprised the WO_3 contained in tungsten ochre which occurs in appreciable quantities in the decomposed portions of the lodes, and which in any case could not be recovered in any concentrating plant. Taken altogether therefore the recovery cannot be described as having been a failure."[1]

London and Burmese Wolfram Co.'s Paungdaw Mill.—A small sampling mill of three stamp batteries having 5 stamps each was erected at this mine. The stamps are lifted by wooden axles and cams, the shafts of which are rotated by a rope drive in two sections, that is, each battery is actuated by a 3½ foot Pelton wheel; the ratio of the drivers and driven being 1 to 5 twice over. 100 blows per minute have been obtained from this machine. It was made on the mine of local timber, with the exception of the stamp heads and the gudgeons of the cam shaft. The wolfram is caught in long sluices and the tailings are subjected to retreatment on perforated sluices which feed the fines on to blankets. The blanket product is cleaned up in mechanically operated bateas. The head of water which drives the whole installation is 135 feet.

In the main mill, which is steam driven, the ore, delivered by an aerial ropeway, is passed through a rock breaker of the Blake-Marsden type to a storage bin. From the bin the ore passes to a revolving trommel with 19 mm. holes. This is sprinkled with jets of water from the outside. The oversize from No. 1 trommel drops into a

[1] H. D. Griffiths (13) p. 214.

second rock breaker of the same type as the first, and thence directly to a pair of rolls vertically below. The undersize with its water passes under the rolls, taking their product to No. 2 trommel, which has perforations of 6 mm. This trommel is over another pair of rolls which treat its oversize. The undersize is again swept with the product of the rolls to the 3rd trommel, which has holes of 4 mm. At this point recovery begins. The oversize from No. 3 trommel falls into the supply launder of the first jig while the undersize is taken into the 4th trommel which has holes of 2 mm. From this final trommel the oversize passes to No. 2 (fine) jig and the undersize to three hydraulic classifiers. It is intended that each of the classifiers shall deliver a spigot product to each of three "Record" tables, while the overflow is to go on to two Frue vanners. The mill is not in final working order and the steps in the flow sheet as outlined are subject to modification.

The Pagaye and Widnes mills are both fitted with rolls, jigs and tables and have been referred to in the descriptive section of this report.

Mr. G. N. Marks' proposals.—Mr. G. N. Marks has designed a flow sheet suitable for Tavoy ores, in which the wolfram and cassiterite are not evenly distributed through the vein quartz, but are patchy and coarse and often in large lumps. He is of the opinion, which the writers share, that fine stamping or grinding with its attendant loss in float is to be avoided. This means crushing the ore as coarse as possible, classifying and recrushing in stages, and avoiding a further crushing of the minerals by separating them out as soon as possible. Rich ore which comes from scattered pockets in the veins must be eliminated before it reaches the mill, and the latter will then be fed with a low grade product. Under such circumstances the smallest unit of any value would have a capacity of 2,000 tons per month. The introduction of a travelling belt or picking table, between the ore bin and the mill, is advocated, to pick out waste and to collect the coarse wolfram and cassiterite which form such a high percentage of the total ore contents. From the picking belt, after passing over a grizzly which will allow say two inch cubes to pass, the ore would be fed to No. 1 crusher, preferably of the eccentric jaw type. The product would then go to No. 2 crusher of the same sort, and be broken to about one inch cubes and less, and then fed on to a picking belt to eliminate a certain portion of mineral without further treatment. The crushed ore would then pass through a set of heavy-duty type crushing rolls set to reduce everything to about $\frac{1}{4}$ inch and less, and it is thought that at this stage a considerable proportion of the values would be released. A conical trommel screen would then divide the material into three grades :—

(1) *Minus* 10 mesh to join the product from a second set of rolls for table concentration.

(2) *Plus* 10 mesh *Minus* $\frac{1}{4}$ inch to go to jigs.

(3) *Plus* $\frac{1}{4}$ inch to the second set of rolls.

The heads from the jigs should produce a fairly clean concentrate and the tailings will join the oversize from the screen and be further reduced through the second set of rolls to $\frac{1}{16}$ inch and less, making suitable feed for Wilfley tables. The ground material will be either classified or sized by further screening to several grades so that each Wilfley table will work on an even feed which admits of the most efficient concentration.

Regarding the percentage of mineral extracted by such a plant this would vary according to the ore treated. Some engineers would grind the tailings again and pass them over further tables and concentrators, as in spite of the attempt to avoid sliming by coarse crushing and the elimination of coarse mineral at the different stages of classification and regrinding, the tailings will account for a large percentage of loss.

Mr. Marks suggests, in the case of Tavoy concentrates, that instead of attempting to reduce the tailings further, a poorer or dirtier concentrate be produced and everything be put through a magnetic separator. He believes that with a well-equipped modern plant on these lines good work could be done and a high percentage of the mineral contents extracted.[1]

Conclusions.—The perfect cleavage which wolfram possesses results in its breaking down to thin mica-like plates when it is powdered or ground. By the action of stamps these naturally become slimed, and while a certain amount of such slimes may be recovered by modern slime tables, canvas tables and other devices, the loss is undoubtedly very high. We have watched experiments in more than one experimental stamp battery erected in Tavoy, and it appears to us to be preferable to adopt a practice in which a

[1] G. N. Marks, (18), pp. 28-29.

minimum amount of fine-powdered mineral is produced. In the bulk of Tavoy ores the wolfram and tin-stone are scattered in irregular bunches throughout the vein matrix and these are often of appreciable size. There are very few instances known in which either of the minerals is evenly distributed through the quartz in fine particles, and the few occurrences of fine acicular wolfram ore are of no great economic importance. While a general scheme cannot be laid down and final details settled without the results of experience gained from experiment, we are definitely of the opinion that concentration systems which make full use of hand picking, coarse crushing, sizing and jigging, with the removal of wolfram and cassiterite in every stage where they can be obtained as coarse as possible, followed by full use of present practice as regards the inevitable fine-ground minerals, are preferable to those methods in which the unsorted ores are taken direct from the mine to stamps, and reduced to powder before any attempt is made to separate their valuable contents.

Sufficient attention has not been paid on small mines to the advantages of jigging after rough sizing. Up to the end of 1918 there was only one small hand jig in use on the field. We believe that it would prove profitable to treat material that will pass a $\frac{1}{4}$ inch screen by this method and that with the water supply available on most mines of this kind, it would be possible to treat large quantities of ore at a low cost. The method would also result in greater savings than those obtained by crushing and panning.

Sampling Surface Deposits.

True placer deposits in the flat portions of the valleys are usually sampled by boring, and as these operations present no greater difficulties in Tavoy than are met with in similar deposits in other parts of the world, they need not be described here.

Deep detrital formations at the foot of slopes generally contain big boulders and beds of tenacious clay above the valuable pay layers. On the hillsides the deposits are thin and, except in cases where values continue down into decomposed granite, shallow pits at regular intervals are used for purposes of preliminary valuation. On flatter ground the depth to be gone through may be anything from 10 to 50 feet, and, in extreme cases like Kanbauk, 80 or 100 feet with a permanent water level about 30 or 40 feet down.

Gangs of trained Chinese sinkers, who have learned their trade in the Federated Malay States, can be obtained to undertake this work, which is done on contract. A typical series of rates is :—

	Rs. A.
For the first ten feet	0-10 per foot.
,, second ten feet	0-12 ,,
,, third ten feet	0-14 ,,
,, fourth ten feet	1 0 ,,
,, fifth ten feet	1 8 ,,
,, sixth ten feet	1 12 ,,
,, seventh ten feet	2 8 ,,

If water is met with, a small extra footage for sinking below its level is given.

The shafts are from 2 to $2\frac{1}{2}$ feet in diameter and are made with a small pick, fitted with a short handle. A ordinary household bucket is used to hoist out the earth. In good ground a depth of 10 to 20 feet can be made the first day. After this a small windlass is erected. Descent to the bottom is made by using niches cut into opposite sides of the pit. When the air becomes foul a portable forge blower is used to ventilate, through a long, oil-coated, calico tube, about 4 inches in diameter. Boulders may require explosives but the low earnings of the sinkers in such cases are compensated for by the rates they can earn in good ground.

The method of sampling has been described as follows :—" The sampling is carried out by making a vertical cut up the side of the shaft and allowing the contents to drop into the suspended bucket. This is usually done in 5 foot sections, the bucket being tipped into a box measuring 8 × 8 × $7\frac{1}{8}$ inches, and whose capacity equals $\frac{1}{100}$ cubic yard. The contents of the box are well rammed down and levelled off, the material then being bagged and taken to the nearest creek for washing. The quantity mentioned is a convenient unit to wash, as it completely fills one of the ore bags used in shipping wolfram concentrates and makes a convenient dishful for washing. The sample before bagging is weighed and its weight compared with that of a measured cube of similar ground cut out of some of the workings. The difference usually gives a fairly high conservative factor for valuation, but allowance must be made for the considerable percentage of large boulders not included in the sample. The product of the washing is taken to the laboratory, when magnetite is removed by a magnet, the coarse material hand-picked clean and the fines rewashed. In weighing, a specially devised set of Weights is used, the unit of which, weighing 70 grains, corresponds to 1 lb. per cubic yard. The weights extend from 3 grains (0·05 lb.), up to 7,000 grains (100 lbs.). Thus the value of the concentrate is read off directly in pounds per cubic yard."[1]

Hydraulic Mining, Sluicing and Pumping.

In a climate like the Tavoy one the quartz veins undergo rapid denudation and shed their contents into the surface soil. Valuable deposits are thus formed, consisting of wolfram and cassiterite in the surface covers of the hill sides and of cassiterite in the true water-sorted alluvium of the valleys. In the early days of the industry the greater part of the output was won by ground-sluicing rich patches of detrital or eluvial ground on the slopes of the hills when water was available in the rainy seasons. Much of this early work was done in a very haphazard fashion, but in more recent times with Chinese, who are the best sluicers, with efficient management and with improved arrangements for bringing in water and recovering the ores, considerable improvements have been effected. Now-a-days on a large mine like Hermyingyi, the Chinese workmen are compelled to use standard boxes for which timber is provided, and definite claims are distributed on the understanding that, if the tributors concerned fail to operate them properly, or if they stack waste stones on unworked ground—a common Chinese failing—they will be forfeited.

It was not long before it was realised that the detrital deposits of the slopes and the mixed detrital and alluvial deposits at the foot of the hills could in many places be worked to advantage with monitors and hydraulic appliances generally, and hydraulic sluicing was first introduced about 1912. Plants of this kind are now in operation at Kanbauk, Hermyingyi, Wagon, Pagaye, Widnes and other mines.

In the first stages of a mine's history the beds and banks of the streams are the first to be cleaned up by tributors, and it may be taken for granted that their methods result in very serious loss unless closely supervised, especially as regards the waste of fine concentrates and the covering up of bearing ground with tailings. Profitable ground lying at a higher level may then be discovered, when surveys of the surrounding natural water systems are necessary to

[1] H. E. Hooper, *Eng and Min. Journ.*, Vol. 102, No. 5, July 29th, 1916.

decide wheher water can be led to the places required by means of ditches or flumes. It is presumed of course that the ground has been valued by careful pitting and that there is a sufficient acreage of it available to warrant whatever expenditure may be involved. Most of the larger mines in Tavoy are supplied with water brought by elaborate installations, often from considerable distances, and as the industry expands an increased use is bound to be made of "water rights."

If a gravity supply is out of the question resource must be made to pumping, and by this means to lift the volume of water required from some more or less permanent supply. There are many small installations of this kind at work and larger schemes are in contemplation. Thus at Hermyingyi, according to G. N. Marks, "One is being worked out to lift 200 cubic feet of water per minute to a height of 920 feet to command an extensive area of rich eluvial. Similar ground this wet season (1917) is yielding 117½ viss per month (=423 lbs.), per cubic foot of water supplied." Mr. Marks also gives details of smaller pumping installations already at work. One of these is at the Kalonta mine, where two pumps lift river water 50 and 100 feet respectively. "The former is driven by an oil engine burning kerosene and the latter by a semi-Diesel engine burning liquid fuel delivering water on to ground impossible to get at with water races at present levels. These enabled wolfram concentrates to be won at an all-in cost landed in Tavoy godown of Rs. 1-6-0 per viss (=£57 per long ton).[1] The volume of water lifted was 22,000 gallons per hour and the cost of the two pumps erected Rs. 16,033. In August 1917, 9 tons of concentrate were won with the water from these pumps."[2]

Another small but interesting pumping scheme which demonstrates how circumstances can be adapted to meet particular cases, and how profits can be made even under adverse conditions, is also given by the same writer. In 1913 a pump was erected to lift water to the top of Kadwe Hill from the Maungmeshaung stream—a height of 700 feet and a pipe line one mile in length. "The volume of water lifted was never more than 60 gallons a minute, and owing to the difficulties with the plant, troubles in getting spare parts from England in war time, the efficiency of the pump was much reduced and the supply fell to 20 gallons per minute; yet six separate

[1] Taking Re. 1=1*s.* 4*d.*
[2] G. N. Marks (18), p. 26.

parties of coolies used the water and have won as much as two tons of concentrates in a month. The cost of running the pump was Rs. 600 per month. The water is collected in miniature dams which when full are suddenly emptied and the water allowed to rush down the hillside through the sluice.[1]

At Wagon South a steam pumping plant was erected to deliver 2,000 gallons per hour against a head of over 700 feet, to treat ground proved by pitting to contain approximately 2 lbs. of concentrate per cubic yard.

Concentrating Pans.

As for treating rich residual deposits when it is not possible nor expedient to break them down by pressure water, they may be excavated by hand and the concentrates recovered in a pan similar to those used in washing gem gravels in the Ruby Mines in Burma and the diamond fields of South Africa. This method has been adopted with some success by Mr. A. H. Morgan in the case of the softer deposits on the southern extension of the stockwork at Pagaye. The pan is 10 feet in diameter and has the usual accessories of grizzly, rotary screen and picking tables. It is driven by a 20 H. P. Hornsby-Akroyd oil engine that also drives a 3 inch centrifugal pump which delivers 150 to 200 gallons of water at a height of 65 feet, sufficient for the whole outfit. The pan saves a larger proportion of fines and does the work with about a third part of the water required in hand working by native sluicing methods. The costs are high but on ground which carries good values the work is profitable.

High Pressure Hydraulic Plants.

Once it is decided to bring in water to any deposit, especially if the ground to be treated is situated at the foot of the hills and is buried under poor or barren overburden, as is so often the case, the question has to be settled as to whether it is not better to break it down and wash it in one operation. The late Mr. C. M. Lyons, O. B. E., who spent over six years in Tavoy and possessed unequalled knowledge and experience of hydraulic machinery under local conditions, was induced to publish his matured views for the benefit of others engaged in the industry. The following notes are taken

[1] G. N. Marks. (18), p. 27.

practically *verbatim* from his paper, as it is felt that they merit the further publicity which they will obtain herein.[1]

Suitability of the ground.—Having decided that the quantity and value of the ground is suitable for sluicing, the percentage of boulders and stones, over say 3 inches in diameter, should be determined by picking them out of the prospecting pits, stacking in a regular heap and comparing the volume with that of the pit. A rough rule for estimating the effect of these stones in subsequent operations is to add 1½ annas to the cost per cubic yard for each 10 per cent. of stones. Particular care should also be exercised in looking for the presence of hard bands of laterite, cemented gravel or tough clays.

Available water.—The source of the water supply should then be most carefully studied and unless a very large excess is available, no considerable expenditure of funds should be incurred until a series of measurements extending over at least one season has been made. The streams in the Tavoy district are most deceptive, and roaring torrents impassable in the rains shrink to nothing in the dry season. A measuring weir should be constructed in the chosen stream and extra attention paid to measurements in the dry weather.

The next matter to be decided is what constitutes sufficient water. This depends on the extent, character and richness of the ground and Mr. Lyons believed that a fair average figure for the district was that one cubic foot per second under sufficient pressure would break and carry away 100 cubic yards daily. Thus, if an average of 750 cubic yards daily over a period of, say, 5 months has been decided on as being the smallest that it would be profitable to treat, the average water must not be below 7½ cusecs. When the water available falls below 1½ cusecs, it is better to revert to some form of hand working.

Disposal of tailings.—On low ground the disposal of tailings is a difficult matter and contoured plans of the area should be made. Sections showing the natural surface and also the bed rock as revealed by borings or pits should be prepared, and on these a line representing the tail race should be plotted. It should start at a sufficient elevation above the valley into which the tailings are to be discharged to allow for the accumulation of a large amount of material. Stony

[1] C. M. Lyons (17), pp. 45-54.

tailings discharged from a race will spread out with an average inclination of 1 in 15 and at the sluice boxes at least 5 feet and as much as 12 feet extra fall should be allowed to enable grizzlies, distributing boxes, etc., to be installed.

Grade line.—If the tail race and sluice box line as plotted on the section rises above the bed rock line it is obvious that the ground between cannot be treated by gravitation and some form of elevator becomes necessary.

Pipe line and monitors.—Mr. Lyons made use of a theoretical case in which it was assumed that a reliable flow of 20 cusecs was available, which could be brought to the head of the pipe line by a flume or ditch at an elevation of 400 feet above the working face. In this case the water may be taken there in 20 inch pipes, $\frac{1}{8}$ inch thick and double rivetted with slip joints. With ordinary care these should have a life of 5 years.

If the pipe line necessary to convey the water to the working face is $\frac{1}{2}$ mile long, the frictional loss of head will be about 50 feet, so that the nozzle pressure will be equivalent to a head of 350 feet. The breaking efficiency of a nozzle increases rapidly with increase of diameter, so that in hard ground it is better to use one large nozzle than two smaller ones delivering the same quantity of water. The larger flow from the bigger nozzle will also move stones of greater weight to the race. Speaking roughly, a 4 inch jet in hard or stony ground will break and convey from the face as much ground as six 2 inch jets, though it consumes only two-thirds the amount of water.

Sluice boxes.—Australian practise favours a width of $2\frac{1}{2}$ feet or more for each cusec. At Kanbauk 2 feet is found sufficient. The grade should be 1 in 20 at least. The theoretical case under consideration, of 20 cusecs, would require a width of 40 feet. This box should be divided into 3 compartments, each 13 feet 4 inches in width. A fourth compartment may be added to divert the flow when cleaning up. The length of the box should be from 100 to 150 feet and to ensure proper working all stones above 1 inch should be eliminated by a grizzly. Of the extra 12 feet allowed in the grade line at the boxes, 4 feet will be absorbed by the grizzlies, the distributing boxes will take another 4 feet, and there will be a clear drop into the box itself to allow for filling up with rough concentrates. The stones from the grizzly should drop into a steel chute laid at a grade of 1 in 10, along which a small volume of water is allowed to flow. This will carry stones up to 7 or 8 inches in diameter into the tail race at the foot of the sluice boxes.

Steps.—The steps in the boxes are movable pieces of timber of say, 4 × 1½ inches section. They are put in at intervals of 20 feet and added to as concentrate accumulates.

Cleaning-up.—With ordinary material the box should take about a month to fill, when it must be cleaned up. It is unprofitable to try to make a concentrate richer than 5 to 10 per cent., as to do so increases the risk of loss. Channelling or guttering is the main source of loss. It is caused by inattention and also by allowing the full body of clear water to flow through the box when the breaking of ground by the monitor is suspended. Six men per shift will keep the boxes in good order.

If much tough clay has been sluiced the material may set hard in the boxes, and, as the one described may hold 700 tons of stuff, the clean-up is not an easy matter. At Kanbauk a modification of the Briseis (Tasmania) practice is followed. A 6-inch elevator is erected at the foot of the boxes so that its swivelled suction may dip into the bottom of any compartment. The contents of the box are sluiced to this with a 1¼ inch nozzle on a fire hose. The concentrates, now mixed with a large volume of clean water, are elevated into a clean-up box with a width of 4 feet, set parallel to the main box but running in the opposite direction, so that the tailings deliver back into one of the compartments of the main box and the chances of loss are reduced.

The concentrates, enriched to about 40 per cent. by this treatment, are shovelled out on to flat sheets and carried into the dressing shed, where they are further treated by hand.

Tail race.—For a flow of 20 cusecs, a tail race 4 feet wide is sufficient. It should have a grade of at least 1 in 25 and should also be paved with wooden blocks or large hard stones. At Kanbauk the tail races are paved with 9 inch blocks cut from round jungle timber and laid on end. These have a life of three seasons.

Hydraulic elevators.—Hydraulic elevation becomes necessary when tailings can no longer be disposed of by gravitation. The hydraulic elevator is a cheap and easily erected machine but it is very inefficient. Continuing the case of 20 cusecs of water under an effective head of 350 feet, and supposing that it is necessary to elevate 65 feet, for this lift the average efficiency of a new elevator may be taken at 15 per cent. but as the throat of the machine wears away with use this amount decreases and it is safer to take 12 per cent. as the figure. Now the ratio between the effective pressure head and the height to be lifted is 5·4, which means that with 100 per cent. efficiency, 1 cusec of pressure water would lift 5·4 cusecs of tailings. But with only 12 per cent. efficiency the amount lifted is 12 per cent. of 5·4, or 0·65 cusecs of tailings. The 20 cusecs available must now be divided in the proportion of 1 to 0·65, or 12 cusecs will be absorbed by the elevator leaving only 8 for the monitor. Such an elevator will require a 4 inch nozzle and the monitor nozzle will have to be reduced to 3¼ inches. The daily yardage will consequently be reduced from 2,000 to 800. The velocity in the upraise pipe should be about 12 feet per second and the diameter of the pipe should be 18 inches. The friction in the upraise pipe may be taken at from 2 to 2½ times the clean water friction. For pipes 12 to 18 inches in diameter an addition of 7 feet for each 100 feet in length will roughly cover the friction head.

Gravel pumps.—The next step is the substitution of the gravel pump for the elevator. A gravel pump will give an efficiency of from 35 to 45 per cent. If the pump is driven by a Pelton wheel the overall efficiency may be taken at 30 per cent., if the tail water can be disposed of without elevating. Treating this in the same manner as the elevator calculation, the ratio of the pressure water to monitor water is now as 1 to 1·6, so that the pump will consume only 7¾ cusecs, leaving 12¼ for the monitor. A 4-inch nozzle can be used and the daily yardage increased to 1,225.

The pump is generally mounted on a barge for convenience in moving up to the face, and thus the conditions of dredging are approached. If water can be obtained from a source very much higher than is necessary for hydraulicing, it may be used to drive a nozzle pump; in this way a small supply of water under a great head may pump a much greater volume of nozzle water and tailings. Such a method is adopted at Kanbauk, but owing to the difficulty of making pipe connections each time the barge is moved, electrical distribution from a permanent generating station is adopted.

Dry dredges.—The system of operating such installations is practically the same as hydraulicing except that the same water is used repeatedly. The barge is erected in a paddock and, as this becomes enlarged and the face recedes, it is flooded and the barge floated to a new site. The tailings are pumped behind a brushwood dam behind the barge, the solids settle down and the water returns to the nozzle pump.

Examples of high pressure hydraulic installations in Tavoy.

Wagon.—At the Wagon mine of the Wagon-Pachaung Wolfram Mines, Ltd., detrital ground is successfully treated by monitors with 1 inch to 1½ inch nozzles, working under a head of 230 feet. The length of piping used from the intake on the Pya chaung is about a mile. The intake is set in a small diversion dam of ferro-concrete and the appliances were designed and erected by Mr. H. G. Mathews. The ground is thin and overlies decomposed granite. Owing to the absence of large quantities of stones the tailings are soft, and as the mine lies at some distance above the elevation of the main drainage channel of the neighbourhood, their disposal presents no great difficulty. Work can only be carried on during the monsoon.

Hermyingyi.—At the Hermyingyi mine an old terrace deposit at the head of the Maungmeshaung valley is treated by monitors with nozzles of 1½ to 2½ inches, working under a head of 220 feet. Water is available only during the rains, and is taken from one of the flumes which also supply the ground-sluicing requirements of the mine. The ground is exceedingly heavy and over 80 per cent. consists of large boulders and stones, some of which have to be blasted and removed by hand. Yet the total cost of the wolfram and cassiterite concentrates produced is only Re. 1 per viss (*i.e.*, per 3.60 lb.) and in lighter ground with better facilities, where a larger quantity could be cut per month, the concentrate ought to be produced at a quarter this cost and consequently much poorer ground could be made to pay well.

Dredging.

Dredging operations proper, for tin ore, are only carried on in one locality in Tavoy at present. This is near Taungthonlon in the valley of the Hindu chaung, about 30 miles from Tavoy town on the Siam road. The area was originally held under a "native methods" lease by one Lubhai Sahib, who carried on small scale sluicing operations, smelted the cassiterite in Tavoy and sold the metal locally.

At a later date the area was sold to a Melbourne company known as the "Hindu Chaung Tin Dredging and Mining Company."

A dredge was built in Melbourne and erected at the site. It commenced working in October 1911 and continued until the outbreak of war in 1914, shipping, it is said, in all about 200 tons of cassiterite. At the end of 1914 the Company went into voluntary liquidation and at a later date the dredge was purchased by Messrs. Booth and Milne. They started work again in 1916 with considerable success and sold the property and machine to the present owners, the Indo-Burma Tin Corporation, Ltd., in 1918. This is a Calcutta concern with an authorised capital of Rs. 45,00,000, of which Rs. 36,75,000 are issued. Operations are being continued with the old suction dredge while others of the bucket type, formerly used for gold dredging in the upper reaches of the Irrawaddy, are being transported to, and erected on, the Taungthonlon area.

The following particulars of the first dredge are of interest :—

Type.—A revolving cutter and suction. Casey's Patent Pontoon with a deck of 100′×40′, and depth of 6′ 6″ forward and 8′ 6″ aft. Draws 4′ of water with tin saving sluices loaded.

Main Pump.—A 12″ Gravel Pump by Thompson & Co. of Castlemaine, driven by a 75 B. H. P. Belliss and Morcom high speed compound condensing engine. This pump raises 1,500 gallons water per minute, and 1 yard of 'solids,' with a 'Duty of Water' of 10.

1,500 gallons of water weigh approximately 6¾ tons,
1 cubic yard of 'solids' weigh approximately 1¼ tons,
so that the total lifted per minute is approximately 8 tons altogether.

Service, or 'Auxiliary' Pump.—A 10″ centrifugal driven by a 25 B. H. P. high speed Belliss and Morcom compound condensing engine.

The dredge is fitted with a surface condenser and an Edwards' air pump. Steam is supplied at 150 lbs. pressure by a Babcock and Wilcox water-tube boiler, with integral superheater.

Sluices.—These are 8 in number, 90 feet long and 4 feet wide each. When loaded the incline is 3 per cent.

The main sluices have 4″ stops or riffles every 8′ of run and this height of stop is not added to, as the clean-up takes place every day.

The cross sluices, under the screen, feeding the main sluices, are stopped up 2″ every 4 hours during working so that at clean-up every day there are 12″ of stops in the cross boxes.

The successful operations of the Taungthonlon dredge in the Hindu Chaung valley have drawn attention to the possibilities of the profitable extraction of cassiterite from similar alluvial deposits in other valleys, and by the end of 1918, a number of prospecting licenses had been allotted to various firms and a busy campaign of testing operations was in progress in the valleys of the Pauktaing, Khamaunghla, Kamaungthwe and elsewhere.

CHAPTER VIII.

THE ORIGIN OF THE WOLFRAM AND CASSITERITE ORES OF TAVOY.

Earlier writers.—A. G. Bleeck, 1913.[1]—A. G. Bleeck, writing in 1913, was the first geologist who attempted to classify the wolfram and cassiterite deposits of Tavoy and to give an account of their origin. He divided them as follows :—

(1) wolframite-quartz lodes.
(2) cassiterite-quartz lodes.
(3) wolfram greisen.

The wolframite-quartz lodes are stated to be the most important ; of the other two classes only a single example of each was observed. The writer refers to the district as a wolframite-cassiterite-columbite zone. " Judging by the petrological and chemical evidence detailed above, there appears to be little doubt that the ore bodies of the Tavoy district indicate a distinct mineral zone, this term being used in a parallel sense to that of petrological province. This mineral zone is characterised by the persistent occurrence of the mineral columbite. In other parts of the district, which were not visited by me, tin ores perhaps predominate over wolfram ores, and in a broader sense and applied over larger areas, the mineral zone might be termed a wolframite-cassiterite-columbite zone." Again, " Columbite in black orthorhombic crystals, was observed in all the lodes."

These observations have not been confirmed. Niobium has been reported to occur in minute quantities in some wolfram concentrates from Tavoy, but the form in which it is present is unknown. The oxides of niobium and tantalum have also been proved in small quantities in wolfram from various localities in the United States and other countries, but free columbite or tantalite has never been found in a wolfram-bearing pegmatite or quartz vein in Tavoy, either by ourselves or anyone else that we are aware of up to date.

Bleeck's observations regarding tourmaline and flourite have also to be corrected in the light of more recent research. " Tourmaline," he writes, " is present everywhere, generally in micro-

[1] A. G. Bleeck (2), pp. 48-73.

scopic crystals," and again, ' it is worthy of notice that no fluor spar was found anywhere." As far as we know tourmaline does not exist in the wolfram-bearing veins of Tavoy, though it is found in pegmatites of later date, while flourite has a wide distribution in small quantities. We believe that this is the unanimous opinion of all geologists who have examined the Tavoy field in recent years. Curiously enough, tourmaline is a common vein mineral with wolfram and cassiterite in the Amherst, Thaton and Mergui districts to the north and south of Tavoy respectively.

Bleeck believes that the veins were formed after the solidification of the main granite mass, by mineral solutions which deposited their load in fissures in the granite and the country rock. Following the igneous effusion but before consolidation, local differentiation is believed to have taken place, causing the heavy metals with some mother liquor to separate from the quartz-felspar-mica magma. The formation of separate cassiterite-quartz lodes distinct from the wolfram lodes is held to be caused by the formation of numerous distinct centres of differentiation. The responsibility of aqueous solution for the formation of wolframite lodes is said to seem abundantly clear, if only from the one fact that the gangue quartz is crammed with liquid inclusions. At the same time the pneumatolytic process of mineral formation went on side by side with the deposition of lode matter from solutions, for such a process " need in no way clash either chemically or physically with the theory of lode formation from magmatic injections or aqueous solutions." Again, Bleeck believes that in some cases the mother liquor which had become differentiated from the granite magma may have been injected into the fissures in a magmatic state and not in the form of aqueous solutions.

J. Coggin Brown, 1916.[1]—In a paper read before the 4th Indian Science Congress at Bangalore in January 1917, only a brief summary of which has been published, the following tentative views were advanced :—

(1) The remarkable absence of such characteristic pneumatolytic minerals as tourmaline, topaz, etc., from the vein association appears to prove that fluorine and boron-bearing compounds, the typical mineralisers of the text books, played a subordinate part as far as the formation of wolfram was concerned.

[1] Coggin Brown (3), pp. 102-103.

(2) Pegmatites carrying wolfram and cassiterite exist and some of them pass laterally into quartz veins with the same metallic minerals. The inference drawn from this is that veins in which the pegmatitic origin is not so clear, may have been formed under conditions approximating closely to those under which the pegmatites themselves arose.

(3) In so far as it may be correct to regard the pegmatite-aplite family of rocks as differentiation products of granites, it seems reasonable to look upon their metal-bearing contents as segregations from acid magmas to an equal extent.

(4) In cases where the pegmatitic origin of veins is obscure they may have been formed by later hydrothermal phases of the same processes.

Admitting the existence of pegmatites and pegmatitic veins on one hand and those of an intimately connected hydrothermal phase on the other, a place must be found for pneumatolysis somewhere, for it is inconceivable that the gases of the magma took absolutely no part in the vein formation. The very common occurrence of greisen bands carrying wolfram or cassiterite or both, bordering veins in granite, or even existing without any vein matter at all, may be due to this cause. In addition to the potent action of superheated steam, the constant association of wolfram with pyrite and other sulphides raises the question as to whether the places of boron and fluorine in the typical pneumatolytic processes may not have been taken by sulphur and arsenic.

J. Coggin Brown, 1917.—In a popular paper, published in 1918, these views were put forward again. The granite was held responsible for the mineralization, the wolfram, cassiterite, molybdenite, bismuth and other metalliferous minerals are believed to have come from it, and the veins to have been formed during a short period of metallization towards the end of the igneous epoch. Many of the quartz veins were formed in the same manner as pegmatites, both quartz and water being of direct igneous origin. Towards the end of the pegmatitic period, an intense hydrothermal phase supervened and some of the veins were doubtless formed then.[1]

[1] Coggin Brown (4), pp. 55-70.

W. R. Jones.—In a paper published in 1918, Dr. W. R. Jones has developed his views.[1] He holds that the origin of the wolfram, tin-ore, scheelite and associated minerals found in the Tavoy district, is closely and definitely related to the fluxes and solvents which emanated from the granite magma, and that there is little doubt that such minerals as those already mentioned, together with molybdenite, bismuth, bismuthinite, pyrite, mispickel and some others, common in the lodes in Tavoy, were formed through the agency of magmatic gases and solutions. The watery acid mother liquor, formed by the differentiation of the magma, and rich in mineralizing gases and solutions, followed immediately and often accompanied the intrusion of the very acid magma, and when they reached a temperature zone sufficiently cool, the minerals were deposited. The wolfram and tin ore occur where the chilling was greatest and this is given as the reason why the hanging and foot walls of veins carry most values and why narrow veins have higher percentages than wide veins. Greisens were formed by gases and solutions attacking the rocks beyond the well-defined vein walls, and wolfram and cassiterite occurring in granite as primary minerals, are regarded as due to the escape of the mineralizing gases with the first main intrusion.

Dr. Jones attaches great importance to temperature as a factor determining the zones of deposition of wolfram and tin-ore and to the powerful fluxing action of the mineralizing gases and solutions, which enabled the magma to crystallize at relatively low temperatures, and hence to be introduced into narrow fissures now forming quartz and pegmatite veins extending hundreds of yards into the adjacent schists and phyllites. He believes that the evidence in the Tavoy district is in favour of regarding sulphides as having played a most important part as "carriers" of wolfram and tin-ore, and finally, that wolfram in general appears to have been deposited at lower temperatures than has tin-ore in the Tavoy district, a theory that has a most important bearing on the future of the mining industry, if it proves tenable.

J. Morrow Campbell, 1918.[2]—Dr. Morrow Campbell rejects both the magmatic and pneumatolytic theories of vein filling in Tavoy, believing that the presence of wolfram disseminated as a primary mineral throughout granite provides a refutation of both.

[1] W. R. Jones (15), pp. 33-44.
[2] J. Morrow Campbell (9), pp. 76-89.

He is of the opinion that the ore minerals were brought up in solution by surface water which gained access to the molten magma through fractures caused by the upheaval of the granite itself. His important paper is difficult to summarize and the interested reader is advised to consult the original. Dr. Campbell can see "no evidence whatever of pneumatolytic origin but much evidence of aqueous origin." He reminds us of the existence of the soluble silicotungstic acid, SiO_2, $4H_2O$, $12WO_3$, and that the alkaline silicotungstates are readily soluble in water. He states, "I believe that highly siliceous water under high pressure and at moderate temperatures is capable of carrying both tungsten and tin in solution, that this is the agent which extracts them from the granite magma and transports them to veins and that they do not pass upward in gaseous form."

Regarding the opinion of Dr. Jones that wolfram is a lower temperature mineral than cassiterite, Dr. Campbell states, "I have examined very carefully the mixed wolfram-cassiterite ores from most of the mines in the district and in the vast majority of cases there is no shadow of doubt that wolfram was deposited before tin .... I have seen many hundreds of samples of cassiterite filling the spaces between wolfram crystals, enclosing wolfram and carrying the impressions of its striations, several where it has filled cracks in wolfram and two excellent examples of tin-ore crystals actually formed on surfaces of wolfram."

The same author has developed his views at greater length in a more recent paper.[1] This may be divided into two parts, the first, a general one dealing with the vertical range of meteoric water in the earth's crust, the genesis of rock magmas discussed with reference to W. H. Goodchild's recent work, and magmatic differentiation; the second portion may be said to apply the theories of the first part in explaining the formation of the mineralized granite and the ore-bearing veins of the Tavoy district, and to the general question of the permanence of wolfram deposits in depth.

The existence of a highly acid mother liquor, which may contain all the constituents of granite or little else but silica and water in which the tin and tungsten minerals are contained, because they are more soluble in the acid differentiates than in the more basic portion, and which deposits either pegmatite or quartz on cooling, is postulated. Further, there is said to be abundant evidence in

[1] J Morrow Campbell (10).

the Tavoy district that this aqueous portion did not segregate below the granite as it is generally supposed to do, but that it appears to have been held to a great extent in a band of granite a few hundred feet thick at the upper margin at the stage when it was only partially solidified, in much the same way that water is held in a sponge. The only explanation of this is said to be that a steady influx of meteoric water has taken place and has been absorbed locally at points on the periphery. The occurrence of aplite dykes, pegmatite veins and patches of granite on the upper margins of batholiths, all carrying tin-ore and wolfram, but only in the vicinity of mineralised quartz veins, and the fact that tin and tungsten minerals usually occur within small circumscribed areas in narrow, numerous and parallel veins, is believed to be explicable only on the hypothesis that meteoric water reached the granitic portion of the magma in varying quantity, and at definite points during the differentiation period.

The pneumatolytic theory is regarded as overworked, but fashionable because those who follow it have not troubled to doubt or to prove its applicability. It is argued that there is good reason for believing the association of tourmaline, fluorides, etc., with cassiterite, presumably anywhere in the world, to be fortuitous and not genetic, and that there can hardly be two modes of origin of cassiterite, one for Tavoy and another elsewhere. The absence of intense local metamorphism of the country rock near veins, leads Dr. Campbell to the belief that the temperature of ore deposition in the veins of sedimentary rocks was below that at which pneumatolysis would be possible.

To most of these opinions we demur.

W. R. Jones, 1919.[1]—Dr. Jones has replied to Dr. Morrow Campbell's first paper. He reiterates his views that both mineralizing gases and mineralizing solutions played their parts in ore deposition and that both were of deep-seated origin. The former have been the chief agents and he sees no point in separating the one from the other on paper, when in nature they are found in many cases to have functioned together. He also mentions recent analyses of the water from a hot spring in Malacca, which have failed to confirm St. Meunier's analysis that it deposited a siliceous sinter containing 0·5 per cent. SnO_2. This analysis had been quoted by Dr. Campbell.

[1] W. R. Jones Second Series of lectures delivered at Tavoy. (In the press.)

Conclusions.—The later work of the Geological Survey in Tavoy has not led to any important modifications of the views already published by one of us. While we do not deny the important part played by water in the vein formation, we prefer to regard it as of magmatic origin rather than to assume its meteoric derivation, as Dr. Morrow Campbell has done. We conclude:—

(1) That the columbite-tantalite group of minerals is absent.

(2) That tourmaline does not occur in the ore mineral association in Tavoy.

(3) That fluorite is a widely distributed accessory mineral in the pegmatites and veins, though it is not found in large quantities. It does not appear to exhibit any preference for veins in granite over those in the sedimentary rocks. Since the earlier report was written fluorite has been found at numerous new localities, and for the supporters of the pneumatolytic theory, as it is generally understood there may be sufficient fluorite present to account for the formation of both cassiterite and wolfram in those veins in which it occurs, provided that the flourine element acted after the manner of a catalytic agent.

(4) That sulphides are common accessory vein minerals, their relative order of importance being sulphides of iron, copper, molybdenum, bismuth, lead and zinc. We are also of the opinion that sulphur played some part in the pneumatolytic reactions that took place.

(5) That wolfram, cassiterite and scheelite occur in pegmatites.

(6) That some of the veins are of hydrothermal origin.

(7) That many of the mineralised veins are of pegmatitic origin.

(8) That in the formation of these pegmatites and veins, water of magmatic origin played a leading part.

Hydrothermal veins a phase of pegmatitic development.—Recent geological literature adds support to this contention. According to Thomas and MacAlister, " a hydrothermal phase of some pegmatites is now recognised, and is generally represented by siliceous deposits (often containing rare minerals), formed in fissures as a continuation or prolongation of the pegmatite. This ultimate phase is explained by the fact that the pegmatites with which it is found contained a considerable amount of water, which was given off as solutions rich in silica and other substances during the final consolidation of the pegmatite."[1] Harker has discussed the vexed question as to whether pegmatites have an igneous or aqueous origin and remarks[2] :—"From our point of view, as already sufficiently indicated, the antithesis marked by these terms finds no place. The magma or solution from which the pegmatites crystallized was igneous, in that it was the residual part of a granitic or syenitic or other igneous magma, of which the greater part had already crystallized under plutonic conditions. It was aqueous, inasmuch as it contained, perhaps very richly, magmatic water, concentrated (with other volatile constituents) in the residual magma by continued crystallization of anhydrous minerals. The pegmatites themselves represent this watery residual magma, except that the greater part of the water and other volatile substances was expelled in the final crystallization. This final crystallization from a solution rich in water and perhaps in other fluxes may have taken place at quite low temperatures, but genetically it is impossible to separate the resulting product from igneous rocks. Logically, indeed, we might include under the same head simple quartz veins crystallizing from solution in water (at perhaps 200°C), if both quartz and water were of direct intratelluric origin, the final residuum of an igneous rock magma."[3] Lindgren, in discussing juvenile waters, makes the following observations, "the best evidence of the existence of juvenile water is furnished, not by observation of its present springs, but by the study of old intrusive regions. Here the granites merge into pegmatite dykes and the latter change into pegmatite quartz and this into quartz carrying metallic ores, such as cassiterite and wolfram. Here we have evidence difficult to controvert that dykes consolidated from magmas gradually turn into deposits the structure and minerals of which testify to purely aqueous deposition." And, later, "yet when we note how veins rich in quartz are at places directly connected with pegmatite dykes, and how strong the evidence is against their deposition by leaching from surrounding rocks, we may well wonder whether this silica in the thermal waters is necessarily derived by solution of rock comparatively near the surface."[4]

[1] Thomas and MacAlister, "Geology of Ore Deposits," p. 31.
[2] Harker; "The Natural History of Igneous Rocks," p. 294.
[3] Harker, *Loc. cit.*, p. 295.
[4] Lindgren, "Mineral Deposits," 1919, pp. 88 and 92.

Pneumatolysis.—Various writers have used this word in many different senses and we believe that a great deal of confusion of thought has arisen through their readers failing, often through no fault of their own, to comprehend the exact shade of meaning of the writer, or to appreciate what processes or phases he intends the word to cover. Rastall thinks that the use of the word is needless in connection with the processes of differentiation which take place in the crystallization of the last residues of an acid magma, in that it seems to imply something unusual, abnormal and out of the common order of events. He prefers to divide the different phases of the processes as follows:—

1st phase.—Concentration within the magma of the metallic constituents in combination with the volatile elements.

2nd phase.—Separation from the crystallizing granite of the compounds thus formed, and escape of the same through fissures.

3rd phase.—Chemical reactions between the compounds in the escaping gases, or solutions, leading to the formation of crystallized ore and gangue minerals.

"This kind of differentiation is perfectly normal; its final results depend mainly on the extent to which highly volatile compounds and water were present in the original magma. The more of these are present the lower will be the freezing point of the final product. The effect of alkaline tungstates in lowering the freezing point of acid silicate melts, and thus enabling quartz and felspar to crystallize, has long been known and used in petrological and mineralogical research."[1]

The subject has been discussed in another connection by Grafton and McLaughlin, who point out that Bunsen, in advancing the term, employed it in a very limited sense to the action of volcanic gases in and near fumaroles, and that its modern usage as generally understood to suggest destructive action by corrosive mineralizers such as fluorine, chlorine, boron, sulphur and phosphorus, with the production of minerals like tourmaline, topaz, fluorite and scapolite, is a liberal extension of its original narrow meaning.[2]

[1] R. H. Rastall, *Geol. Mag.*, 1918, p. 369.

[2] L. C. Grafton and D. H. McLaughlin, "Further Remarks on the Ores of Engles, California," *Econ. Geol.*, Vol. XIII, pp. 81-99, 1918.

These writers, in an earlier paper than one quoted below, extended the term to include the formation of pegmatites containing tourmaline and titanite associated with sulphide ores, regardless of whether such minerals were of destructive or constructive origin. In so doing they believed they were following competent and predominant, even if not unanimous, opinion. They now agree that the word pneumatolytic is not wholly satisfactory, if used in its broader sense, as it does not apply with adequate specificness and exclusiveness to a group of post-magmatic sulphides in the case which they are discussing, nor does it sufficiently imply the close affiliations to the truly magmatic stage exhibited by the group as a whole: while if the term be limited to the narrower sense it is even less satisfactory. To overcome the difficulty, they have come to the conclusion that there is need for two specific definite names, each independent of the word "magmatic," and they have coined the words "orthotectic" and "pneumotectic" for the purpose. The first designates "those processes and products, strictly magmatic in the narrowest sense, exemplified in the normal crystallization of normal igneous rocks." The second is used for "those next-subsequent processes and products of magma consolidation in which fundamental influences of a sort that was magmatic in the strictest sense were recognisably modified and to some extent controlled by gaseous constituents or so-called mineralizers which accumulated in relative concentration, by elimination, when in the preceding, orthotectic stage the major portion of the magma crystallized without incorporating more than a minor portion of those volatile substances that had been components of the initial molten solution. Thus the orthotectic products do not necessarily fail to include metalliferous ores, provided the ore minerals are on an identical footing with the customary rock minerals. But in case it is necessary to assume that the fluidity of the ore minerals requisite for their localization is dependent on the influence of mineralizers, such deposits would fall in the pneumotectic group. In consequence of the establishment of these two prior periods it is suggested that the term pneumatolytic might be limited to those processes and products in which the fundamentally dominating influence is no longer the straight melt, but is, instead, the still further concentrated and controlling gases. The stages might go on with pneumato-hydatogenetic if an intermediate term is considered necessary to the hydrothermal, and beyond, if required or justifiable. Any or all of these periods or divisions would be collectively regarded as magmatic by those who believe in the versatile efficacy of igneous processes in mineral formation and deposition."[1]

It is our belief that the wolfram-cassiterite-sulphide deposits of Tavoy district were formed partially under conditions closely allied to strictly magmatic ones, were also formed by processes in which gaseous agencies, including compounds of fluorine and sulphur, to some extent played a part, and, in rarer cases, by hydrothermal reactions which followed as a consequence of the former ones. It is impossible to draw any hard and fast lines between the different stages, which are all part of one continuous process, doubtless proceeding concurrently in some cases. In fact the whole process of mineral vein formation associated with the great granite chain extending from the southernmost limits of Burma to an unknown termination in the Shan States, as far as we have examined it at present, appears to be a direct sequence of processes of differentiation or fractional crystallization through a series of varying phases induced in the original magma by decreasing temperature.

[1] L. C. Grafton and D. H. McLaughlin, *Loc. cit.* pp. 83-86.

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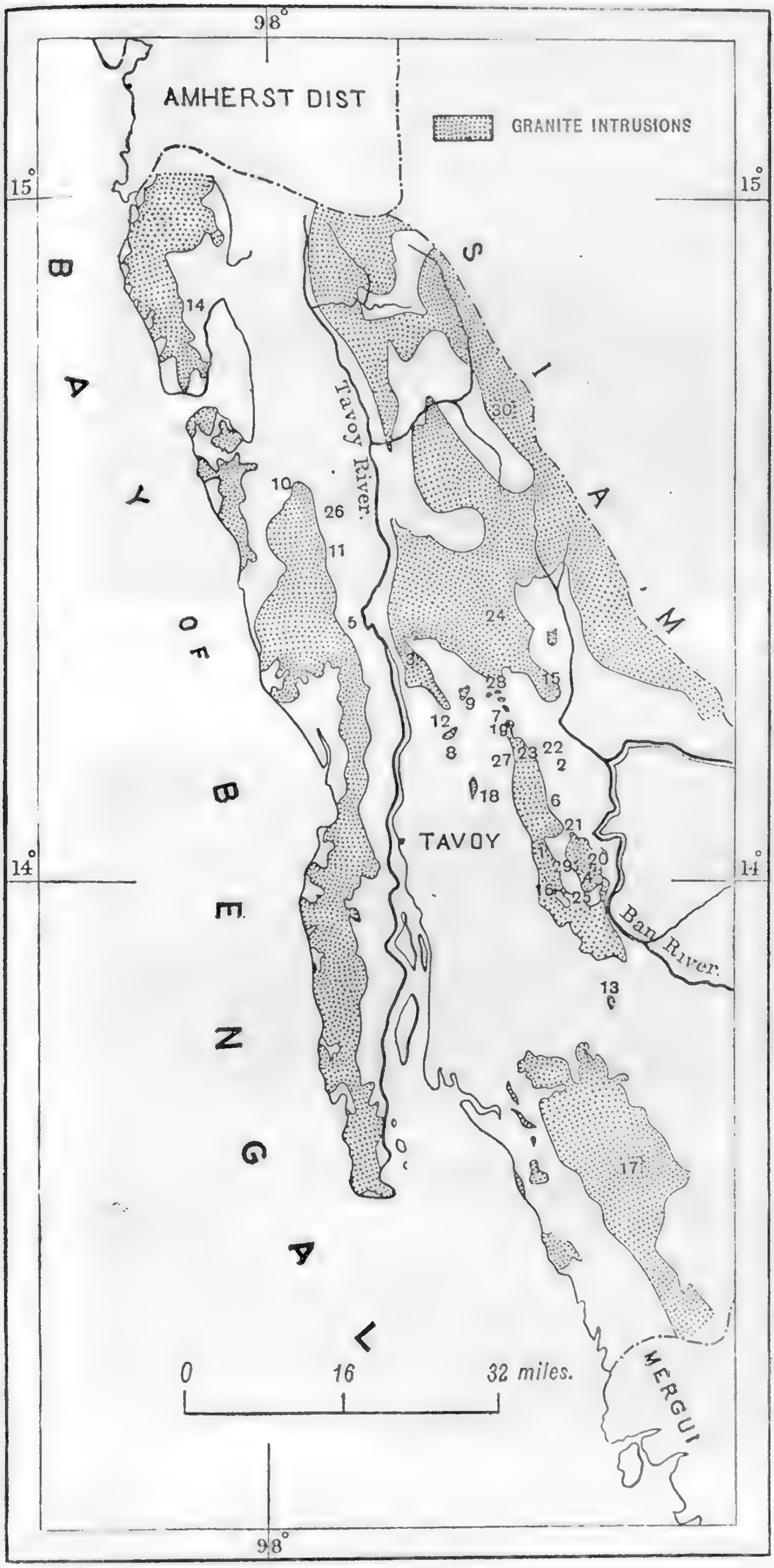

MINES.

1. Anyapya.
2. Bawabin.
3. Byaukchaung & Talaingya.
4. Crest & Darichaung.
5. Egani.
6. Heinda.
7. Hermyingyi.
8. Kadwe.
9. Kalonta.
10. Kanbauk.
11. Kechaung & Pachaung.
12. Kyaukanya.
13. Meke.
14. Medaw.
15. Myekhanbaw.
16. Nwalabo.
17. Padauk (Pe).
18. Pagaye.
19. Pa-in & Taungpila.
20. Paungdaw.
21. Putletto.
22. Rubber Mile.
23. Sheffield & Wagon.
24. Sinbo Sinma.
25. South Paungdaw.
26. Taungshun.
27. Thingandon.
28. Thitkado.
29. Widnes.
30. Zinba.

G. S. I. Calcutta

MAP OF TAVOY SHOWING POSITIONS OF PRINCIPAL MINES WITH REFERENCE TO GRANITE INTRUSIONS.

FIG. 1. TYPICAL TAVOY BEACH, showing platy weathering of granite, sandspit edged with Casuarina trees, and granite hills behind.

A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. TYPICAL TAVOY LAGOON, sandspit with small Casuarina trees on left, and mangrove swamp in background.

FIG. 1. JUNCTION OF KAMAUNGTHWE (left) AND BAN (right), to form Great Tenasserim River (centre), view looking east.

A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. TAVOY RIVER AT SHINTABI. Gorge in Mergui Series quartzites, with granite hills behind.

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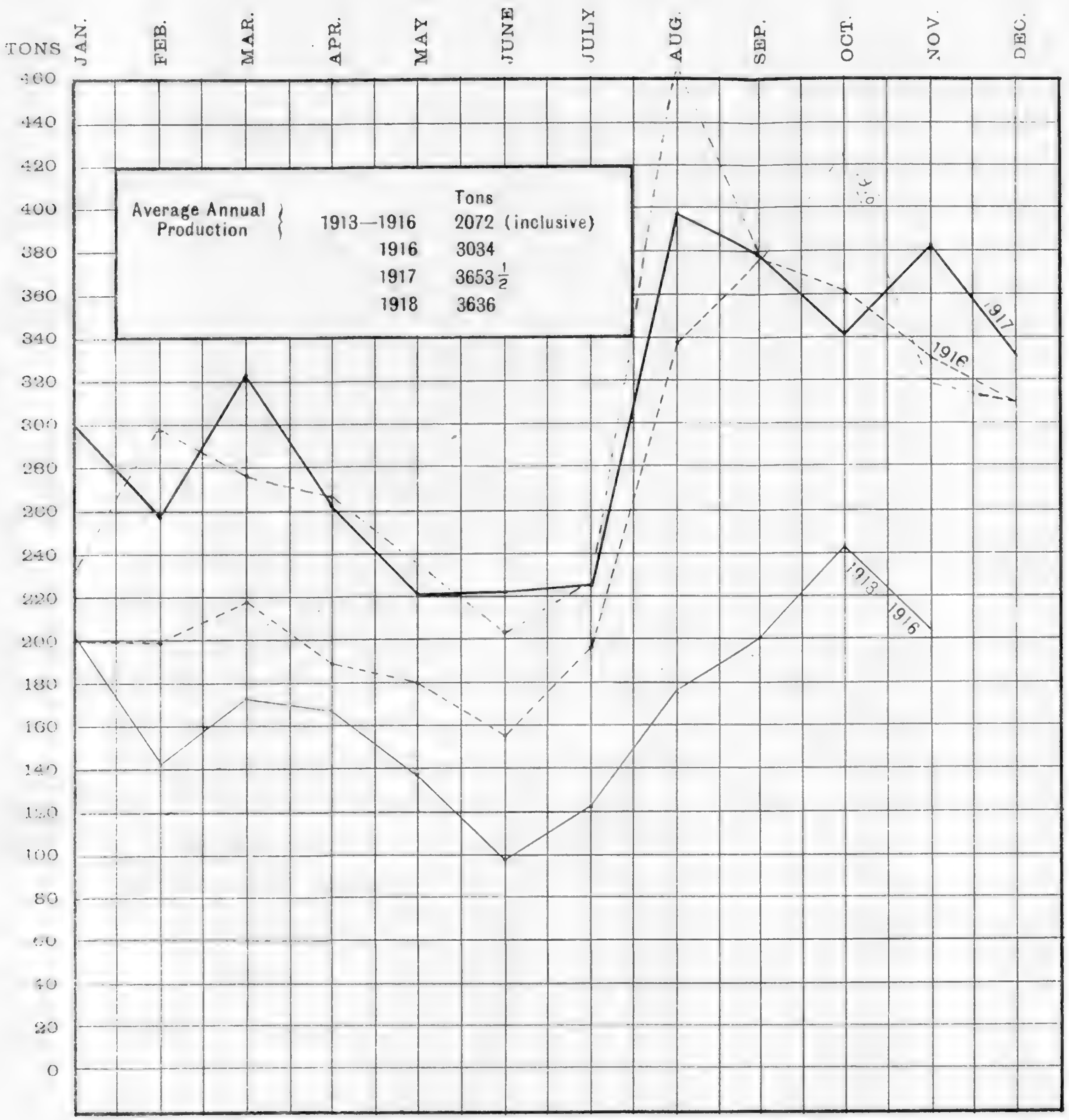

FIG. 1 WOLFRAM PRODUCTION OF TAVOY 1913–1918.

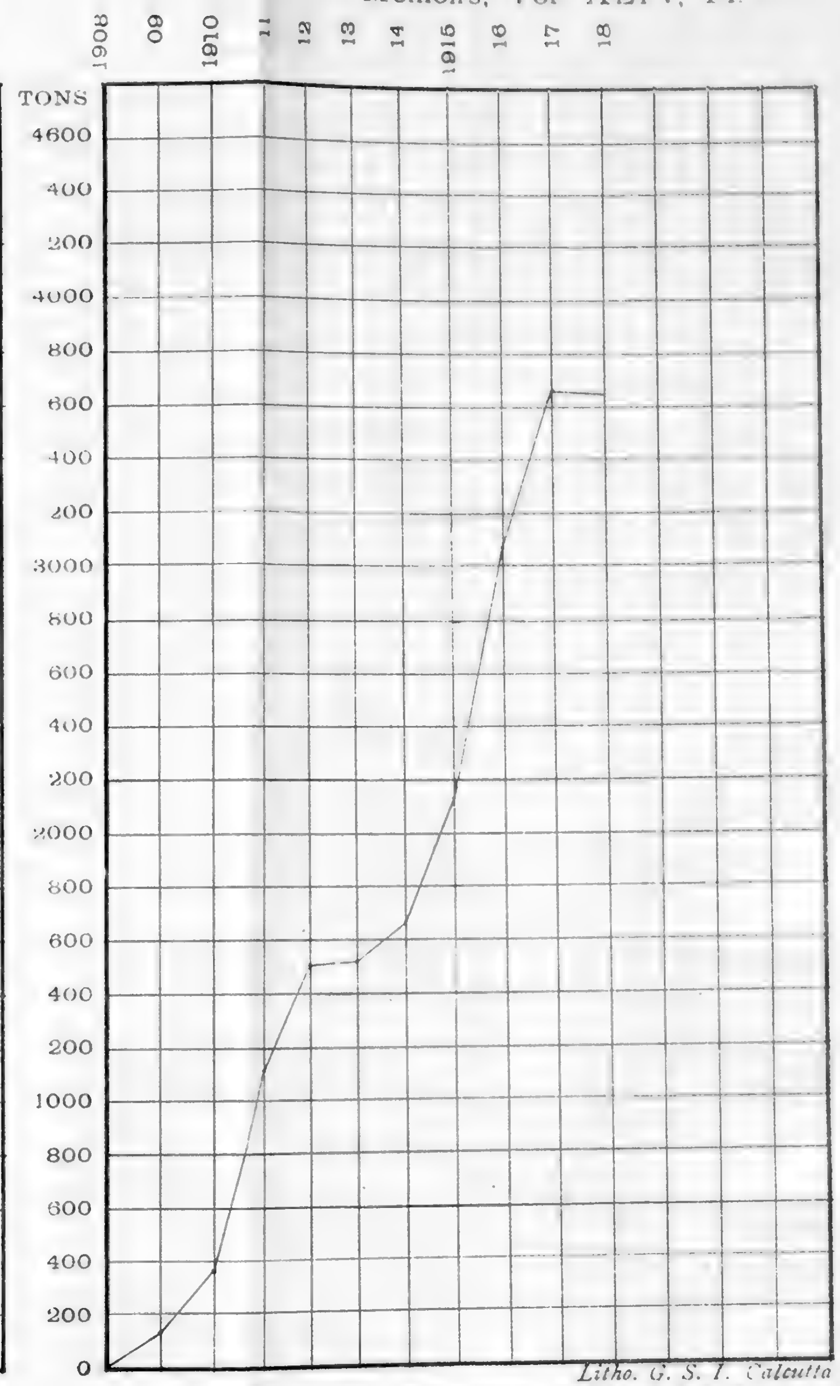

FIG. 2. CHART SHOWING GROWTH OF WOLFRAM MINING IN TAVOY (1908 -1918).

(Figures are based on royalty returns of mixed concentrates).

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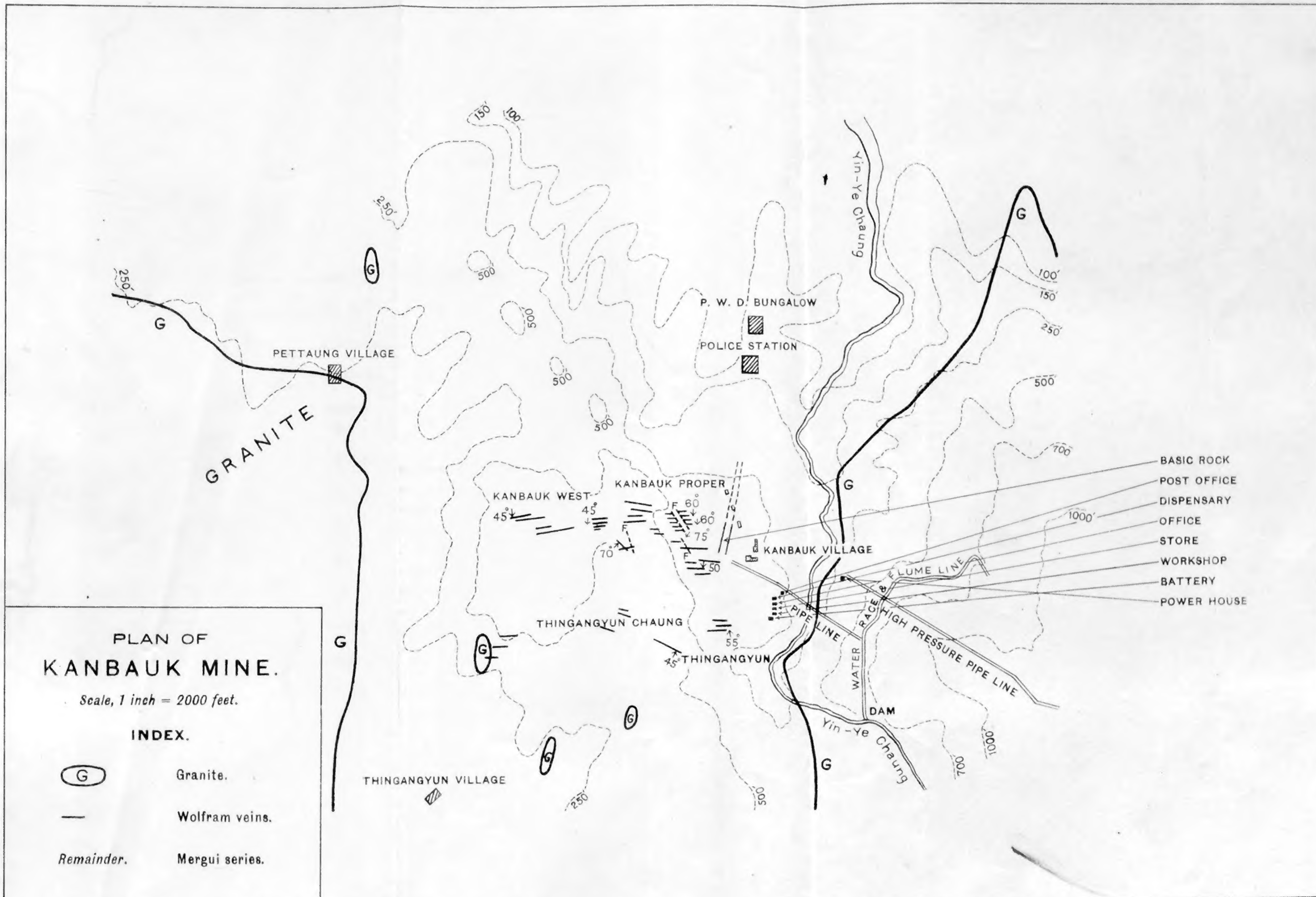

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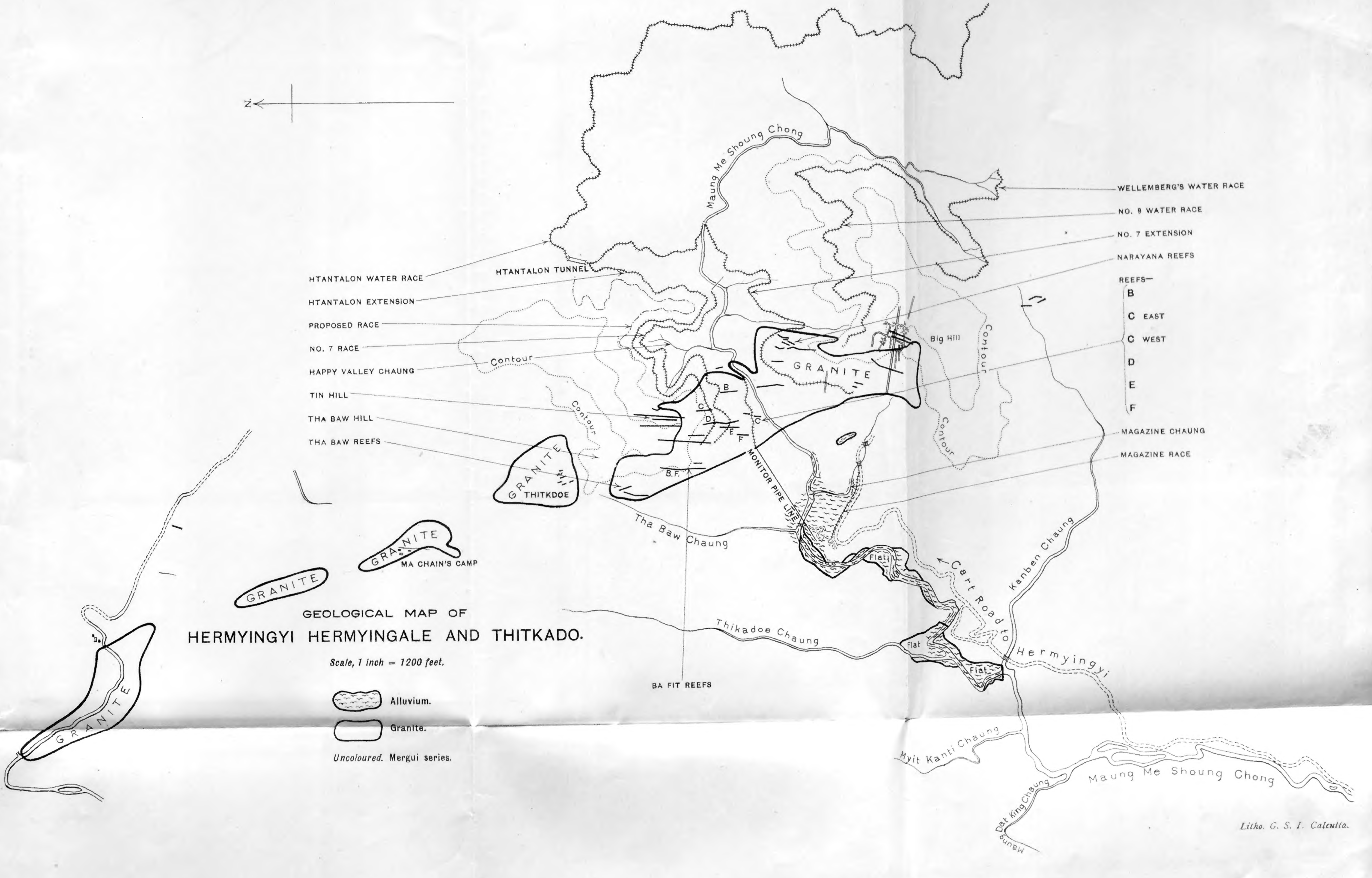

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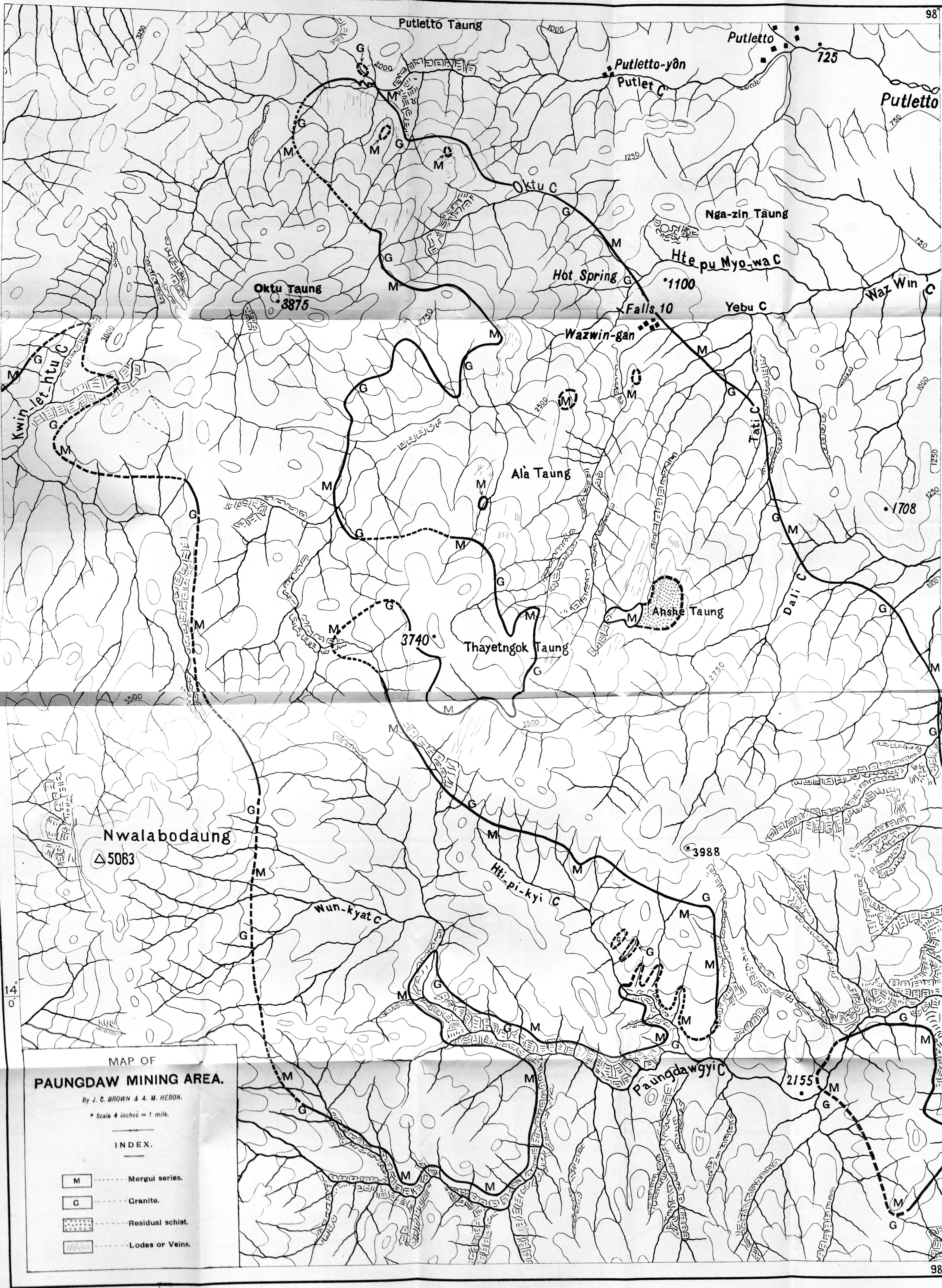

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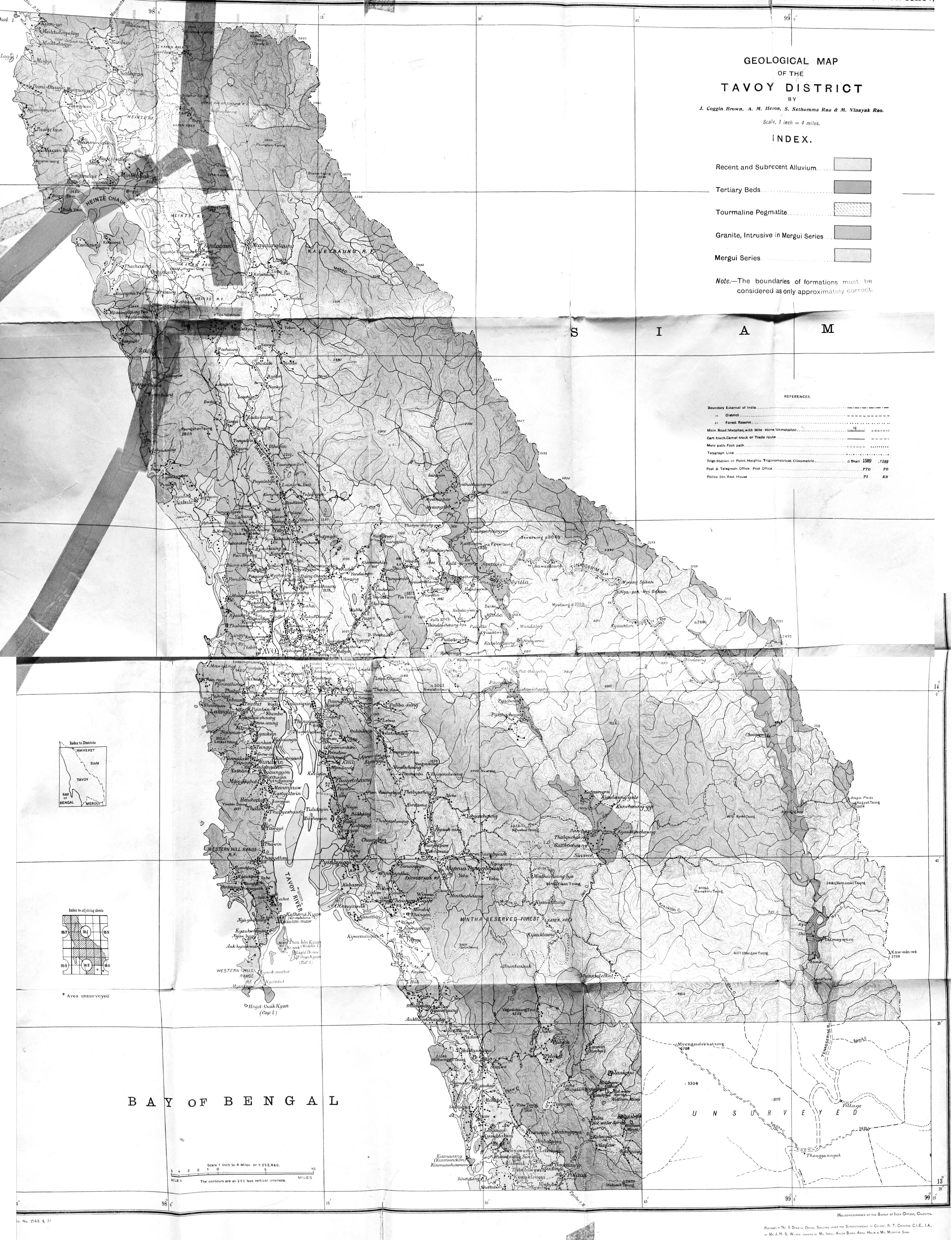
GEOLOGICAL MAP
OF THE
TAVOY DISTRICT
BY
J. Coggin Brown, A. M. Heron, S. Sethurama Rau & M. Vinayak Rao.
Scale, 1 inch = 4 miles.
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Mergui Series
Note.—The boundaries of formations must be considered as only approximately correct.
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MERGUI
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* Area unsurveyed
Scale 1 Inch to 4 Miles or 1:253,440.
MILES
The contours are at 250 feet vertical intervals.