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RECORDS

OF

THE GEOLOGICAL SURVEY OF INDIA.

Part 2] 1937 [December

The Snout of the Gangotri Glacier, Tehri Garhwal.

By J. B. Auden, M.A., F.G.S., *Geologist, Geological Survey of India.* (With Plates 2 to 7.)

CONTENTS.

I.—INTRODUCTION.

This paper describes the observations made on the snout of the Gangotri Glacier, which I visited when on leave in October, 1935. The Gangotri glacier is situated in Tehri Garhwal State, on the north side of the Main Himalayan Range, and is the source of the Bhagirathi branch of the Ganges river. This branch is considered to be more sacred than the Alaknanda, and Gaumukh, the name given to the snout of the glacier, is visited annually by pilgrims and sadhus.

An account of the excursion I made to the region, in the company of Dr. D. G. Macdonald, occurs in the *Himalayan Journal*, Vol. 8, p. 96, for 1936.

The Gangotri glacier lies in Survey of India 4 miles to 1 inch map No. 53 N, at Lat. 30° 56′ N.; Long. 79° 04′ E. The altitude of the snout is 12,770 feet. The scenery is very fine, the glacier being dominated by the Satopanth group of peaks (21,364 and 22,520), and the isolated Shivling peak (21,466), which bears a strong resemblance to the Matterhorn.

I am indebted to the Director, Geodetic Branch, Survey of India, for supplying an advance copy of a portion of Map 53 N, which is reproduced here as Plate 3.

1. Route.

The best route to the glacier is from Mussoorie, whence it can be reached in from 10 to 12 days. The more direct route is *viâ* Deosari and the east shoulder of Nag Tibba (53 J/N.W.), but this involves somewhat severe changes in gradient and is scenically less attractive than the slightly more circuitous path through Dhanaulti and Kanatal (53 J/S.W.). After about October 1st, the last place at which rations for porters may be obtained is at Harsil (53 I : 31° 02′ : 78° 45′), though during the pilgrim season it is probable that supplies may be bought in the shops at Gangotri. After leaving Harsil it is necessary to use tents, and there is a good camping ground at Gaumukh, where small shrubs are available for fuel.

2. Historical.

The glacier has been visited, presumably for centuries, by pilgrims. It was roughly surveyed by the Survey of India in the middle of the 19th Century. Griesbach sketched the snout during the course of his geological traverses in the region [*Mem. Geol. Surv. Ind.*, XXIII, p. 27, (1891)]. The Marco Pallis expedition of 1933 was the first to climb any peaks within the Gangotri basin [*Himalayan Journal*, Vol. 6, p. 106, (1934)], although peaks and cols on the watershed between the Gangotri and Arwa drainage systems had been climbed two years earlier, by the Kamet expedition of 1931 [*Himalayan Journal*, Vol. 4, p. 35, (1932)]. Shipton and Tilman descended to Gaumukh from British Garhwal in 1934 [*Geogr. Journ.*, 85, p. 305, (1935)].

A re-survey of the region by the Survey of India was begun in 1935, and a party under Mr. J. C. Ross was on the glacier at the time of my visit. Captain C. E. Wright, in charge of this party, arrived at Gangotri at the end of October. I am greatly indebted to him and to Mr. Ross for kindly checking the plane table sketch which I made (Plate 2).

II.—MAPPING OF THE GANGOTRI SNOUT.

The snout was mapped by plane table on the 16th and 17th October, 1935. The scale adopted was 1″=400 feet, (1 : 4,800), but the map has been reduced to a scale of 1″=800 feet (1 : 9,600) for the purpose of reproduction as Plate 2. A base line of 868 feet was made along a grass-covered moraine ridge on the north-east side of the glacier, and cairns were erected at both ends; cairns C and D of the map. They were marked with marine red paint *C, 16.10.35, G. S. I.* and *D, 16.10.35, G. S. I.* C lies at the north-west end of a slightly inclined portion of the moraine, while D is at the edge of a gully just below a buttress of granite. Subsequently Captain Wright and Mr. Ross built two more cairns four feet to the south-east of each of the cairns which I put up. On these they inscribed the marks *G.B.I./C '35* and *G.B.I./D '35.* Another cairn, No. E, was built on the south-west side of the glacier at the top of a ridge of old lateral moraine. The south-west side of this moraine is grass-covered, but the north-east side, facing the glacier, is steep and without vegetation. The cairn itself was not marked, but a flat stone immediately adjacent to it was painted *G. S. I., E, 17.10.35.* Independently of plane table sighting, directions were taken to the centre of the snout from these cairns by prismatic compass. They are given in the table below.

Cairn number.	Cairn marks.	Prismatic compass readings to snout.
C	C 16.10.35 G. S. I.	168°
D	D 16.10.35 G. S. I.	190°
E	G. S. I. E 17.10.35	60°

Cairn A lies outside the map, due east of cairn C, on the south-west side of the glacier and on a flat stone about 200 feet above Gaumukh camping ground.

Cairn B is on the same side of the valley as C and D, and a short distance to the north-west of them. It is not shown on the map as it was impossible to locate during the survey which was carried out subsequent to its erection. The photograph, Plate 5, fig. 1, was taken from this cairn and is of interest in showing the sand flat left by the recent retreat of the glacier.

III.—RETREAT.

1. Recent Retreat.

One of the most striking features of the Gangotri glacier is the obvious retreat and shrinkage which it has undergone in very recent years. In front of the snout is a sandy flat about 2,400 feet (about 730 metres) in length, which must have been occupied by the glacier within the last century. This flat is shown in the map, Plate 2, and is clearly seen in Plate 5, fig. 1, and again, though very foreshortened, in Plate 4. The decrease in thickness of the glacier is about 200 feet near the snout, but becomes less higher up, although it must persist for some way, since freshly exposed moraine, still uncolonised by vegetation, continues beyond the first lateral valley descending from the north-east (Plate 4).

2. Secular Retreat.

It is often very difficult to decide to what altitude Himalayan glaciers descended during the Pleistocene Ice Age, because the original glacial features have been so often obliterated or obscured by the products of later erosion. In particular, talus fans tend to convert what were almost certainly at one time U-shaped valleys into a modified V-form (Plate 7, fig. 2).

Smooth glaciated pavements of granite are found for about a mile below Gangotri temple on the left (south) side of the Bhagirathi valley. They may occur as far down as Bhairongathi. It can be said definitely that the Gangotri glacial system once descended as far as Gangotri, down to an altitude which is now 10,000 feet, but which may have been lower during the ice age on account of the isostatic uplift which has since occurred.

Besides glaciated pavements, there are old high level moraines to indicate the height in the valley to which the glacier once rose. A bank of old lateral moraine is seen in Plate 5, fig. 1, at a height of about 400 feet above the snout. Almost certainly the same moraine extends down the valley, being seen as a slight terrace in Plate 7, fig. 2, and lying at least 1,000 feet above the valley floor about midway between Gaumukh and Gangotri.

Between Gangotri and Jangla (53 I, 31° 03′ : 78° 51′) the original valley, if formerly glacial, has been modified greatly by deep incision due to rejuvenation. At the foot of what may have been a U-shaped valley, there is a remarkable gorge with vertical walls which has been cut through the granite.

The extensive river flat between Dharali (53 I, 31° 03′ : 78° 47′) Harsil and Jala (53 I, 31° 02′ : 78° 43′) is due, I believe, to a catastrophic landslide at Sukhi (53 I, 31° 00′ : 78° 43′), which must have blocked the valley and formed a lake. Erosion of a channel through the upper part of the landslide, and partial filling up of the valley with gravels and silts, have caused the lake to disappear. I do not think that the Sukhi barrier is a terminal moraine. It has more the appearance of a landslide which originated on the eastern slopes of Banderpunch.

Below Sukhi, the Bhagirathi valley has the typical features of river erosion, with magnificent overlapping spurs.

Summarising the evidence :—It can be stated with certainty that during the Pleistocene period the Gangotri glacier descended at least as far as just below Gangotri ; it may have descended as far as Jangla. There are no signs of glacial action below Sukhi.

It may be remarked that the glaciers of the neighbouring Saraswati-Arwa-Alaknanda system were found to have descended as far down as Badrinath, which, like Gangotri, is at an altitude of about 10,000 feet [*Rec. Geol. Surv. Ind.*, LXVI, p. 391, (1933)].

IV.—NOTE BY MR. J. C. ROSS, SURVEY OF INDIA.

Mr. J. B. Auden's large scale survey of the snout of the Gangotri Glacier was checked by me on the 30th October 1935. The survey appeared to be very accurate.

Some eight months later, at Mr. Auden's request, the position of the snout was rechecked by me on a tracing of his survey. This was done on the 18th and 19th June 1936. On the first day plane-table observations were made at Mr. Auden's cairns C and D, on the right bank, and no change whatsoever in the position of the snout could be detected. On the second day cairn E was visited, on the left bank, with the same result; further the thickness of the ice at the cave did not appear to differ from that noticed by me in October 1935.

It is perhaps significant that the first observations were made a month or so after the end of the monsoon and the latter at the end of the driest part of the year, otherwise weather conditions were similar, midday temperatures rising a few degrees above freezing point, sky generally overcast with light afternoon snowfalls.

V.—EXPLANATION OF PLATES.

PLATE 2.—Sketch map of the snout of the Gangotri glacier. Scale 1″=800 feet (1 : 9,600). 16th and 17th October 1935. Mapped by J. B. Auden, and checked at the end of October by Capt. C. E. Wright, R.E., and Mr. J. C. Ross, Survey of India.

PLATE 3.—Map of the Gangotri area. Scale $\frac{3}{4}''$=1 mile.

PLATE 4.—General view of lower part of the Gangotri glacier from a height of 14,000 feet on slopes leading up to the east side of the lateral Kedarnath valley ('Bhirgupanth Glacier' of the modern map, Plate 3.) from the Bhagirathi valley. Old high level moraine in the foreground. Shrunken snout of the Gangotri glacier. Satopanth group of peaks.

PLATE 5, FIG. 1.—View of Gangotri snout and sand flat from cairn B. Direction of view south-east.

FIG. 2.—View of Gangotri snout from cairn C in the direction 155°. Satopanth massif on left; Shivling on right.

PLATE 6.—View of Gangotri snout and Shivling from cairn D in the direction 175°.

PLATE 7, FIG. 1.—View of Gangotri snout from cairn E in the direction 60°. The tip of the snout is hidden by moraine and lies to the left of the exposed cliff of ice.

FIG. 2.—View down the Bhagirathi valley towards the north-west, from the left lateral moraine of the Gangotri glacier. Top of old high level moraine seen as a slight terrace just below the twin peaks on the left of the sky-line. Modification of U-shaped valley by talus fans.

NOTES ON PETROLEUM TECHNOLOGY IN BURMA DURING 1936 WITH SPECIAL REFERENCE TO THE PROTECTION OF OIL AND GAS SANDS. BY E. J. BRADSHAW, B.A., B.A.I. (DUBLIN), M.SC. (CALIFORNIA), *Resident Geologist, Burma Geological Department, Yenangyaung, Upper Burma.*

CONTENTS.

Introduction.

The Warden, Burma Oil Fields, who is an officer of the Indian Civil Service, is advised on technical matters relating to drilling in competitive areas by two Advisory Boards, at Yenangyaung and Chauk respectively. The oil companies nominate members of their technical staffs to membership of the Advisory Boards, on each of which the Resident Geologist, Burma Geological Department, Yenangyaung, is the Government representative. The Yenangyaung and Chauk Advisory Boards normally meet once a week to discuss, and advise upon, technical operations in the oil fields. Besides routine business the Boards are frequently called upon to advise on problems which are of general interest to oil field operators, and the purpose of this paper is to summarise briefly some of the more interesting general questions which were discussed by the Yenangyaung and Chauk Advisory Boards during the year, in the hope that the record may be of some value to a wider circle of petroleum technologists than that directly connected with the Burma Oil Fields. The views expressed are not necessarily those of the compiler of this paper but include opinions expressed in discussions by members of the Board and, in some cases, statements made in written notes submitted by members of the technical staffs of the operating companies. Since the chief function of the Boards is to advise the Warden, Burma Oil Fields, on matters relating to the protection of the oil sands in areas where competitive drilling is being carried out, it naturally follows that casing policy is the main subject of discussion and the chief concern the making and testing of isolations.

Comparative efficacy of protection by shoe cementation surmounted by mud fluid and back-cementation with cement.

In Burma the normal cementation policy in rotary wells is to back-cement with sufficient cement to rise behind the casing to cover all known oil or gas sands. As a result of a case in which it was ascertained that the cement had not risen as high as had been anticipated, an interesting discussion arose as to the comparative efficacy of protection by shoe cementation surmounted by mud fluid outside the casing and by back-cementation with cement. It was contended that cement was preferable to mud because it reduced the likelihood of corrosion and supported the casing. It was also suggested that the prospects of the success of a shoe cementation were enhanced by using fairly large quantities of cement and that so long as the quantities of cement called for under the existing policy were not unmanageable, back-cementation afforded the safest form of protection. It was, however, agreed that special cases might arise in which it would be desirable to rely on the protection afforded by the mud fluid surmounting a shoe cementation. It was suggested that protection by mud should be restricted to wells which had not encountered heaving shales or high pressure oil, gas or water sands and which had been drilled without any abnormal loss of circulation. It was pointed out that in any event it was desirable that good mud should surmount the cement used in a back-cementation since this would ensure a measure of protection in cases where the cement had not risen as high as had been anticipated, or where productive sands were subsequently discovered at horizons above the top of the cement column. It was suggested that it was unlikely that there would be excessive caving of the walls of a well in which the annular space between the casing and the strata was filled with mud of good gelling qualities and it was thought that even if part of the filter cake were removed from the face of a sand by caving, and there were any resultant movement of fluid into the strata the filter cake would be rapidly built up again by dehydration of the mud fluid. It was contended that good mud might even be preferable to cement on the ground that while a gelled mud remained impervious, cement might set in such a manner as to permit the passage of water through channels.

The importance of the quality of the mud was recognised, but it was suggested that special treatment of the mud fluid might not be necessary where the mud used or made during the course of drilling satisfied certain requirements. Should protection by mud be resorted to, it was suggested that before the casing was run the formations to be left behind the casing should be mudded by open circulation until the loss of mud fluid was reduced to a satisfactory minimum. The mud fluid pumped into the well ahead of the cement should be of relatively high stability and preferably of gel-forming or thixotropic type with a maximum gelling time of four days and a maximum water separation of 4 per cent. in 24 hours when tested in a 250 c.c. measuring cylinder. If water were pumped into the well ahead of the cement, the volume should not be excessive; a limiting volume of 10 barrels of water was suggested. After cementation the column of mud in the annular space outside the casing should be maintained to the surface for a period of at least 30 days, being replenished, if necessary, by mud of the approved quality. The whole of the operations should be subject to Advisory Board inspections.

The decision of the Warden was that protection by back-cementation should remain the standard practice but that special cases would be separately considered on their merits if it appeared desirable or necessary to rely on the protection afforded by a column of mud fluid above a shoe cementation. In the course of the discussion it was pointed out that a disadvantage of the practice of affording protection by mud would be that in such wells it would not be possible to perforate the casing if it were desired to take production from upper sands.

The effecting and testing of recementations.

During the year increasing use was made of the gun perforator in testing recementations, and in ascertaining, in cases of doubt, whether certain sands had been protected against the possibility of damage by water. The procedure developed was to make a series of perforations above and below the sand in question. If water came into the well through the perforations suitable measures were taken to protect the sand by a recementation through rips or perforations or by attempting to force additional cement round the shoe of the casing. The success, or otherwise, of the recementation was tested in the same manner. In either case, if no water entered the well through the perforations, it was assumed that the necessary protection had been afforded, but the perforations were left open so that water would be detected if it broke in later. The desirability was emphasised of making such perforations before the objective sand was penetrated; in a flowing well it might not be possible to detect the presence of water coming through the perforations, or to carry out the necessary repair operations without first plugging the well.

In the course of discussions on the practice of carrying out recementations opinion was divided as to the desirability or otherwise of using special quick-setting cements, or ordinary cement treated with an accelerator, as opposed to ordinary untreated cement. It was, however, agreed that it was always desirable to test a recementation as soon as it was safe to do so, and that, whatever the nature of the cement used, it should be safe to test the recementation in three days, provided that the repair had only involved the use of a small quantity of cement. If, however, the quantity of cement used was large, so that the recementation was comparable to an original cementation, then it might be wiser to wait for the usual period before drilling out the cement in the casing.

Determination, by means of the Dionic tester, of the source of water entering a well.

In the Lanywa oil field it is found that down to certain depths the values obtained in dionic tests of well waters give a reliable index to the horizon from which the water is coming. In general, down to these depths, there is a progressive increase in the dionic value of the waters. This fact is of great value in determining the source of water entering a well. In other areas, however, caution is necessary in the making of deductions from such observations. In a case at Chauk, for instance, it is known that the water from a certain sand has a much lower dionic value than water from a sand somewhat higher in the succession. The need for caution is further emphasised by the result of an interesting experiment in which a thin grout of ordinary cement was mixed and allowed to set at 120°F. The specimen was then broken up and mixed with distilled water and left to digest for four days. At the end of that period it was found that the water contained calcium hydroxide and gave a dionic reading of 13,500. It is therefore possible, in some cases, that water giving a high dionic reading may not necessarily have been derived from a deep source, but may simply have been in contact with cement.

Determination of the position of the top of the cement column after back-cementation.

It is always a matter of difficulty to determine whether or not a back-cementation has achieved its object of filling the annular space outside the casing to a point above all the sands which it is desired to protect. Vibration tests are negative at best; if vibration is obtained it is clear that there is no cement outside the casing at that point, but if vibration is not obtained it does not necessarily follow that the cement column has reached that point. There is therefore considerable interest in a technique devised by the Schlumberger Company for detecting the top of the cement column outside the casing by electrical measurement of the temperature gradient within the well. The heat developed by the chemical reactions involved in the setting of the cement results in a marked change in the temperature gradient at the point in the well which corresponds to the top of the cement column outside the casing and this point can therefore be determined with ease and certainty. It may also be of interest to note here that the Schlumberger Company have also developed a technique for determining the position of leaks in casing by an electrical method which was successfully adopted in the case of a well discussed at a meeting of the Chauk Advisory Board.

Isolation tests in deep rotary wells.

With the ever-increasing depths to which wells are drilled the question of the ability of the casing to withstand the heavy pressures of external fluids becomes a factor of great importance in the determination of casing policies. In Burma the precautions taken to exclude water from the oil and gas sands are probably more stringent than in any other oil producing area. Thus, when an operator has cemented a string of casing he is normally required to clean out, bail, and show a dry hole at the shoe. In the case of deep rotary wells this procedure may impose very severe stresses on the casing, which is normally surrounded by the heavy mud fluid surmounting the column of cement outside the casing.

It was suggested that the severity of these stresses might justify the substitution of a test of the isolation by the observation of fluid levels, but it was pointed out that where no further string of casing was to be cemented in the well a time would come when in any event the fluid in the well would have to be bailed down to the neighbourhood of the casing shoe to enable production to be taken by pumping without having the back pressure of too high a fluid column on the producing sand. If the casing were unable to withstand the pressure of the external fluid column, it would be better that this fact should be ascertained before the objective sand had been penetrated. It was suggested that in the course of time there was likely to be caving of the wall of the hole with the result that there might be bridging of the annular space outside the casing. If this occurred it would have the effect of dividing the external fluid column into two or more columns and the maximum external fluid pressure on the casing would be reduced to that at the base of the longest of these columns instead of the very much greater pressure exerted at the base of the original single column of mud fluid. It therefore followed that if the bailing of the hole might be postponed, the casing might not then be exposed to stresses anything like so severe as those to be expected if the well were bailed dry shortly after the casing had been cemented. It was thought that the effect of this factor would be difficult to estimate and that it would be unwise to rely upon it otherwise than as a possible but uncertain additional safety factor.

The magnitude of the stresses to which the casing is subjected depend, in the main, upon the height of the external cement column and the specific gravity of the mud fluid surmounting this column. In the ordinary way the height of the cement column depends upon the horizons of the oil and gas sands which it is designed to protect, but in deep wells it may be desirable to introduce extra quantities of cement for the purpose of reducing the length of the fluid column outside the casing, so that it is not subjected to external fluid pressures greater than the known collapsing strength of the particular string of casing used in the well. Practical considerations, however, limit the amount of cement that can conveniently be used.

In determining the casing policies for deep wells it is customary to adopt a safety factor of 2 in computing the collapsing depths of strings of casing. Local experience, however, suggests that this safety factor may be unnecessarily large and it was agreed that it would be considered safe to bail wells in which there was a safety factor of 1·5 in respect of the theoretical collapsing depth. In the case of composite strings made up of casing of different grades it might appear that the heaviest casing need only be provided in the neighbourhood of the top of the cement column, since the lower part of the string would not be subject to external fluid pressures after the cementation had been carried out. In practice, however, allowance has to be made for the possibility of a cementation failure, and it is therefore wise to make up the whole of the lower part of the string with casing of high grade.

It was therefore agreed that no alteration need be made in the existing procedure for testing isolations. An exception might be made in cases where another string of casing was to be inserted and cemented inside the string which was the subject of the test. In such cases, if circumstances dictated such a course, it might be permissible to substitute a test by observation of fluid levels for the normal isolation test made by bailing the well and showing a dry hole at the casing shoe.

Another discussion of general interest was on the desirability or otherwise of permitting, in rotary wells, the penetration of an objective sand before casing had been cemented above it. The main objection to the proposal was that it would not be possible to test the success of the isolation in the ordinary way, by bailing the well dry and showing a dry hole, before penetration of the objective sands was permitted. A secondary objection was that damage might be done to the objective sand by the mud fluid.

Penetration of an objective sand before cementing casing above it.

With respect to the main objection it was pointed out that the object of a back-cementation is two-fold : to protect sands outside the cemented casing above its shoe, and to protect the objective sand from exposure to top water. It was contended that the showing of a dry hole before penetration of the objective sand merely proved that the cementation had been successful at least in the neighbourhood of the casing shoe and therefore only demonstrated with certainty that top water was being kept off the objective sand. Without such a test there could still be certainty that no damage was being done to the objective sand by top water so long as the well in question yielded no water other than that known to be coming from the objective sand. With respect to protection of the upper sands it was argued that the conclusion as to whether or not a back-cementation had been successful depended largely on mechanical and chemical data connected with the actual carrying out of the cementation, and that this type of evidence was available even when the objective sand had been penetrated before cementation. Only actual perforation of the cemented casing could prove with certainty that the back-cementation had been successful. On the other hand, if the actual cementing operation had been carried out without mishap, if an adequate volume of cement had been displaced, and if good mud had been circulated ahead of the cement, there would be good reason for supposing that the upper sands were protected if it could be shown, as in the normal isolation test, that the cementation had been successful at least in the neighbourhood of the casing shoe. With regard to the secondary objection it was suggested that if proper attention were paid to mud supplies and avoidance of loss of circulation, there was little likelihood of causing damage by mud to a comparatively undrained objective sand.

It was further argued that in certain circumstances there might be strong reasons for desiring to penetrate the objective sand before casing was cemented above it. It might, for instance, be desirable to make a drill stem test of a sand before deciding to cement above it; or, as was actually the case in certain areas, there might be great difficulty in maintaining successful isolations in certain shales which were liable to break down when exposed to drilling water when drilling the well into the objective sand with cable tools after a dry hole had been shown below the shoe of the cemented casing. On these grounds permission was given by the Warden, in certain cases, to penetrate the objective sand, by rotary drilling, before casing had been cemented above it.

Penetration of a group of sands by rotary, before cementing casing above the uppermost.

A problem closely related to the above was the extent, if any, to which it should be permissible to penetrate a number of sands, preparatory to group production, before cementing casing above the uppermost. This problem does not differ in its essentials from that which has just been discussed but there is the added complication that if water is encountered, its source might be difficult to determine. As in all cases of group production, care would have to be exercised as to what sands might be included in a group. It was suggested that it would be undesirable to group sands of widely differing pressures or to include sands which were likely to turn to water before others in the group; with respect to this latter consideration it was pointed out that if the uppermost sand turned to water, it could be cased off behind a liner, while the lowest sand could be plugged if it yielded an excessive quantity of water. It was agreed that all the water coming into a well should be produced and that in any event the total amount of water that might be produced from all sources should not exceed 40 barrels a day. On the grounds of special local circumstances permission was given in certain cases to penetrate a group of sands by rotary before cementing casing above the uppermost, but it was thought undesirable to make the permission general. It was pointed out that extension of the practice of perforating cemented strings by the gun perforator might provide the most satisfactory solution of the problem.

Recementation above a penetrated group of oil sands.

Arising out of the last case there was a discussion as to the steps to be taken in the event of an unsuccessful cementation of the casing above the uppermost of a group of sands which had been penetrated before the cementation had been effected. It had been ordered originally that in such an event the hole should be plugged with cement, from the bottom to a point close below the casing shoe, before the recementation was undertaken. Subsequently it was decided that if the lower part of the hole was filled with mud of good quality, it would be sufficient to set a bridge and cement plug below the casing shoe. In either event it would be necessary to put the cement plug in place with considerable care for if too much cement were used it might come up into the casing and plug off the leak at the shoe so that it would not be possible to obtain circulation round the shoe and it would thus be impossible to carry out the recementation of the casing. It was further argued that if the mud in the lower part of the hole were re-conditioned, the bridge and plug might be omitted. An objection to this proposal was the difficulty of ascertaining, by prior circulation of water, how much fluid could be got round the shoe. It was further suggested that, when high pressures were applied, fluid might be forced into the oil sands exposed below the shoe. On the other hand it was argued that the prospects of a successful recementation depended largely on the possibility of obtaining adequate circulation and that the delay caused by the placing and setting of a cement plug might diminish the prospects of success, inasmuch as caving might result in the filling of the channels through which it was hoped to obtain circulation. In the particular case under consideration it seemed unlikely that high pressures would have to be applied during the recementation and, since the other circumstances were particularly favourable, permission was granted to carry out the recementation without setting a bridge in the hole.

THE CRETACEOUS VOLCANIC SERIES OF ASTOR-DEOSAI, KASHMIR, AND ITS INTRUSIONS.

BY D. N. WADIA, M.A., B.Sc., F.R.G.S., F.R.A.S.B., F.N.I., *Offg. Superintending Geologist, Geological Survey of India.* (With Plates 8 to 10).

CONTENTS.

I.—INTRODUCTION.

A belt, twelve miles wide, of well stratified volcanic ash, tuffs, agglomerates and basaltic lavas, with fossiliferous limestone intercalations of Cretaceous age, has been mapped during the survey of northern Kashmir by the writer, extending from south of Astor (34° 57′ : 74° 54′), through the head of the Burzil valley, to beyond the Deosai valley and thence proceeding towards Dras (34° 26′ : 75° 4′) in Ladakh. The belt cuts across the Great Himalaya range and is in conformity with the tectonic strike of the mountains, showing a complicated series of folds and inversions, but no considerable metamorphism of the various rock-constituents. The best preserved fossils in the limestones are *Orbitolina*, belonging to two or three species, besides other fragmentary foraminifers, corals, some doubtful impressions of ammonite shells, echinoids and bivalves. The most interesting feature about this Cretaceous development in Kashmir is the intimate association of marine sediments with pyroclastic, volcanic, hypabyssal and plutonic rocks producing interesting suites. Dykes, sills and bosses of gabbro, pyroxenite, and serpentine have invaded perfectly stratified tuffs, ash-beds and trap-flows, while hornblende-granite has penetrated the whole series, the acid injections varying from thin veins to bosses several miles across. Their intrusive relations towards the tuffs containing pockets of Orbitolina limestone definitely dates the granite as post-Cretaceous.

It is highly probable that outlier strips of the Eocene, containing the foraminifera *Alveolina* and *Dictyoconoides* in a poor state of preservation, are involved in the foldings of the Cretaceous in the Burzil valley. These fossils have been identified in a thin band of limestone in Dras, overlying an identically constituted Cretaceous volcanic series. Dras is situated on the direct continuation of the strike of the Burzil Cretaceous, 32 miles south-east of Karobal pass (13,647 feet) (34° 39′ : 75° 15′), where the outcrop is 10 miles broad.

II.—AREA AND LOCATION.

The Cretaceous band commences near Chechri, 35 miles south of Astor, where it has a breadth of only about a mile. It proceeds due south-east along the main strike of the country, attaining between the Burzil pass (13,775) and the Karo ridge, forming the Tilel watershed, a width of 12 to 16 miles. From Minimarg it trends further in the same direction, along the barren, highly weathered mountains between the Tilel and the Nagai branches of the upper Kishanganga. These rocks constitute the bleak black country of deeply dissected anastomosing valleys through forestless, uninhabited mountains. A number of glacial basins—the Gulam Sar group of lakes—lie in deeply scoured hollows at the foot of the gabbro mountains. The Cretaceous belt, here some ten miles broad, crosses the Botikul tributary of the Deosai river, immediately after it has traversed the Great Himalaya range. The geological survey of north Kashmir has proceeded up to this point only, but from the persistence in force of all the units of the series here there is no doubt that the belt extends without material change of facies to Dras, where, in 1919, Mr. C. S. Middlemiss collected Eocene foraminifers and gastropods from a limestone interbedded with the top of the volcanic series.

The central Himalayan watershed range, dividing off the Indus drainage from the Kashmir rivers, which is here coincident with the Great Himalaya range, has dwindled in altitude to barely 18,000 feet maximum elevation and has, between the Zoji La and Burzil passes, a N. N. W. alignment that is discordant to the main Himalayan strike, which is N. W. by W.—S. E. by E.; thus the Cretaceous outcrop runs more or less astride the central watershed range.

III.—PREVIOUS WORK.

Except Lydekker no one had done any systematic field work in this area. In his Memoir, (*Mem. Geol. Surv. Ind.*, XXII, 1883) he has included the Astor-Burzil-Karobal belt of volcanics in his Panjal system (Silurian and ?Cambrian), though he has mapped some patches of Subathu series (Eocene) in Dras. Sir H. H. Hayden in 1906 traversed this route on his way to Astor and Gilgit and among his collection from 'E. side of Dorikoon (Burzil) pass' there are foraminifera limestones. The fossils were identified as *Orbitolina* by H. Douvillé in 1926 [*Rec. Geol. Surv. Ind.*, LVIII, p. 349, (1926)]. Mr. C. S. Middlemiss, F.R.S., during his Mineral Survey of Kashmir State in 1919, worked in the Dras area and mapped a broad band of volcanic rocks at Dras, containing a thin strip of Eocene rocks charged with foraminifers and gastropods; the former were identified by Mr. G. H. Tipper as *Alveolina* and *Conulites* (*Dictyoconoides*). Mr. Middlemiss' map of Dras is reproduced in Plate 8.

IV.—LITHOLOGY AND ROCK FORMATIONS.

A highly interesting assemblage of rock-types is met with in this belt. The chief constituents of the series are some thousands of feet of purple and green, laminated, shaly ash-beds, with some siliceous bands, slates, coarse, gritty and siliceous tuffs, agglomeratic slates, conglomeratic agglomerates and subordinate flows of basic amygdaloidal lavas (augite-andesite or basalt). Lava-flows, unlike the Panjal Volcanic series, which in other respects, *e.g.*, in the lithology of the various constituent members, bears a strong resemblance to the Cretaceous volcanic series, form a small part of the Cretaceous volcanics, the bulk of the series being composed of pyroclastic products. They are chloritised and epidotised to a marked extent, as in the case of the Panjal traps, but are distinguished from them by the presence of bright crimson chert or jasper as an alteration product. The ash-beds have a laminated, shaly appearance, being fine-grained and perfectly stratified and containing at intervals nests, lenses and interbedded layers of foraminiferal or coral limestone, their size varying from a pocket a few feet across to evenly bedded layers more than a hundred feet thick. The agglomeratic slates and sandy sedimentary beds cover a wide extent of the ground and are indistinguishable from similar members of the Panjal Volcanic series. They also contain stray fossil fragments, carbonised impressions of leaves, *etc.* The matrix of the agglomeratic slate, as has been now proved in the case of the Panjal series, is chiefly composed of devitrified glassy base with a few crystalline particles.

Quite a large part of the Burzil Cretaceous is composed of acid, basic and ultra-basic intrusives. Stocks, sills and bosses of coarse dolerite, epidiorite and pyroxenite are to be seen at irregular intervals throughout the series from Chechri to Botokul, and are reported to be present in equal force from Dras as well. The pyroxenite has generally altered along an extensive system of joints and fissures, into serpentine, dark green in colour and of waxy lustre, which forms a very conspicuous rock body in this tract of country. Under the microscope the pyroxenite is found to be composed chiefly of amphiboles undergoing serpentinisation. Large plates of pleochroic hornblende show variable degrees of change to serpentine. Uralitisation is most common, only small remnants of the original augite being visible. The gabbro has large idiomorphic plates of diallage; the plagioclase is fresh. In the dolerite both labradorite and augite are fresh, with brilliant grass-green chlorite. The ophitic relation of augite to labradorite is typically seen. Epidote is subordinate. In some sections augite shows transformation to hornblende by uralitisation.

The largest masses of the basic plutonics are in the Gulam Sar area, where they build prominent, black, rugged mountain-peaks, 14,000 to 15,000 feet in elevation. The acid intrusives are confined to the north, the entire north-east margin of the volcanic belt being in intrusive contact with hornblende-granite, along a highly indented line, full of bays and tongues. Besides hornblende-granite,—a white or grey, fine-grained felspathic granite, with only subordinate amount of hornblende—the commonest members of the acid suite are vivid coloured felspar-porphyries, pink, grey, or blue, occurring in the form of sills. These sills are the hypabyssal offshoots of the granite body. Dykes and sills of granite proper become numerous as the main mass of granite is approached. The bulk of the rock is formed of white or grey orthoclase and microperthite, with some oligoclase and acid plagioclases, ?andesine; besides hornblende, the femic minerals are scarce, biotite being only occasionally present; free quartz is conspicuous and sphene occurs as an accessory in visible grains. Epidote and apatite are generally present. The rock is non-porphyritic, differing markedly in this respect from the biotite-granite (Central gneiss) of the Himalayas. It is unfoliated and massive, except in rare cases where banding or foliation, in the direction of the prevalent N.W.-S.E. strike, appears. The injection-contact with the volcanic rocks is laid bare at milestone 61¼ on the Gilgit road, where the granite penetrates bedded traps; at the mouth of the Rathak stream, near Minimarg, where it is injected into tuffs and agglomeratic slates; and at Kalapani (34° 52′ : 74° 54′) where a large apophysis of the granite is thrust into the centre of a syncline of trap-flows and ash-beds. The hornblende-granite is rarely free from an extensive system of basic intrusions of dolerite, now altered to a black epidiorite, at places almost a pure phanerocrystalline hornblendite, with abundance of newly formed pleochroic hornblende. These basic injections of the granite have at places fused with the surrounding rock, producing a hybrid or mixed rock, in other cases the two rocks have preserved their identity, the epidiorite veining the granite with sharp clean-cut edges. The volume of the epidiorite stocks and masses increases markedly north of the Burzil.

A most interesting rock in this complex is the agglomeratic conglomerate occurring in rudely stratified beds and attaining nearly a thousand feet in thickness. The rock is composed of rounded as well as sub-angular pebbles and boulders of six or seven varieties of rock, in size varying from a few inches to two feet in diameter, embedded in an abundant matrix either of lava, showing clear fluxion-lines, or of tuff or a sandy sediment with bedding-planes. The larger masses are sub-angular while the smaller boulders show perfect rounding. The following rock-types are assembled in the agglomerate: felspar-porphyries of various colours; trap (Cretaceous); hornblende-granite; jasper and chert; quartzite; slate; limestone with fossil fragments. The pebbles are mostly the debris of contemporary formations, which must have been subjected to active sub-ærial denudation as well as to intensive volcanic explosions and plutonic eruptions. The most illustrative outcrop of this rock-formation is exposed in the deeply scarred line of precipices on the south side of the Nagai valley to the east of Minimarg.

An extraordinary type of explosive volcanic action is indicated by this agglomerate, which grades off, horizontally as well as vertically, either into agglomeratic slate or into well bedded, highly fluid lava-flows. This explosive volcanic action must have taken place at the end of the volcanic period, to account for the presence of derived pieces and pebbles of so many of the units of the local Cretaceous series. Outcrops of the conglomerate are local and fitful, swelling out and disappearing abruptly.

The close petrographic resemblance of several members of the Burzil volcanics with the Panjal Volcanic series is deceptive and led me to ascribe them at first to the latter series, in my previous papers, where this outcrop is briefly referred to [*Rec. Geol. Surv. Ind.*, LXVI, p. 223, (1932); LXVIII, p. 155, (1934)]. It was the discovery of fossils in some of the enclosed limestone pockets, towards the close of the field season in 1934, which revealed the much higher stratigraphic horizon of the series and ultimately led to the correct identification of the age of the group.

V.—STRATIGRAPHY.

The following table summarises the geological section of the series laid bare in the gorge of the Burzil river between milestones 54 and 70 of the Srinagar-Gilgit road. The river here has excavated a deep gorge, more or less transversely across the structural strike of the folded belt of volcanic strata.

Dip, mainly N. N. W. at high angles.

Hornblende-granite.

————————————————Intrusive contact.

Shaly tuffs with stocks of coarse serpentinised pyroxenite.

Indurated shaly slates with cherty trap. Some fossiliferous limestone lenses.

Sills of felspar-porphyry.

Well-stratified slaty tuffs, laminated ash-beds containing lenses of grey limestone, crowded with *Orbitolina*.

Interbedded trap flows.

————————————————Intrusive contact.

Hornblende-granite (six miles wide boss).

————————————————Intrusive contact.

Basaltic, amygdaloidal lava-flows, epidotic, with red jasper; many sills and apophyses of granite.

Agglomeratic conglomerate, swelling to great thickness in the Nagai cliffs on the south bank, passing off into lava flows on the north-west.

Agglomeratic slate, some thousands of feet thick, containing pebbles and fragments of foreign rocks, with sandstone and grit bands.

Green and purple slaty ash with some agglomeratic bands and limestone layers, over 100 feet thick.

Gritty and sandy tuffs and white and brown agglomeratic quartzite.

Purple and green, finely laminated ash-beds, with limestone lenses containing echinoid, coral and shell fragments. A few thin lava-flows and siliceous bands.

Shaly and slaty beds with dolerite and gabbro sills, well bedded. Ultrabasic masses of black pyroxenite altered to serpentine. Small bosses of gabbro and pyroxenite scattered throughout the series.

————————————————Unconformity.

Salkhala series: phyllites, schists and finely crystalline limestones, generally black.

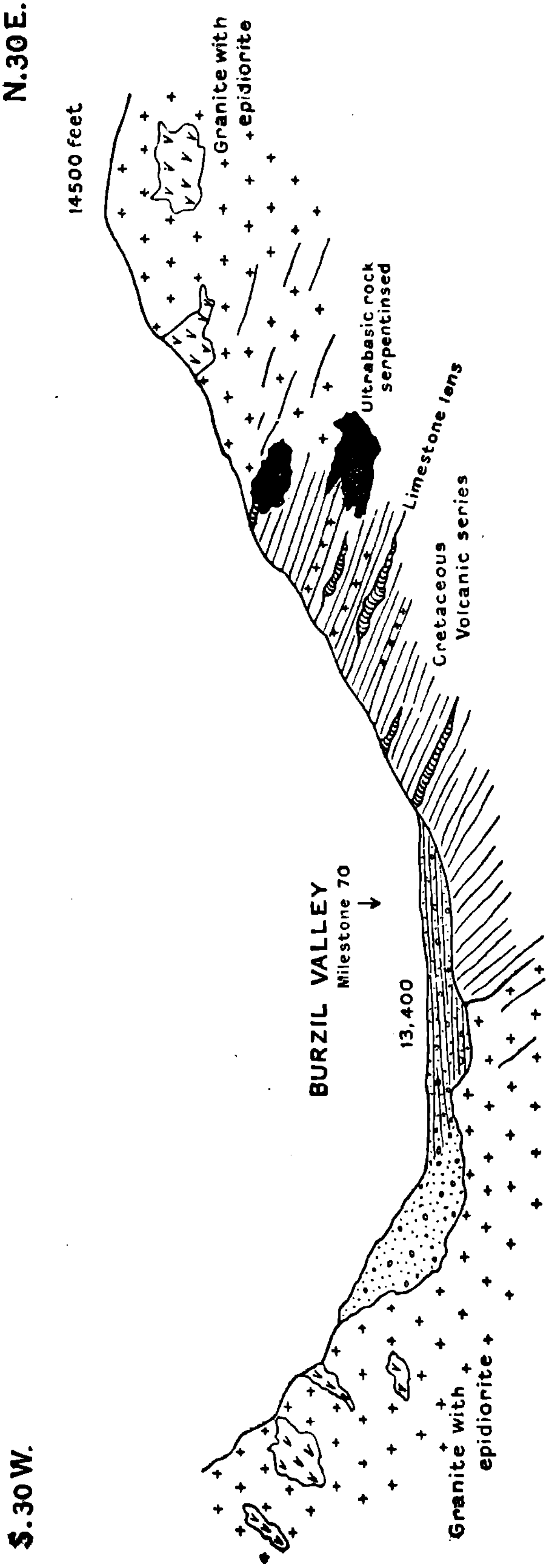

FIG. 1.—Sketch Section of Cretaceous Volcanic Series of the Burzil Pass and its relation to acid and basic intrusions. (Scale 1 inch=660 feet approximately).

The disposition of the belt is in a basin-like depression, extending in a north-west and south-east direction, in the oldest crystalline sediments (Salkhala series) of the central ranges of the Himalaya. It has a clearly defined border on the south-west, where it abuts on the Salkhalas, overlying these with a profound but concealed unconformity. Basic instrusions are more prevalent on this border, being especially preponderant in the mountains between Pashwari and the Karobal pass. The north-east border is defined along its whole length by a boss of hornblende-granite, six miles wide in the middle, which has detached from the main body of the outcrop a strip of shaly tuffs, with their limestone intercalations. This is about a mile in width; other smaller detached masses occur as islands in the granite. The granite contact is a highly irregular indented line, the acid intrusive penetrating the basic pyroclastic products in numerous veins and apophyses. The gabbro and serpentine masses are found in close proximity to some limestone pockets. A very good example of the latter occurs at a height of about 600 feet above the actual saddle of the Burzil pass (13,775) on its east side. The best preserved fossils are found in the limestones from this locality and from some sporadic lenses embedded in the tuffs of the cliffs on either side of the small tarns at the head of the Baro Biats tributary of the Deosai river. The limestone is usually an unaltered, white or grey coloured rock, crowded with discs of *Orbitolina*, the characteristic Lower and Middle Cretaceous foraminifer, 10-15 mm. in diameter, together with some shell fragments. In the defile of the deep tributary branching off the river near Mapnun, as well as near Minimarg, the limestone is white, cream or pink coloured, partly crystalline, and not so fossiliferous, but a more detailed search will, doubtless, reveal some prolific pockets of better preserved corals, echinoids, ammonites and gastropods. *Orbitolina*, the most abundant fossil, is represented by two or more species. *O. bulgarica* was identified by H. Douvillé in 1926 from some specimens from this locality brought by the late Sir Henry Hayden in 1906, during a traverse to Gilgit. [*Rec. Geol. Surv. Ind.*, LVIII, p. 349, (1926)]. The other species shows affinities to *O. discoidea* and *O. concava*. The remaining fossils so far collected are too fragmentary for determination though it is probable that the genera *Alveolina* and *Dictyoconoides*, denoting a higher stratigraphic level, occur among the top beds of the Burzil volcanic series, as in Dras. It was during the last day of my camp in the Burzil valley that I chanced upon the *Orbitolina* pockets and the amount of detailed field work necessitated by the discovery could not be given to the area. Further search for fossils in the ridge (between the San Sangrila and the Burzil passes), capped by the granite peaks 15,393 and 15,360 and in the valley-slopes south of the Baro Biats stream is likely to yield more material throwing light on the stratigraphy and age of this group. The following section is laid bare between milestone 70 on the road and the top of the precipice (14,500), across the prevalent dip:

Dip, N. to N. N. E., moderate; strike variable.

Hornblende-granite.

———————————————Intrusive contact.

Black, slaty tuffs and ash-beds.

Trap flows with sills of acid porphyry.

Black, fine-grained, shaly slates, imperfectly cleaved,—500 feet thick.

Brown tuff, agglomeratic and sandy beds with masses of ultra-basic rock and serpentine.

Bedded trap, veined with red chert and epidote.

Interbedded tuffs with limestone lenses—10-50 feet thick, crowded with foraminifera.

Indurated black siliceous slates, tuffs and limestone.

Bedded flows of green trap, amygdaloidal,—50-100 feet thick.

Sills of porphyry and hornblende-granite.

The section here is obscured by scree and river alluvium.

———————————————Intrusive contact.

Hornblende-granite with masses of black epidiorite.

The presence of the Eocene in small outliers, enclosed in the synclinal fold of the Cretaceous, is possible on hypothetical grounds and is inferred from the discovery by Mr. Middlemiss of limestones containing Eocene fossils, overlying the Cretaceous volcanic series of Dras (Kargil dist. Ladak) which is identical in all respects with the Burzil series. The Dras Eocene outcrops are situated 32 miles E. S. E. of the Karobal pass and 50 miles south-east of the Burzil pass, along the continuation of the structural axis of the Cretaceous belt. The Dras fossils were examined and reported on by Mr. G. H. Tipper in 1921. He identified the foraminifers as *Conulites* (*Dictyoconoides*) and *Alveolina*. The gastropods were indeterminable.

The above facts clearly prove that the acid, basic and ultra-basic plutonic rocks described here are of later age than the Cretaceous and are possibly post-Eocene. The relative age of the granite with respect to the gabbro suite is not yet certain, though it appears probable that the granite belongs to a later phase of injection. Instances of re-injection of the basic material into granite, during a later eruptive period, are rather common. The wide distribution and great bulk of epidiorite masses in the granite show that they are magmatically related to the ultra-basics of this area and of Astor and Gilgit.

VI.—STRUCTURE.

The Burzil Cretaceous lies in a structural basin, a broad synclinal flexure. Between Chechri and Kalapani, the belt is a normal synclinal fold resting upon a basement of the Salkhalas. The synclinal crest is clearly seen at the head of the precipitous cliff overlooking the Kalapani valley-bed for some miles south-east of the Kalapani rest-house. Here a conspicuous geological feature is a tongue of white granite, an apophysis from the main body of granite, penetrating the black trappean rocks. In the wider part of the belt, east of the Kamri pass, inversion and isoclinal folding become more apparent, with a N. N. E. regional dip. The granite, which occupies the greater part of the north half of the belt, is unaffected by structural disturbances and remains massive and unfoliated. A number of small sharply pitching brachyfolds are seen among the major isoclinal flexures of the series.

The plane of contact with the Salkhalas at the south-west margin is an unconformity, well seen at the head-waters of the numerous transverse defiles descending into the Tilel river. That the intrusion of granite is subsequent to the folding of the Cretaceous is evident from the fact that the granite takes no part in the tectonic deformation of the country. Where it shows any foliation planes, the latter are independent and do not share in the general N. N. E.'ly dip.

A more intense type of tectonic disturbance than is seen in the Cretaceous is observed in the Triassic belt of the Tilel and Sind valleys which also lies among the Salkhalas, some miles to the south of the Cretaceous basin. The Triassic, especially the Upper Triassic, limestones and dolomites are thrown into complex plications and inversions such as are not seen in the newer series. Many of the cliff-sections in the Sind basin recall structures seen in the High Calcareous Alps of the Bernese Oberland in Switzerland.

VII.—METAMORPHISM.

While the Salkhalas show the usual grade of dynamic or stress metamorphism in all the constituent units, the Cretaceous rocks of Burzil are remarkably free from the effects of severe pressure metamorphism. Many of the shaly beds have not developed any cleavage, and the slates, though they possess an oblique cleavage, are free from foliation or crystalline structure, or phyllitisation. The limestone lenses, even when occurring at the summit of the Great Himalaya range at a height of 15,000 feet, preserve their grain and fossil structures unaltered. At other situations the limestones have undergone recrystallisation to some extent partly effacing but not obliterating the fossil structure. Changes induced by the acid and basic magmas invading the tuffs, materials so susceptible to contact metamorphism, are also not of a pronounced description.

The ultra-basic eruptives are devoid of accessory metallic compounds and ores in any marked quantities at the surface. Besides the magnetite, chromite and ilmenite present in small grains and crystals, the serpentine and pyroxenite masses do not commonly bear chromite ores in large visible aggregates such as is so markedly the case with the dunite intrusions of Dras. The gabbro area however needs prospecting for native elements and compounds of the platinum group. For this purpose the Gulam Sar area, lying between the Karobal pass and south-east of Pashwari, is recommended for investigation by the washing and panning of the river sands and other alluvial matter collected in the hollows around the drainage-courses.

VIII.—EXPLANATION OF PLATES.

PLATE 8.—Geological Map of Cretaceous volcanic belt of Burzil and Dras, Kashmir State. (Scale, 1 inch=4 miles).

PLATE 9.—Head of the Burzil Valley. The scree conceals Eocene limestone intercalations in volcanic tuffs.

PLATE 10, FIG. 1.—Sills of dolerite and gabbro, Pashwari, Burzil valley.

FIG. 2.—Volcanic agglomeratic, conglomerate near Minimarg, Nagai valley.

PERMO-CARBONIFEROUS LIMESTONE INLIERS IN THE SUB-HIMALAYAN TERTIARY ZONE OF JAMMU, KASHMIR HIMALAYA.

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CONTENTS.

I.—INTRODUCTION.

A chain of large inliers of an unfossiliferous dolomitic limestone, hitherto designated, from a total lack of stratigraphical and palaeontological data, as the 'Great Limestone', but tacitly regarded as belonging to the Kioto limestone (Upper Trias to Liassic) of the Kumaon and Spiti Himalayas, occurs in the Tertiary zone of the Jammu hills. By reason of the association of some important coal seams and bauxite deposits of considerable economic importance, with the Nummulitic rock-group immediately overlying this limestone, it has attracted the attention of geologists since 1876. Recent field work in the area by the present writer in continuation of his Poonch survey, has brought to light evidence of a probable Upper Carboniferous or Permo-Carboniferous age of this limestone. In the lowest beds of one of the inliers, belonging to the base of the series, brought up by the upthrow of a large strike fault, there is observed distinct interstratification of the limestone with the

Agglomeratic Slates of the Panjal Volcanic series—a very characteristic stratigraphic horizon of Kashmir, which in adjacent areas, has yielded a well-preserved *Productus* fauna of Uralian age, at several localities.

II.—AREA AND LOCATION.

The inliers occur as a series of hog-backed masses of dolomitised limestone of mountainous dimensions, the cores of denuded anticlines, in the system of flexures traversing the broad belt of the Murree sandstone series. They stretch in a north-west and south-east direction from Purl (33° 35′ : 73° 55′) in Poonch to beyond Riasi (33° 0′ : 75° 10′) in Jammu, a distance of 70 miles, along the prevalent strike of the Outer Himalayan ranges. The Murree belt here is 24 miles wide, composed wholly of barren ferruginous sandstones and shales. These limestone masses are the only instance (with the exception of the Tal series of the Kumaon Himalayas) of a pre-Tertiary marine formation occurring in the sub-Himalayan zone. The Riasi inlier is the largest of all the 'Great Limestone' masses. It is surrounded on the north flank by a well-defined rim of Nummulitic strata carrying important deposits of anthracitic coal, iron-ore and bauxite, overlying the older limestone with a pronounced unconformity; its south-west flank is dislocated by a steep fault. Structurally as well as in their lithological constitution all the inliers are remarkably uniform. The discovery of the association of the 'Great Limestone' with the Panjal Volcanic series, referred to above, was made on the south flank of a small inlier, the Devigarh inlier, about seven and a half miles in length, partly attached to the south-east extremity of the much larger Dandili inlier, these two outcrops being echelloned on one another and separated by a strip of Tertiaries. The peak of Ranjoti (6,303) is the highest point of the latter inlier and is four miles due north of the Devigarh peak (5,132), which falls away in a precipitous fault-scarp to the Murrees at its foot. The section containing the intercalation is exposed near the village of Sumlar (33° 23′ : 74° 3′), Kotli tehsil, Jammu Province, lying on the edge of the Murree belt. The accompanying map (Plate 11) gives the geological formations and their structural relations as seen in the two Kotli inliers, which are typical of the rest, but which possess the additional feature of association with a rock-group of known geological horizon, which thus bears indirect testimony to the age of the 'Great Limestone'.

III.—PREVIOUS WORK.

Reference to this rock-body is made in Medlicott's paper on the 'Sub-Himalayan series in Jamu (Jammoo) Hills' (1876), where he tentatively refers this limestone to the unfossiliferous, or sparsely fossiliferous, Kioto limestone of Spiti, which occurs from Kumaon, through Spiti, to Kashmir and Hazara. The next reference is by C. M. P. Wright (1906), who in his report on the Dandili Coal-field and coal deposits of the Kotli tehsil, mentions this limestone without discussing its age. Mr. C. S. Middlemiss, F.R.S., since 1917 has done a great deal of work in the 'Great Limestone' of Riasi district in connection with the various ore-veins, bauxite and coal deposits of that area. Though he has not definitely stated his views regarding the stratigraphic horizon of the rock in the various Economic Reports that he has published (Jammu, 1928-1930), he has often in discussions and in personal communications to me held the view that the 'Great Limestone' is allied to his 'Infra-Trias' limestone of Hazara. In my Memoir on the Geology of Poonch (1928), I have also expressed doubt regarding the Jurassic age of the 'Great Limestone', though I have there suggested retaining this name till more specific reasons for finally changing it are obtained.

IV.—STRUCTURE.

The anticlinal cores building the long, jagged, broad-backed ridges of white-weathering, hard limestone form an abrupt feature in the comparatively soft red sandstones and shales of the Murrees. The north limbs of the anticlines are preserved intact, with the unconformably reposing Nummulitics forming a uniform ribbon-like belt round their edge, while the south limbs are generally, though not always, disrupted by steep strike faults of large throw, which obliterate this half of the folds, completely or in part, bringing up the north-east dipping 'Great Limestone' strata in contact with the Murrees, or with the severed edges of the Nummulitics of the opposite limb of the fold. Faulting is most pronounced on this side in the middle portions of the anticlines, disappearing towards the pitching extremities of the folds. These south-faulted anticlinal folds are common features of the tectonics of the Outer and Sub-Himalayas. The faults have a steep plane of inclination, tending to pass over into reversed fractures. They produce prominent fault-scarps of the older limestone overlooking the subdued ranges of the Tertiary foot-hills. The Devigarh fault-scarp is less

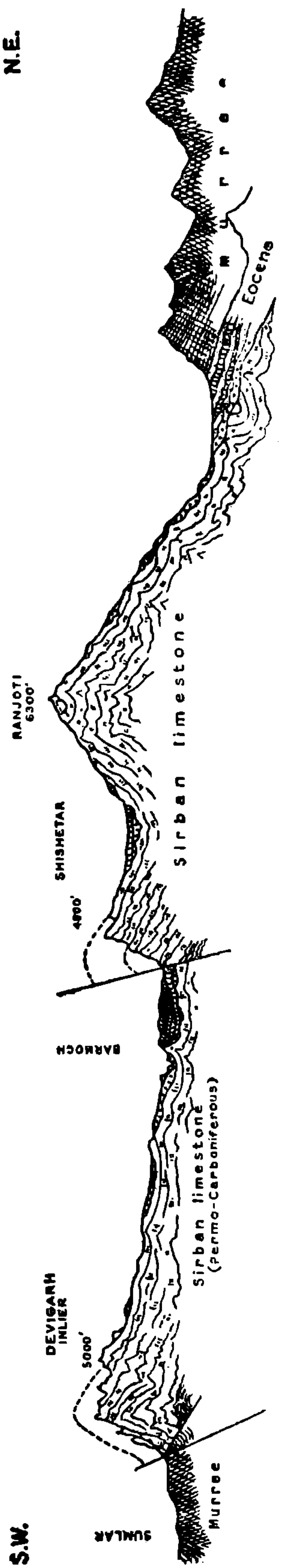

FIG. 1.—Section across Ranjoti and Devigarh inliers showing structural relations with the Tertiaries (Scale 1 inch=1 mile approximately, horizontal and vertical).

than half a mile north of the Main Boundary Fault of Kotli, thrusting the Murrees over the Upper Siwaliks.

For the most part the crown and flanks of the limestone cores are bare of the Nummulitics, the next succeeding series, only a few irregular patches of them being left as a skin over the older limestone in the warpings and corrugations of its surface. Important aggregates of bauxite and bauxitic clays, which together with coal-bearing shales constitute the base of the Nummulitic series, thus cover the gently inclined dip-slopes of the 'Great Limestone' on the north limb in most of the inliers from Riasi to Dandili. The unconformity at the base of the Nummulitics is most conspicuous at some places and concealed at others. At Tahi in Poonch, gently dipping Eocene beds overlie the edges of 75° dipping 'Great Limestone' beds. There is a pronounced pitch of the fold-axes at both the ends, due to the anticlines nosing down and disappearing abruptly under the Murrees. The system of folding is of the broad, open type of anticlines and synclines, without any considerable compression. There is no inversion of the folds (isoclinal structure), in the older series, though this phenomenon is curiously more apparent in the younger and less competent rocks of the Murree belt, among which these resistant fold-cores stand out prominently. There is a good deal of subordinate folding and warping in the major anticlines of the limestones.

It should be stated that the Ranjoti ridge, the highest mountain in the area, is mainly anticlinal while the Shishetar valley at its foot is a structural syncline; these features prove that the tectonic deformation of this region is of very recent date and that the topography is yet very youthful and immature. The same relation between tectonics and topographic relief is observed in Devigarh.

V.—LITHOLOGY.

The limestone is a hard, dense, usually non-crystalline rock, locally dolomitised and silicified to varying extents. Some beds approach true dolomite, assuming a yellow colour, greater density and resistance to acid, effervescing only in fine powder. It is blue-grey to cream-coloured or white, generally thin-bedded and extensively fissured and jointed in an irregular manner. Its thickness is over 1,500 feet, but the base is nowhere exposed and the existence of minor folds and crumpling within the formation does not enable a true estimate of its thickness to be made. There is present in the upper layers an intense degree of silicification, both of contemporaneous as well as of epigenetic nature, for besides the abundance of disseminated flint and chert concretions, there occur entire beds of slaty chert up to two feet in thickness, interspersed in the rock, bearing evidence of metasomatic replacement. At times the replacing substance is crystalline silica. The top beds especially show this silicification to a marked extent, the lower beds being free from secondary silica, generally speaking, and are composed of grey well-stratified limestone. There are no shaly or slaty partings in the rock from top to bottom. The only associate of the 'Great Limestone' is a foreign rock, a largely silicified serpentinised dunite, occurring in dykes and stocks. At places this ultrabasic intrusive has altered to a green and orange earthy mass, cut up by silica-veins.

The weathering of this limestone is peculiar, producing on exposed parts deeply grooved or 'chop-marked' surfaces, the cuts being straight and intersecting. This mode of weathering recalls exactly the weathering of the Infra-Trias limestone of Hazara.

VI.—ECONOMIC MINERALS.

Besides the coal, iron-ore and aluminium-ore deposits of the Nummulitic series which is closely associated with the older limestone in all its folds and warps, the 'Great Limestone' itself constitutes a repository of some ore-bodies in the form of vein-fillings and metasomatic replacements. The siliceous waters charged with metallic compounds, especially sulphides, have brought about a mineralisation of the rock in some areas, notably in the vicinity of Riasi. Sulphide ores of copper, nickel, lead and zinc are spread over a fairly wide area, in fine disseminations and occasional concentrations in lodes and veins, and need careful prospecting for their successful economic exploitation. The distribution of the high-grade aluminium ore, which, according to Middlemiss, aggregates over ten million tons in the Riasi tehsil alone, but which continues without any notable change in composition or in its genetic relations, to some of the north-western inliers as well, is intimately connected with this limestone. This fact is but inadequately shown by the outcrops of the Eocene in the accompanying map (Plate 11). The bauxite deposits occur at the base of the Nummulitics and form a skin, two to three feet thick, on the wrinkled surface of the 'Great Limestone'. Detailed mapping of the inliers on a scale of six inches, or four inches, to a mile is necessary before an accurate estimate of the total quantities of these ores in the inliers north-west of Riasi can be obtained.

VII.—STRATIGRAPHY AND AGE.

The rock is almost wholly barren of fossils, the only approach to fossil structures being exhibited by some beds of crystalline limestone, lately found near the base of the series, containing some slender, rod-like bodies, about 10 mm. long, looking like foraminiferal discs (? *Fusulina*) seen edgewise. No organic structure is, however, visible under the microscope in the prevailing crystalline matrix of the rock. It is also free from any other associated sedimentary rock, thus affording no clue as to its position in the geological column. From its lithology Medlicott assigned to it a Jurassic age (Kioto series) on purely hypothetical grounds. A tentative suggestion of its affinity with the Infra-Trias limestone of the Sirban mountain, Hazara, based on strong lithological resemblance and mode of weathering, was advanced by Middlemiss and myself, but no evidence resting on fossils or stratigraphic relations of this rock was obtained till lately. The discovery, during the 1934 field-season, of a series of black, slaty tuffs, occurring at what is most probably the base of the formation, distinctly interbedded with the 'Great Limestone', throws new light on the question of the age of this limestone. A small outcrop of this black slaty tuff, about 200 feet thick, exhibiting this interesting intercalary junction, is exposed near the village of Sumlar, below the ruined fort of Devigarh, at the foot of the south-facing fault-scarp. This mass is evidently a disrupted portion of the upthrown north-east limb of the Devigarh anticline, while the south-west limb has all but disappeared under the Murrees, leaving only a few shreds of the Nummulitics. The fortunate occurrence of strata of 'Great Limestone' in the body of this slate and of their interstratification with the higher beds of the slate are convincing evidence that the latter form part of the 'Great Limestone'. [See text-fig. 1.] The Sumlar tuff is a dense, compact, sooty black, slaty rock of higher specific gravity than argillaceous slate. It weathers to a light, ashy grey tint on the surface. Under the microscope it is composed of yet undevitrified isotropic glass, with tiny crystals of felspar, quartz and biotite; its external characters as well as mode of weathering

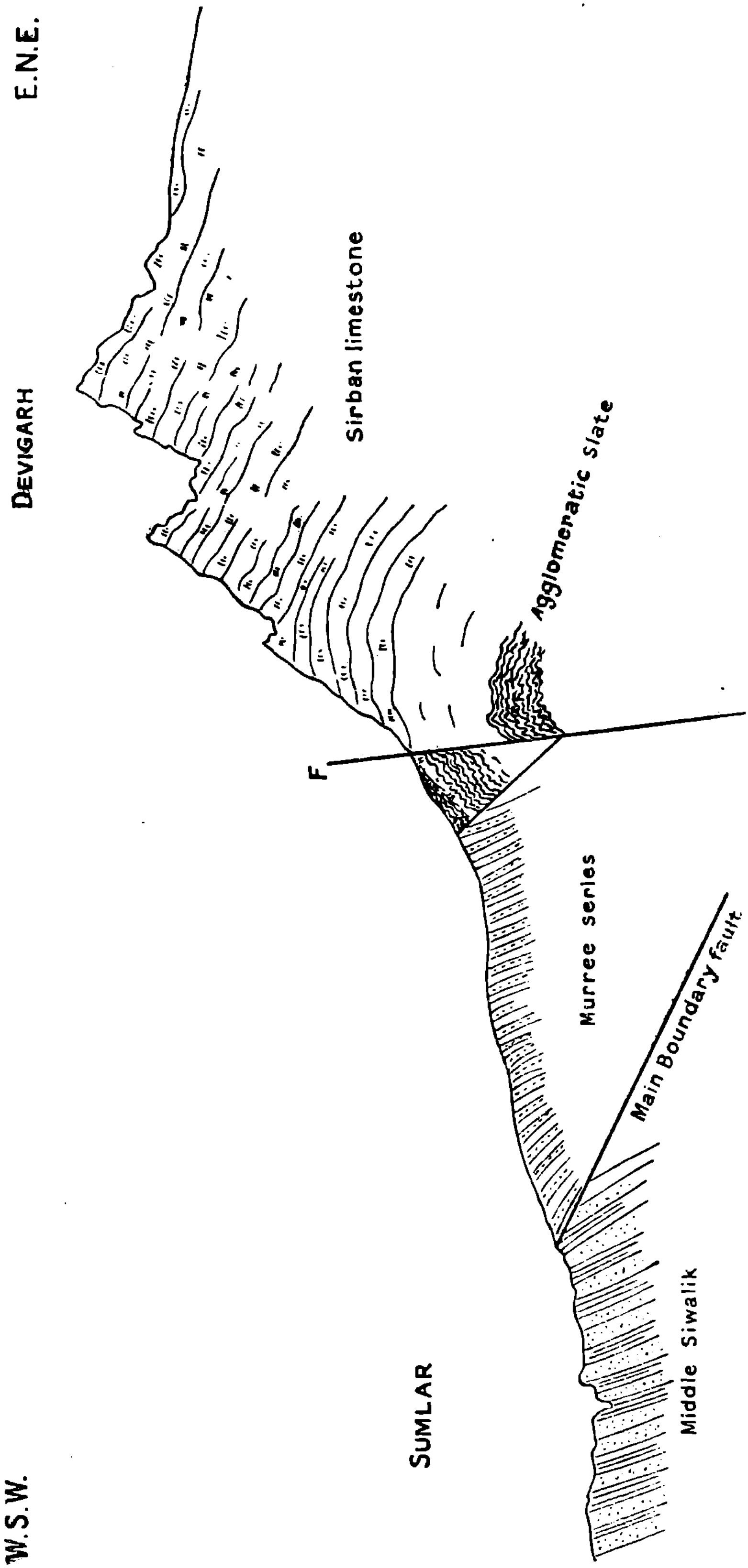

FIG. 2.—Sketch section north-east of Sumlar village, showing outcrop of Agglomerate Slate.

are similar to those of the black slaty members of the Agglomeratic Slate series of so many parts of Kashmir and Hazara. These facts leave no doubt that these tuffs belong to the Agglomeratic Slate series of the Panjal Volcanic group of the Pir Panjal range and the rest of Kashmir and tend to substantiate the correlation of the 'Great Limestone' with the 'Infra-Trias' limestone, an exactly similar intercalary relation having been repeatedly observed by me in numerous sections in Kaghan (Pascoe, 1930), Muzaffarabad and Uri areas, (Wadia, 1934).

Sections of this rock (23,825—23,828)[1] are wholly composed of volcanic glass, with fine dusty magnetite and some ? carbon; the bleached surfaces are free from magnetite. In the majority of sections the field is wholly isotropic; in 23,826 the glass is devitrified and replaced by a minutely crystalline base. Tiny crystals of felspars, quartz and biotite are scattered in the glassy base in 23,827 and 23,828. Veins of calcite infiltrations are present.

In the Rajaori Pir Panjal, about 20 miles north-east of Sumlar, interstratification of beds of an unfossiliferous limestone, lithologically akin to the Devigarh and Ranjoti limestone, was commonly observed among the volcanic ash-beds, agglomerates and slates, constituting the base of the Panjal Volcanic series, where the latter is overthrust on the Murrees. This phenomenon is vividly seen all along the south-west foot of the Pir Panjal between Sangiot and Budil (36 miles due east of Sumlar). It may be useful here to mention other examples of limestone intercalations, some of them fossiliferous, in the Agglomeratic Slates and traps of adjoining areas: (1) A lenticular bed of fossiliferous limestone containing comminuted brachiopod shells occurs in the Panjal trap near Badar (33° 21′ : 74° 51′) in the Riasi Pir Panjal. (2) A dark grey crystaline limestone with fossil traces is seen in the Agglomeratic Slate outcrop between Kund Radhan and Budil. (3) At Kul (33° 37′ : 74° 44′) a band of dolomitic limestone, about 200 feet thick, is interbedded with Agglomeratic Slates at their junction with the overlying Panjal trap. (4) At Parore (33° 22′ : 74° 29′) and near Daraba (33° 35′ : 74° 17′) massive unfossiliferous limestones occur in the volcanic slates and trap of the same series.

The age of the Agglomeratic Slate series, on the evidence of its well-preserved fossil fauna (Bion 1928; Cowper Reed 1932), obtained from several localities in Kashmir, is proved to be Upper

[1] These numbers refer to the serial number of micro-sections registered in the Geological Survey Laboratory.

Carboniferous (Uralian) in the main. Bion and Middlemiss have shown that its horizon may vary at different localities from the Moscovian, top of the Middle Carboniferous, for its lower beds, to the Artinskian, Permo-Carboniferous, at the latest, for its top beds. The interstratification of such a well-marked geological stage with the 'Infra-Trias' and 'Great Limestone', therefore, must be regarded as a fortunate circumstance helping to determine within precise limits their true stratigraphic position.

The name 'Great Limestone', now that the Upper Carboniferous or Permo-Carboniferous age of this rock is inferable with reasonable approximation and its similarity with the better-known 'Infra-Trias' limestone of Hazara (resting on a glacial boulder-bed and underlying the Trias) is evident, is no longer necessary or justified. It, as well as the 'Infra-Trias', may now more appropriately be named 'Sirban limestone' from the typical locality near Abbottabad where this latter limestone outcrops in perfect development and where it was first studied by Wynne (1872) and Middlemiss (1896).

One further circumstance which points to the lithological resemblance with the Hazara limestone is the mode of silicification observed in these rocks. The extensive metasomatic silicification of the Infra-Trias limestone of Garhi Habibullah and Muzaffarabad into 'quartzite' and 'grit' beds and into powdery silica collected into heaps of snow-white dust at the foot of the limestone cliffs was reported on by me in 1928 (Pascoe 1929). More or less similar phenomena have been observed at several localities in the present area, a typical example being the spreads of dusty and powdery silica around the small hamlet of Karjai; much unconsolidated silica of secondary formation also occurs on the top as well as the cliff-face of the Devigarh scarp. White, crystalline metasomatic quartzite is very conspicuous in the limestone beds north of Sumlar.

VIII.—RELATION WITH THE REST OF THE HIMALAYA.

The occurrence of marine limestones of Upper Palæozoic age in the outer Himalaya, so far south of the main boundary of Himalayan geosynclinal formations and within the Tertiary zone, must be regarded as an exceptional circumstance; the only other instance is the outcrop of the marine Tal series of the Garhwal Outer Himalaya, which, however, is much younger and of Jurassic age. They must be the deposits left by temporary inroads of the Himalayan sea to the south of the Gondwanaland coast-line, flooding portions of the foreland. The Riasi transgression must be of a very transient nature, for no Permian or Trias has been met with in the Sub-Himalayan zone south of the foot of the Pir Panjal.

The Jammu limestone also shows close lithological similarity to the Krol limestone of the Simla Himalayas. The identity of the Krol series with the Infra-Trias series of Sirban has been suggested (Fermor, 1931) on grounds of a more or less exact parallelism of their stratigraphic succession, commencing with a basal boulder-bed of glacial origin. The former group overlies a basement of the Blaini boulder-bed, the homotaxis of which with the Tanakki conglomerate of ice-scratched pebbles at the base of the Sirban limestone series and with the much better-known Talchir boulder-conglomerate of the Salt Range is now accepted by Indian geologists. The close analogy between these three occurrences of unfossiliferous limestone —of Hazara, the Riasi-Dandili belt and the Krol area—therefore suggests a widespread transgression of the Himalayan Productus sea to the south of the main axis of the range. This took place during the epoch in which the Spiti and Kashmir portion of the same sea was depositing the richly fossiliferous limestones of the Kuling and Zewan series in the north and the Productus limestone of the Salt Range in the south (in a distant southern arm of the same Himalayan sea, branching off from Hazara). The totally unfossiliferous nature of the limestones in the former sites as contrasted with the organic richness of their probable homotaxial equivalents in the Himalayas and Salt Range, is one of the puzzles of Indian geology. One explanation, perhaps, may be that the southern invasion produced a land-locked basin that did not offer favourable conditions for migration of animals from the main ocean.

The Nummulitic sea of much later times, which has left its records in the Outer Himalayas from Kumaon to Punjab, Kohat and Sind, transgressed over a floor of the Permo-Carboniferous from Simla to Hazara.

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X.—EXPLANATION OF PLATES.

PLATE 11. Geological map of the Dandili-Devigarh Inliers, Kotli district, Jammu. (Scale, 1 inch=2 miles.)

PLATE 12, FIG. 1.—Cliff of 'Great Limestone,' Dandili, Kotli.

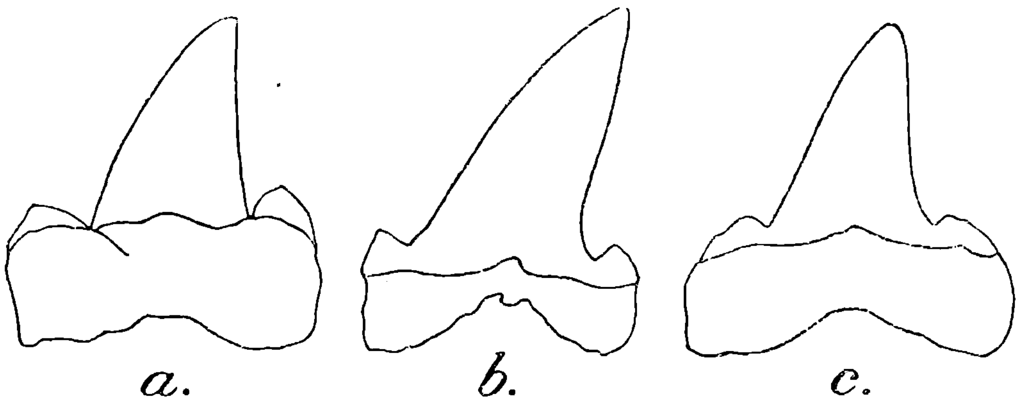
FIG. 2.—' Great Limestone ' cliffs—a fault scarp—near Sumlar village, north of Kotli *Dun.*

PLATE 13, FIG. 1.—Weathering of 'Great Limestone.' Outcrop near Kamroti village, Kotli.

FIG. 2.—Minor fold in ' Great Limestone ' with a shell of the Nummulitics carrying bauxite, Kamroti village. (The smooth uppei surface is formed of a bed of bauxite.)

ON A SHARK TOOTH FROM THE LOWER EOCENE. BY SUNDER LAL HORA, D.Sc., F.R.S.E., F.N.I., *Assistant Superintendent, Zoological Survey of India, Calcutta.**

The shark tooth[1] reported here was sent to me by Mr. E. R. Gee of the Geological Survey of India who obtained it in 1931, from just south of the Salt Department Rest House at Sar Kalan, 3 miles E.S.E. of Nurpur in the Salt Range, Jhelum District, Punjab. It was found in "the flaggy, foraminiferal, pinkish-grey (weathering yellow-brown) limestone, which is associated with variegated sandstones below the Nummulitic coal shale horizon." Mr. Gee has informed me that, on stratigraphical grounds, the fossil should be referred to the Ranikot (Lower Eocene) age (Gee, 1935; Davies and Pinfold, 1937).



Teeth of three species of *Lamna* Cuv. *a. Lamna appendiculata* Ag.; *b. Lamna* sp. from the Salt Range, Punjab, ×1⅛; *c. Lamna obliqua* Ag.

Figures *b.* and *c.* are copies from Zittel and all the three teeth are enlarged to the same length for the purpose of comparison.

The tooth (No. K39/514*a*) is of a burnt amber colour; it is very stout and consists of a large, conical cusp and of two well-defined, fairly broad, somewhat obtuse, lateral denticles, one at each side of the base of the cusp. The root, which was embedded in the rock and has been exposed by using acid to dissolve the rock, is large, expanded laterally and only slightly bifurcate. The surface of the tooth is well polished and ornamented with small pits; the central

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[1] Besides one complete tooth, lateral denticles or portions of lateral denticles of several other teeth were found embedded in rock No. K39/514.

portion is somewhat raised so that the exposed surface (probably external) is somewhat convex. The lateral edges of the cusp are sharp and entire and the tip is pointed. The measurements of the tooth are:

Length of cusp	17 mm.
Width of base of cusp	10 mm.
Width of base including that of denticles . . .	15 mm.

From the nature of the tooth it is clear that it should be referred to the family Lamnidae[1] in which the teeth are pointed and are usually of a large size; the lateral denticles may or may not be present. Of the genera of the Lamnidae, the teeth of the genus *Lamna* Cuvier possess a somewhat broader cusp; the lateral denticles are also larger. The fossil tooth should, therefore, belong to this genus. According to Zittel (1932, page 77), *Lamna* is

> "very abundant in the Chalk, Tertiaries, and existing seas. Teeth of *L. appendiculata* Ag. universally distributed in Upper Cretaceous. *L. obliqua* Ag. sp., large teeth from the Eocene. *L. gafsana* White. Eocene; Tunis."

So far as I am aware *Lamna* (*sensu stricto*) has not hitherto been recorded from the Indian seas.[2] The recent species, *L. nasus*, is, however, known "from the British Isles, the Mediterranean, the Western Atlantic, and from Japan" (Garman, 1913, p. 35). A species has recently been described from New Zealand (Phillips, 1935, p. 239). The discovery of a tooth of *Lamna* from the Salt Range is, therefore, of special interest.

The teeth of the present-day, widely distributed porbeagle shark —*L. nasus*—are provided "with broad two-rooted base and slender lanceolate cusp at the base of each side of which in the larger specimens there is a sharp denticle." (Garman, 1913.) The fossil tooth described here seems to represent an intermediate type between the more massive teeth of *L. appendiculata* and *L. obliqua* and the slender teeth of *L. nasus*.

[1] Garman in his monograph on "The Plagiostomia" (*Mem. Mus. Comp. Zool. Harvard Colloge*, XXXVI, 1913) considers *Lamna* as a subgenus of *Isurus* Rafinesque and has, therefore, adopted the family name Isuridae. *Lamna* is, however, distinguished from *Isurus* by the fact that the teeth of the former are provided with denticles on either side of the base in adults, while in *Isurus* the teeth are without denticles.

[2] Attention may here be directed to the teeth of *Carcharias tricuspidatus* Day (= *Odontapsis taurus* Müll & Henle) which are "very large, awl-shaped, smooth except at the base, where there exists a small basal cusp on either side" (Day, *Fish. India*, p. 713, pl. clxxxvi, fig. 1, 1878). From Day's figures of the teeth it is clear that the fish should be referred to the genus *Odontapsis* Ag. The teeth of *Odontapsis* are similar to those of *Lamna*, but are much more slender and the basal denticles are very small and sharp.

In describing the Tertiary fishes of India, Lydekker (1886, p. 243) described two vertebrae under the family Lamnidae but he was unable to assign them to any genus. He observed:

"The vertebra of a shark represented in plate XXXVII, figs. 9, 9a, is one of two similar specimens in the Indian Museum from the Siwaliks of Perim Island. They agree very closely with the vertebræ of *Lamna cornubica*, and not improbably belong either to *Lamna* or *Carcharias*."

Both the fossil tooth described above and the vertebra figured by Lydekker show that fishes similar to *Lamna nasus* flourished in the Tertiary seas and estuaries of India.

As regards the specific identity of the fossil tooth it is very difficult to come to any definite conclusion, as Weiler's (1931, 1932, 1933) and Murray's (1930) recent papers, in which species of *Lamna* are figured, are not available in Calcutta. I have, however, consulted White's (1931, 1934) papers and find that the tooth under report does not agree with any of the species of which the teeth are figured by him.

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ON FOSSIL FISH-REMAINS FROM THE KAREWAS OF KASHMIR.

BY SUNDER LAL HORA, D.SC., F.R.S.E., F.N.I., *Assistant Superintendent, Zoological Survey of India, Calcutta.* (With Plate 14.)*

I.—INTRODUCTION.

In 1932 and 1935, Dr. Hellmut de Terra, Leader of the Yale North India Expedition, collected a number of fossil fish-remains in the Kashmir valley which he sent to me for study and report. These remains, which are of a very fragmentary nature, are not in a good state of preservation. The earlier lot, which consisted of bits of spines and vertebrae, was almost indeterminable. The 1935 lot, however, comprised one greatly crushed skull (Specimen No. K40/247), impressions of the caudal region of two specimens and a counterpart of one of these, a piece of skin with scales and two pharyngeal teeth. From the nature of the scales it has been possible to refer the entire material to the sub-family *Schizothoracinae* (Family: Cyprinidae) which, as is clear from Mr. Mukerji's (1936) report on the fishes collected by the Yale North India Expedition, forms, even at the present day, the most dominant element in the fish fauna of the valley.

Most of the specimens reported upon were collected from Ningal Nullah, near Gulmarg, at an altitude of about 9,800 feet. Dr. de Terra in his letter dated April, 7, 1937 informs me that

> "The specimens collected in Ningal Nullah, near Gulmarg, come from an exposure of Lower Karewa beds at an altitude of 9,800 feet. The Lower Karewas, as was indicated in several publications of mine, should be referred to the first Interglacial. At this particular locality the laminated Karewa silts are tilted and unconformably overlain by Glacio-fluvial outwash deposits belonging to a retreat phase of the second Ningal glacier. These fish-bearing beds also yielded many fossil leaves representing a Pine-Oak-Willow flora. A petrologic analysis of the Lower Karewas has just been completed by Dr. Krynine of Yale University, who states that these beds were laid down in a lake, and that part of the sedimentary material suggests derivation from windblown silt."

* This article forms a continuation of the Biological Reports Nos. XVII and XVIII of the "Scientific Results of the Yale North India Expedition" (*Mem. Conn. Acad.*, X, pp. 299-359, 1936), and is published here with the permission of the Director, Zoological Survey of India.

According to Mr. D. N. Wadia of the Geological Survey of India the matrix of the fossil fishes consists of

"A fine micaceous sandy clay such as occurs in thick beds in the Karewas of Kashmir. It may be a fluviatile or lacustrine deposit in still water; there is a faint trace of lamination showing intermittent deposition."

In the following account I propose to describe first the recognisable fragments and then to refer to their affinities. The ecological association of the fossil fish fauna is also discussed and it is pointed out that the occurrence of these fossils at an altitude of 9,800 feet affords additional evidence in favour of recent orogenic uplift movements in the Himalayas.

The whole of the material is deposited in the collection of the Geological Survey of India.

II.—DESCRIPTION OF THE COLLECTION.

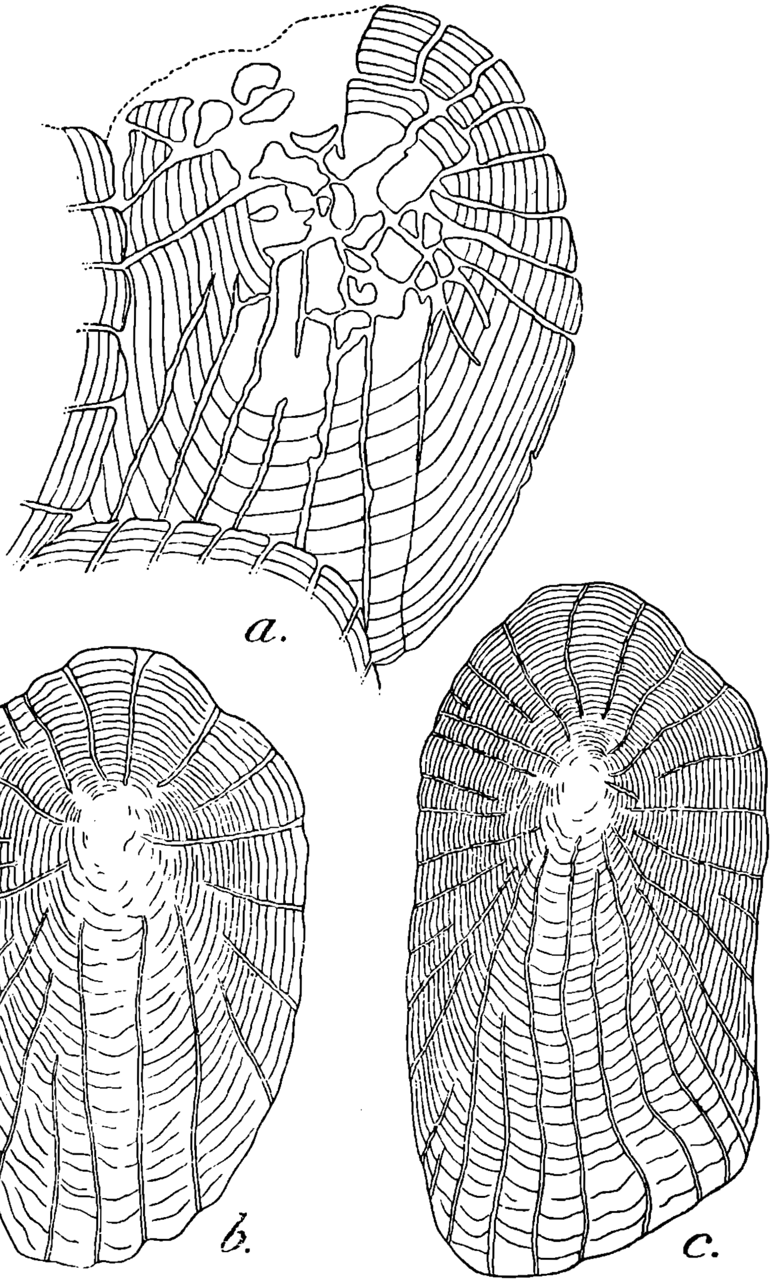
Specimen No. K40/241. A piece of skin immediately behind the head region and below the vertebral column preserved in lateral view.

Locality.—Ningal Nullah, near Gulmarg.

The bony elements are too fragmentary to be determined, but the skin is covered with small scales which slightly overlap one another (Plate XIV, fig. 1). All the scales show perfectly developed circuli and complete radii in all fields (Plate XIV, fig. 2). Each scale is somewhat oval in outline, with a number of radii arranged all over the surface; the apical radii, however, are much longer than others and are more widely spaced (Text-fig. 1*a*). The nucleus of the scales is basal and there are about 8-10 apical radii and an almost equal number of smaller lateral and basal radii.

The scales of the type described above are characteristic of the Schizothoracinae, (Chu, 1935), but there are slight differences in the case of different genera. The structure of the scales also varies according to the portion of the body from which they are examined. The genera that are known from the Kashmir valley are *Schizothorax* Heckel, *Oreinus* McClelland, *Schizopygopsis* Steindachner, *Diptychus* Steindachner and *Ptychobarbus* Steindachner. Of these *Schizopygopsis* possesses a more or less naked body, but the scales of other genera from above the pectoral fins were examined and it was found that the fossil scales described above show very close resemblance to those of *Schizothorax* (Text-fig. 1*b*) and *Oreinus*

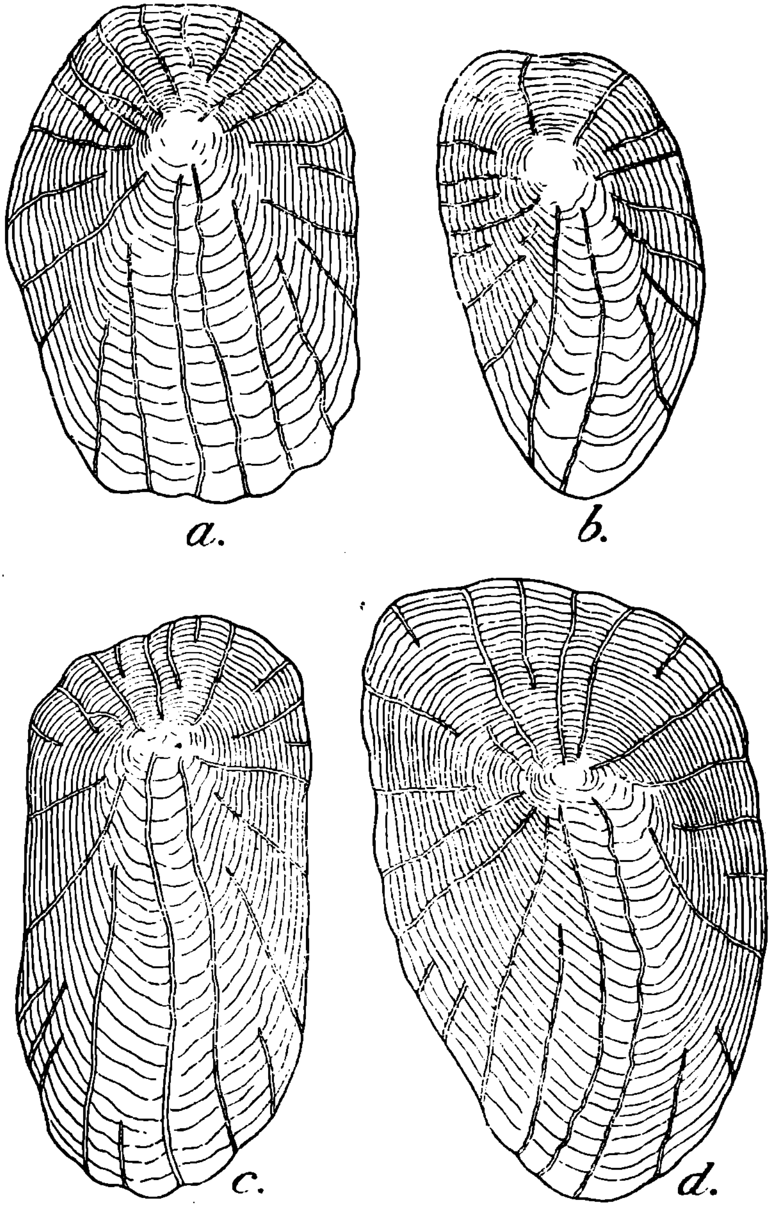
(Text-fig. 1c). The scales of a number of species of *Schizothorax* occurring in the Kashmir valley (Text-fig. 2) were examined, and it was found that the fossil scales are more closely allied to *Sch.*



TEXT-FIG. 1.—Fossil scales and scales of *Schizothorax* and *Oreinus* from above pectoral fin for comparison.

a. An incomplete fossil scale with portions of two neighbouring scales to show the nature of lepidosis and the structure of the scale. ×52 ; *b.* Scale of *Schizothorax esocinus* Heckel. ×38 ; *c.* Scale of *Oreinus sinuatus* (Heckel). ×38.

curvifrons (Text-fig. 2*a*) than to any other species of *Schizothorax* known from the Kashmir valley.



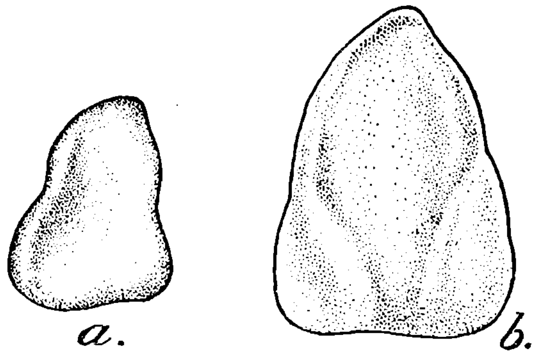
TEXT-FIG. 2.—Scales of certain Kashmir species of *Schizothorax*.

a. Schizothorax curvifrons Heckel. ×44; *b. Schizothorax micropogon* Heckel. ×44; *c. Schizothorax planifrons* Heckel. × 44; *d. Schizothorax longipinnis* Heckel. ×44.

Specimen No. K40/242. Underterminable pieces of bone and two pharyngeal teeth with their crowns exposed (Plate XIV, fig. 3).

Locality.—Ningal Nullah, near Gulmarg.

The two pharyngeal teeth are preserved in different positions (Plate XIV, fig. 4). The grinding surface of one is fully exposed while that of the other is inclined obliquely. The outline of the fully exposed tooth corresponds with the outline of the crown of a pharyngeal tooth of *Oreinus sinuatus* (Heckel) from Kashmir but the grinding surface of the fossil tooth is more worn out and plain (Text-fig. 3). Grinding pharyngeal teeth of the type represented by the fossil teeth are characteristic of the Schizothoracine genera, such as *Oreinus*, *Schizothorax*, etc. (*vide* Chue, 1935).



TEXT-FIG. 3.—Outline of the crown of a fossil pharyngeal tooth and that of *Oreinus sinuatus* (Heckel).

a. Fossil toth. ×22; *b.* Tooth of *Oreinus sinuatus* (Heckel). ×17.

Specimens Nos. K40/243 and K40/244. Three pieces of clay containing bones and impressions of the caudal region of a fish of the same type (Plate XIV, fig. 5).

Locality.—Ningal Nullah, near Gulmarg.

The anal fin is short, consisting of 5 branched rays and 2 undivided rays. The caudal fin is long and deeply forked. This region of the fossil fish agrees with the corresponding region of the Schizothoracine fishes, such as *Oreinus* (Plate XIV, fig. 6). The whole structure is of such a generalised nature that by itself it is not capable of specific determination.

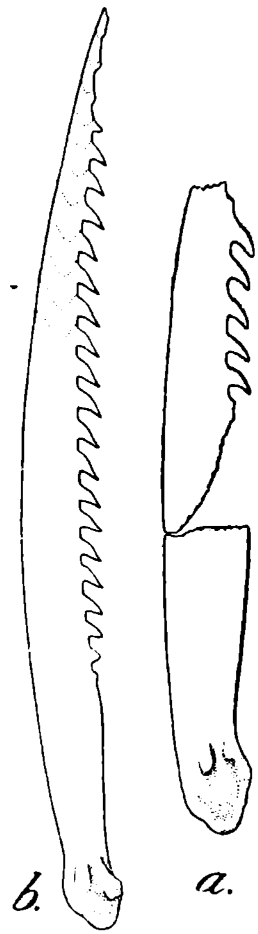
Specimen No. K40/245. Several loose, incomplete vertebrae of the opisthocoelus type.

Locality.—Several places in the Kashmir valley and Ladak.

Both caudal and trunk vertebrae are represented in this lot. They do not possess any special features which could be utilised in their determination. However, they resemble very closely the vertebrae of the Schizothoracinae.

Similar vertebrae were collected by Dr. de Terra from several localities.

Specimen No. K40/246. An incomplete dorsal spine in two pieces (Text-fig. 4).



TEXT-FIG. 4.—An incomplete, fossil, dorsal spine in two pieces, and a normal dorsal spine of *Oreinus sinuatus* (Heckel).

a. Fossil spine. × 3 ; *b*. Spine of *Oreinus sinuatus* (Heckel). ×3.

Locality.[1]—Unknown.

The basal portion of the spine is provided with an articular surface, while the distal portion is strongly denticulated along the inner border. The serrations are prominent and widely spaced.

[1] Dr. de Terra believes " that this and other localities referred to all come from the same Lower Karewa beds; mainly, the locality at Sombur on the right bank of the Jhelum, above Pampur ".

Of the genera of the Schizothoracinae found in Kashmir, the dorsal spine is feeble in *Diptychus* and *Ptychobarbus*, while it is, strong and serrated in *Oreinus*, *Schizothorax* and *Schizopygopsis*. The last named genus is devoid of scales, so on *a priori* grounds the fossil spine may be referrable either to *Oreinus* or to *Schizothorax*.

The collection contains several other fragments of the nature of spines but it is very difficult to assign to them any definite systematic position.

III.—AFFINITIES OF THE MATERIAL.

From the foregoing account of the various fragments of fossil fishes, it is clear that they should be referred to the genus *Oreinus* or *Schizothorax*. It has already been indicated (Hora, 1936) that the two genera are very closely related and are capable of interbreeding. In fact, all gradations of form between *Schizothorax* and *Oreinus* were found in a collection of recent fish from Chitral and it was concluded that the latter represents a fluviatile form of the former. In the collection of fish made by the Yale North India Expedition, Mukerji (1936) found a series of forms intermediate between *Schizothorax* and *Oreinus* and described two hybrid forms. At the present day both these genera are well represented in the lakes and larger streams of the Kashmir valley. It appears reasonable, therefore, to infer that the beds from which the fossil fish were obtained must have been laid down either at the bottom of a lake or a large sluggish river. This conclusion was also reached by Mr. D. N. Wadia from an examination of the matrix of the fossil fishes (*vide supra*, p. 179).

Both *Schizothorax* and *Oreinus* are comparatively low altitude genera and their occurrence at a height of 9,800 feet in the fossil state needs some explanation. To form some idea of the altitudinal distribution of the various Kashmir species of the *Schizothoracinae*, I give below a list of the present day fishes obtained by the Yale North India Expedition with the number of specimens of each and the altitudes, in feet, at which they were obtained.

1. *Schizothorax labiatus* (McClell) . .	1 specimen from 10,730 ft.
2. *Schizothorax longipinnis* Heckel . .	1 specimen from 5,196 ft.
3. *Schizothorax esocinus* Heckel . . .	10 specimens from 5,200 ft. and 2 specimens from 10,700 ft.
4. *Schizothorax planifrons* Heckel . .	9 specimens from 5,200 ft.
5. *Schizothorax micropogon* Heckel . .	10 specimens from 5,200 ft.
6. *Schizothorax curvifrons* Heckel . .	5 specimens from 5,200 ft.

7. *Oreinus sinuatus* (Heckel) . . . 5 specimens from 5,200 ft.; 5 specimens from 8,700 ft. and 3 specimens from 10,730 ft.
8. Hybrids between *Schizothorax* × *Oreinus* . 11 specimens from 5,200 ft.
9. *Schizopygopsis stoliczkae* Steind. . . 13 specimens from 10,730 to 14,203 ft.
10. *Diptychus maculatus* Steind. . . . 17 specimens from 10,250 to 15,215 ft.
11. *Ptychobarbus conirostris* Steind. . . 5 specimens from 8,790 to 13,521 ft.

It is clear from the above that, as a general rule, *Schizothorax* and *Oreinus* are inhabitants of comparatively low altitudes, whereas *Schizopygopsis*, *Diptychus* and *Ptychobarbus* are only found at much higher altitudes. *Oreinus*, in particular, is a genus of the southern slopes of the Himalayas and is not found on the tableland of Central Asia. Though there are no definite observations on the migrations of *Schizothorax* and *Oreinus* to small torrential streams for breeding purposes, it seems probable that, like the trout, they may also ascend at times into the smaller streams of the higher reaches. The time during which the Yale North India Expedition collected fishes from the higher altitudes coincided with the breeding season of these fishes, *viz.*, June to September, and it is no wonder, therefore, that some specimens of *Oreinus* and *Schizothorax* were obtained by the Expedition at comparatively higher altitudes. The sizes of the specimens also indicate that more or less mature fishes were collected from the higher regions.

The fact that all the fossil fish remains obtained by Dr. de Terra are referrable to *Schizothorax* or *Oreinus* leads one to infer that the beds in which they are now found may have been laid down at an altitude of about 5,000 feet or lower and that their present position on the slopes of the Pir Panjal is due to recent orogenic uplift movements in the Himalaya (Sahni 1936*a*). This belief is further strengthened by the fact that the fossil scales probably belong to *Schizothorax curvifrons* Heckel, which, at the present day, is indigenous to the valley of Kashmir and has not been found at an elevation higher than that of the valley. In an article on the Karewas of Kashmir, Sahni (1936) has stated:

"The fossil-bearing sediments near Gulmarg, like many other deposits of clay, sand and gravel on the NE slopes of the Pir Panjal, were no doubt laid down, as Dr. Stewart suggests, in the bed of a lake. *But that lake never existed at the high altitude where its bed is now seen.* Strange though it may seem, this lake must have been situated several thousand feet lower, at the same level as the main valley of Kashmir. Since the time when the plants and animals, of which the fossil remains are now found at 11,000 feet or even higher, flourished in and around this lake, the sediments have been *lifted out of their original horizontal position* and have been *upheaved through at least five thousand feet with the (geologically speaking) recent upheaval of the Pir Panjal Range.*"

The studies on the fossil fishes of the Karewas of Kashmir fully bear out Sahni's contention and afford further evidence of comparatively recent orogenic uplift movements in the Himalayas.

IV.—SUMMARY.

Fossil fishes collected by Dr. H. de Terra from the 2nd Interglacial clay in the Kashmir valley comprise a piece of skin with scales, pharyngeal teeth, caudal portions of the skeleton, vertebrae and bits of dorsal spine. From the lepidosis and the structure of the scales, it has been possible to refer the entire material to the subfamily Schizothoracinae (Family: Cyprinidae). The detailed structure of the various parts shows that the fragments are referrable to the genera *Schizothorax* Heckel or *Oreinus* McClelland. From the present day distribution of these genera it is concluded that the fossils may have been laid down at the bottom of a lake or a large, sluggish river situated at an altitude of about 5,000 feet; their present position in the Ningal Nullah above Gulmarg at an altitude of 9,800 feet, therefore, affords evidence of recent orogenic uplift movements in the Himalayas.

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VI.—EXPLANATION OF PLATE 14.

Fossil Fish-Remains from the Karewas of Kashmir.

FIG. 1.—A portion of the skin of specimen No. K40/241, showing lepidosis. $\times 11\frac{1}{5}$

FIG. 2.—Same as above with the structure of scales better defined. $\times 11\frac{1}{5}$.

FIG. 3.—Pharyngeal teeth (Specimen No. K40/242). $\times 5\frac{3}{5}$.

FIG. 4.—Pharyngeal teeth further magnified. $\times 16$.

FIG. 5.—Skeleton of caudal region of a fossil fish (Specimen No. K40/243). $\times \frac{3}{5}$.

Fig. 6.—Skeleton of caudal region of *Oreinus sinuatus* (Heckel) for comparison with figure 5. $\times$ *ca* $\frac{3}{5}$.

FOSSIL FISH-REMAINS FROM THE SALINE SERIES OF NORTH-WESTERN INDIA. BY SUNDER LAL HORA, D.Sc., F.R.S.E., F.N.I., *Assistant Superintendent, Zoological Survey of India, Calcutta.* (With Plate 15.)*

A large number of small fossil fish-remains were obtained by Mr. E. R. Gee of the Geological Survey of India from "within the gypsum stage, at the top of the Saline series near Malgin (33° 19′ 30″ : 71° 31′ 30″), Kohat district" (Gee, E. R. The Saline Series of North-Western India. *Cur. Sci.*, II, p. 461, 1934). They were examined by Dr. E. I. White who reported them to be of the post-Cretaceous type. The material was later passed to me by the Director of the Geological Survey of India for a detailed examination and report. It is of a very fragmentary nature and its state of preservation is far from satisfactory. There is only one fairly complete specimen (G. S. I. Type No. 16361),[1] but even in this case the head region is very obscure. Taking the entire material into consideration, 4 types of fishes can be recognised. Of these one belongs to the family *Clupeidae*, one can be referred with some doubt to the family *Dorosomidae*, while the remaining two can only be assigned to the order *Percomorphi*. The Clupeid seems to be the most predominant form, as it is represented in the collection by a large number of fragments. A careful study of a series of these fragments has rendered it possible to determine this form specifically; while in the case of other fishes it has not been possible to identify them even generically. In the following account I propose to describe a few of the better preserved fragments and to discuss the probable affinities of each type.

Both the Herrings and the Perches date from the Cretaceous and are at the present day among the predominant families of the Teleostei. The probable genera represented in the collection are known only from the Tertiary formations. The fish-association, as represented by the fossil material, shows that the Saline series may have been laid down either in a lagoon, a bay, an estuary or near a sea shore. Clupeid fishes are very gregarious and often enter estuaries in vast shoals. Some species are known to breed in

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[1] The number refers to the registered number of the specimen in the collection of the Geological Survey of India.

estuaries, and at certain seasons very large numbers of young forms swarm in these areas. The preponderance of the small Clupeid fishes in the material thus indicates the type of habitat in which the Saline series may have been laid down.

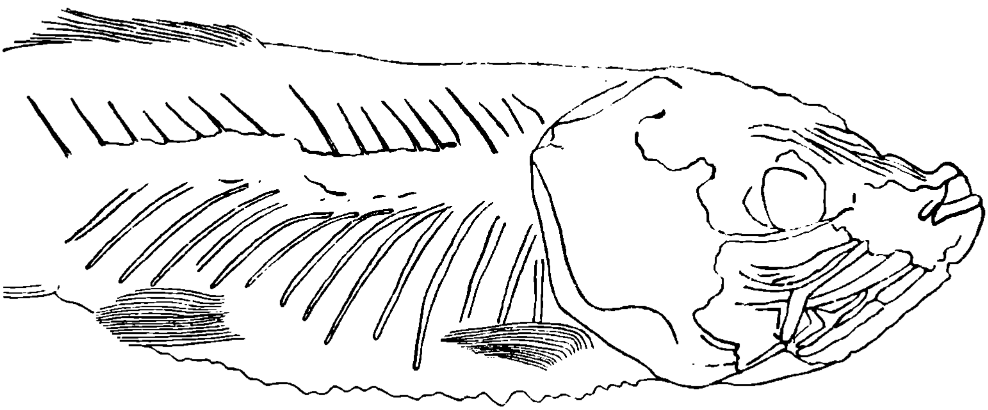
Order: ISOSPONDYLI.

Family: *CLUPEIDAE.*

Subfamily: *CLUPEINAE.*

Clupea geei, sp. nov.

Specimen G. S. I. Type No. 16359. Bones and impressions of a fish preserved in a slightly ventro-lateral view. (Plate XV, fig. 4; text-fig. 1.)



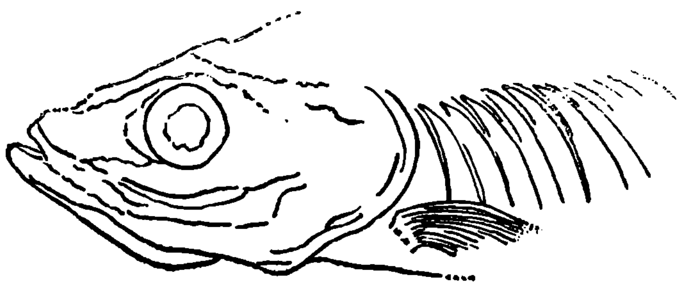
TEXT-FIG. 1.—*Clupea geei,* sp. nov. Outline drawing made from an enlarged photograph of specimen G. S. I. Type No. 16359. ×9.

Approximate measurements in millimetres.

Total length including caudal	20·2
Length of caudal	4·2
Length of head	5·0
Depth of body	4·5
Length of snout	2·0
Diameter of eye	1·2

In this specimen the bones and impressions of the head and the trunk region are clearly marked while those of the caudal region are obscure. The mouth is small and turned upwards. A small portion of the head behind the mouth is obscure, while behind this region the maxillary and the supplemental bones are clearly indicated. These bones seem to extend below the middle or the hind border of the orbit. The eyes are lateral and are placed almost in the middle of the head. The neural spines and ribs are clearly marked in the anterior region. The dorsal fin commences in advance of the ventrals and its commencement is somewhat nearer to the tip of the snout than to the base of the caudal. It lies folded against the back and about 12 rays can be counted in it. The pectoral fin is considerably shorter than the head and contains about 12 rays. The ventral fins are well developed and each consists of eight rays. The anal fin is obscure; its commencement is situated behind the ventrals and about 8 rays can be made out in it with considerable difficulty. The caudal fin is bifurcate and both the lobes are pointed; it is shorter than the length of the head. The impression of the ventral edge of the body shows that the abdominal serrations commence before the base of the pectoral fin and are continued to the commencement of the anal fin.

Specimen G. S. I. Type No. 16360.—Bones of head and of anterior part of body preserved in lateral view (Plate XV, fig. 6; text-fig. 2).

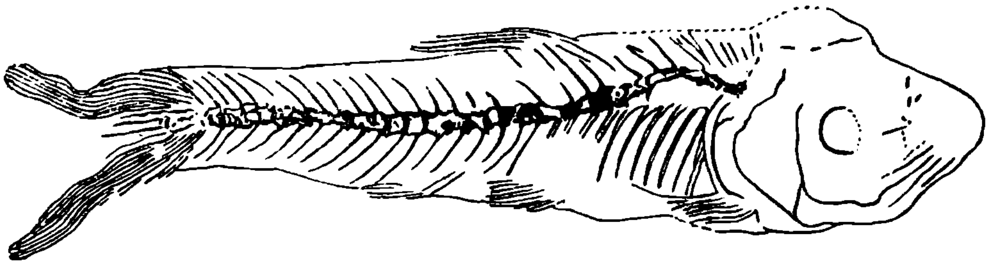


TEXT-FIG. 2. *Clupea geei*, sp. nov. Outline drawing made from an enlarged photograph of specimen G. S. I. Type No. 16360. ×7½.

The form of the head and mouth, the nature of the various bones and the position of the eye are similar to those described above for specimen G. S. I. Type No. 16359, except that this specimen is not preserved in ventro-lateral view. The area of the neural spines has been obscured by scratching, but the anterior ribs are very clear.

Specimen G. S. I. Type No. 16361.—A complete specimen preserved in lateral view, with the head region very obscure and the extremities of the dorsal, anal, pectoral and ventral fins not properly preserved. (Plate XV, fig. 5; text-fig. 3.)

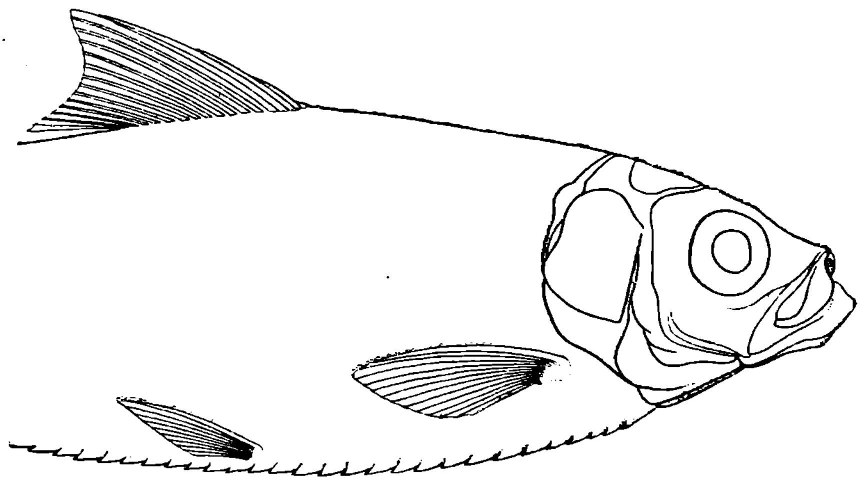
This specimen is about 22 mm. in total length. The vertebral column, which is out of position in the anterior part, is well-preserved ; the neural spines and the ribs are clearly marked. The



TEXT-FIG. 3.—*Clupea geei,* sp. nov. Outline drawing made from an enlarged photograph of specimen G. S. I. Type No. 16361. ×5.

head region is greatly crushed and the structure of its various parts cannot be made out.

Affinities : *Clupea geei* probably represents a young stage of some species, but the nature of the material does not permit a close study of its relationships. Moreover, the young stages of all the Indian Clupeidae are not known. In view of this and on account of differences in proportions, number of fin rays, etc., between *C. geei* and the already known species it has been considered advisable to recognise the Clupeid of the Saline series as a distinct species and to associate it with the name of Mr. E. R. Gee who discovered it. The fossil species appears to be similar to the young stages of *Hilsa ilisha* (Ham.), the well known anadromous fish of India. For comparison the figure of a young specimen of *ilisha* in a slightly ventro-lateral view is given here (text-fig. 4).



TEXT-FIG. 4.—Head and trunk of a young specimen of *Hilsa ilisha* (Ham.) in slightly ventro-lateral view. ×3½.

According to Zittel, (*Text-book of Palaeontology*, II, 2nd Ed. p. 155, London: 1932) the species of *Clupea* are "Not certainly known below the Upper Eocene of Monte Bolca, near Verona." Fossils of the family Clupiedae are, however, known from the Cretaceous period.

Family: *DOROSOMIDAE.*

? **Dorosoma** sp.

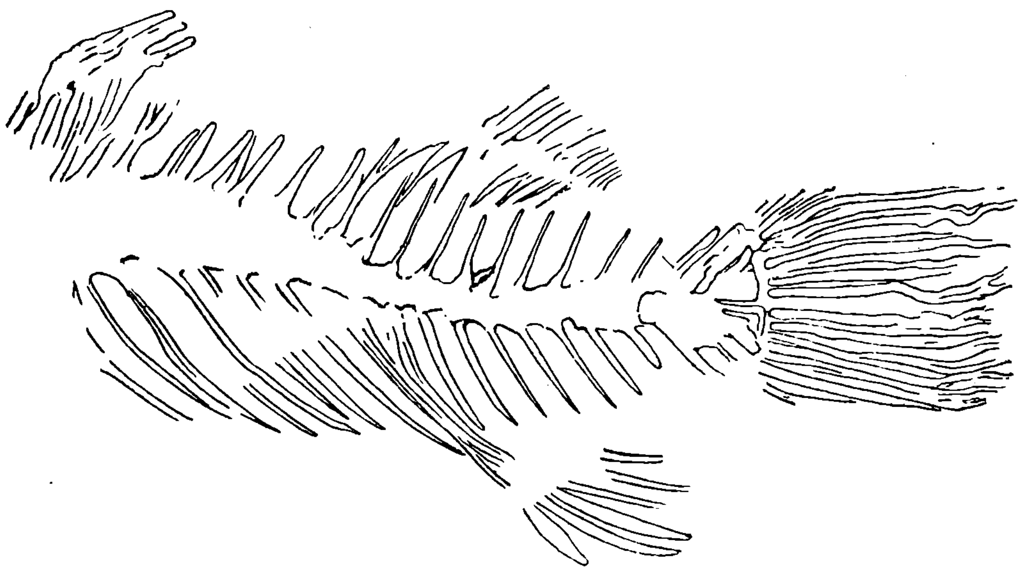
Specimen No. K40/527 and its counterpart specimen No. K25/528, (Plate XV, fig. 3).

This is a small fish about 40 mm. in length, without the caudal, preserved in lateral view. The bones are obscured by the skin which is preserved with scales. The structure of the scales cannot be made out. From the nature of the snout, which is obtuse and seems to overhang the mouth, I doubtfully assign this specimen to the genus *Dorosoma*. The fins, with the exception of the proximal part of the caudal fin, are not preserved.

Species of *Dorosoma* are mud-eating fishes of the coasts and estuaries and one species *D. manminna* (Ham.) is very common in the estuaries of the large rivers of India.

Order: PERCOMORPHI.

Specimen No. K28/240.—An imperfect specimen, without the head region, preserved in lateral view. (Plate XV, fig. 1, text-fig. 5.)



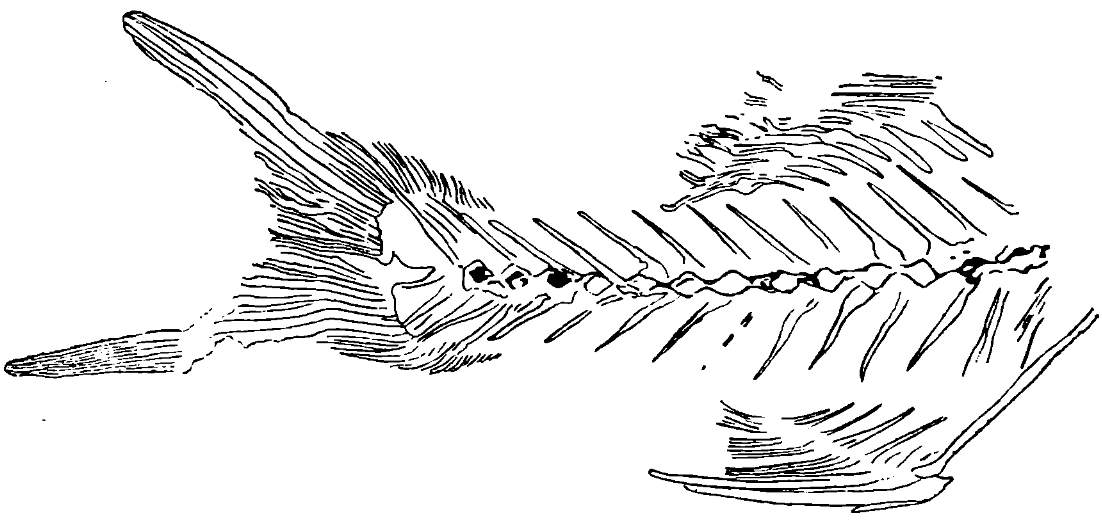
TEXT-FIG. 5.—Trunk and tail region of a Percoid fish (specimen No. K28/240). ×4⅔. Outline drawing made from an enlarged photograph of the specimen.

This is a small fish about 27 mm. in total length without the head. The body skeleton is well preserved; the middle portion of the dorsal fin is, however, missing.

The body is short and deep. The vertebral column is composed of about 24 vertebrae, of which 11 to 12 are caudal. The dorsal fin extends almost along the entire length of the back; only 4 to 5 spines of its anterior spinous portion and about half-a-dozen soft rays of the posterior region are preserved. The anal fin is situated below the posterior part of the dorsal fin and is composed of 3 strong spines and a few soft rays. The caudal fin is rounded and contains about 15 rays. The paired fins are not preserved; there are, however, faint indications of their stumps.

Affinities.—In its general facies and the nature of its dorsal and anal fins the specimen seems to belong to the Perciformes. The presence of one continuous dorsal fin with the anterior portion composed of spines, three anal spines continuous with the rest of the anal fin and the rounded caudal fin indicate that the fish may belong to the family Serranidae. Representatives of this family and other Perches are known from the Tertiary formations of Europe and America.

Specimen No. K28/205 and its counterpart specimen No. K28/249 Caudal region of a small fish preserved in lateral view. (Plate XV, fig. 2; text-fig. 6.)



TEXT-FIG. 6.—Caudal region of a Percomorph fish (Specimen No. K28/205). ×3⅘.
Outline drawing made from an enlarged photograph of the specimen.

In this imperfect specimen only the posterior portion of the dorsal fin, containing about 12 soft rays, is preserved. The anal fin is short and contains 3 spines and about 5 soft rays. The first spine is short while the second is probably the longest. The anal fin is situated below the posterior part of the dorsal fin. The caudal fin is deeply forked, with the two lobes pointed; it contains about 17 rays besides a few small ones at the sides.

Affinities.—From the very fragmentary nature of the specimen it is very difficult to assign it to any family. The nature of the anal and the caudal fins suggests that the fish may belong to the genus *Ambassis* Cuv. and Val., several species of which are found in the seas, brackish and fresh waters of the Indo-Pacific Region. Like its allied genus *Apogon* Lacép., *Ambassis* is probably not older than the Tertiary period of the earth's history.

EXPLANATION OF PLATE 15.

FIG. 1.—Trunk and tail region of a Percoid fish (Specimen No. K28/240). ×3.
FIG. 2.—Caudal region of a Percomorph fish (Specimen No. K28/205). ×3.
FIG. 3.—A Clupeoid fish, probably belonging to the genus *Dorosoma* Rafinesque. (Specimen No. K25/527). ×1½.
FIG. 4.—*Clupea geei*, sp. nov. (Specimen G. S. I. Type No. 16359). ×4½.
FIG. 5.—*Clupea geei*, sp. nov. (Specimen G. S. I. Type No. 16361). ×3.
FIG. 6.—*Clupea geei*, sp. nov. (Specimen G. S. I. Type No. 16360). ×3.

FOSSIL PLANTS FROM THE PO SERIES OF SPITI (N. W. HIMALAYAS). BY PROFESSOR W. GOTHAN, *Geologische Landesanstalt, Berlin* AND PROFESSOR B. SAHNI, Sc.D., F.R.S., *University of Lucknow.* (With Plates 16 to 18.)

CONTENTS.

I.—INTRODUCTION.

The small fossil flora described in the following pages was collected over thirty years ago by the late Sir Henry Hayden (1904, pp. 44-47; see also Burrard and Hayden, 1908, p. 233) of the Geological Survey of India. The plant-bearing beds were seen exposed near the village of Thabo (32° 5′ : 78° 27′) on the Spiti river, a large tributary of the upper Sutlej. Apart from provisional identifications by Zeiller (in Hayden, 1904, p. 47),[1] who compared the flora with species from the Culm of Europe and Australia, the fossils have received very little attention. The localities are in an unfrequented region of the interior Himalayas, and Hayden states that the plant-bearing beds on the bank of the river are frequently under water during summer floods. Our knowledge of the flora is thus still confined to the few specimens collected by Hayden.

Geographically this Himalayan outpost of the so-called *Rhacopteris* flora is important because, so far as we know, no trace of it had previously been found between Europe on one side and

[1] Zeiller's labels are still attached to the specimens. His handwriting is easily recognised. Zeiller in the provisional investigations generally was quite right and so was he in the indication of the geological horizon.

Eastern Australia on the other. Stratigraphically, too, the fossils are of some considerable interest. Although the Po series as a whole is now generally regarded by geologists as Middle Carboniferous (Middlemiss, 1910, p. 233; Hayden, 1910, p. 261; Wadia, 1926, pp. 86, 100, 347)[1], the evidence of the plant-remains from the Thabo stage, representing the lower of the two fossiliferous horizons, clearly shows that at least this part of the series must be of Lower Carboniferous age.

We wish to express our thanks to the Director of the Geological Survey of India for permission to describe the fossils and to discuss their stratigraphical bearings.

II.—DESCRIPTION.

1. Fossil from the Fenestella-shales (?)

RHACOPTERIS OVATA (McCoy) Walkom=RH. INÆQUILATERA Feistmantel (*non* Gœppert).

(Pl. 16, figs. 1, 2.)

"From a bed with marine fossils (Fenestella-shales), ½ mile NNE of Po, Spiti." This is one of the best preserved specimens in the collection and it is important, because it was found associated with marine organic remains which are referred to *Orthoceras*.

It is said to come from the Fenestella shales. These shales are regarded by the Geological Survey of India as Middle Carboniferous, that means about Upper Namurian or Lower Westfalian in the sense of the Heerlen nomenclature, though Burrard and Hayden (1908, p. 232) had at first classed them as Upper Carboniferous, that means about Stefanian. The specimen is quite clearly a real *Rhacopteris* of the same kind as the European ones of the Visé of different localities, *e.g.* Rothwaltersdorf in Lower Silesia. Unfortunately the pebble with the fossil was not picked up from the outcrop of the shales themselves, but was found as a rolled pebble. This is the only specimen attributed to the Fenestella shales; all the others containing that species come from the Lower Thabo stage of the Po

[1] One of us (Sahni, 1922, p. clviii; 1926, p. 238) had, rather uncritically, accepted for the whole of the Po Series the correlation with the Middle Carboniferous based upon geological considerations advanced by Hayden and Middlemiss.

series. At any rate the pebble cannot have come from a deeper horizon than the Thabo stage. Hayden states that some of the beds are exposed near the water's edge on the bank of the Spiti River and it is possible that it has been rolled out of the Fenestella shales. It is also possible that it was derived from the Thabo stage exposed, too, at the river; but from the nature of the rock this is not very probable, the matrix of the Thabo specimens being different. If the fossil comes from the Fenestella shales they must be classified as Lower Carboniferous too, like the Thabo stage. But it must be borne in mind that the specimen is the only one assigned to the Fenestella shales with the marine fossils and some caution is necessary. To be on the safe side we will not pronounce an opinion about the age of the Fenestella shales.

It is obvious that the species of this pebble plant is the same as the *Rhacopteris* from the Thabo stage to be discussed below.

2. Fossils from the Thabo stage.

The preservation of the other fossils, coming with certainty from the Thabo stage, is not so good, mostly in consequence of the compression and high diagenesis of the slate. Notwithstanding this the form of the pinnules as well as the venation is in places clearly seen even with the lens.

SPHENOPTERIDIUM ? FURCILLATUM, Ludwig sp.

(Pl. 18, figs. 1, 2.)

The specimen determined already by Zeiller as such is rather clearly shown in Fig. 10 (x2). Besides *Sph. furcillatum* there is also a certain similarity with *Sph. dissectum* Goeppert sp., a well known and frequent representative of the Lower Carboniferous flora in Europe, especially of Silesia, Saxony, France, *etc.* We believe that the determination given already by Zeiller is as correct as possible since the slight division and differentiation of the pinnules is more in favour of the former species. The types of Ludwig and many specimens of the other species are preserved in the Geological Survey of Prussia, Berlin, and have been compared carefully again for determination. Because of the incompleteness of the specimen we give a mark of interrogation.

SPHENOPTERIS sp. (RHODEA sp.).

(Pl. 18, fig. 3.)

This is a specimen identified by Zeiller as *Sphenopteridium* cf. *rigidum* Ludwig sp. This determination is certainly not right. *Sphenopteridium rigidum* is closely allied or identical with *Sph. schimperi* Goeppert as emphasised, *e.g.*, by Oberste-Brink (1914) and that is a quite different species. This specimen is reproduced in twice natural size and is only a fragment, the pinnules of which show a strong midrib and rather broad lamina in comparison with *Sph. schimperi*. It looks somewhat like a *Palmatopteris* too, but because of its scarcity it is better to avoid a final determination. It is also of the so-called "Rhodea" type of certain finely lobed *Sphenopteris*.

Some of the other plant-remains (? partly roots) are too poor for a real determination and we leave those aside, the more because they are of no value for stratigraphical purposes.

RHACOPTERIS OVATA (McCoy) Walkom.

(Pl. I, figs. 3-4; Pl. 17, figs. 1-4.)

Otopteris ovata McCoy Ann. Mag. Nat. Hist., 20, 1847, p. 148, pl. 9, fig. 2.

Rhacopteris cf. *inæquilatera* O. Feistmantel Palæontographica, Suppl. 3, 1876, S. 74, Taf. 2, fig. 3, 3*a*; Taf. 3; Taf. 4, fig. 1, 2.

Aneimites ovata Arber Quart. Journ. Geol. Soc. London, 58, p. 21, 1902. Dun, Rec. Geol. Surv. N. S. Wales, 8, 1905, p. 159, pl. 22, fig. 3; pl. 23.

Rhacopteris ovata (McCoy) Walkom, Proc. Linn. Soc. N. S. Wales, 59, 1934, p. 431.

Archæopteris cf. *archetypus* Schmalhausen bei Gothan in Engler Bot. Jahrb. 52, 3, 1915, S. 228.

The most important and most frequent species is the above named. Because of the squeezing and high diagenesis of the matrix most of the specimens are badly preserved. The contrast between the matrix and the plant—hardly any coal is preserved—is not great; notwithstanding this some specimens are better and it is from those that the photographs have been taken.

Before entering upon the determination it should be emphasized that the Indian specimens and the Australian to be mentioned below are obviously the same species, so that the determination of the Australian forms embraces that of our Indian specimens. The determination of the species has been discussed by several authors. It is known that Feistmantel compared it with *Rhacopteris inæquilatera* Goepp., and many of the later authors did the same. But some authors (Arber, 1902 ; Dun, 1905) found it different from the European genus " *Rhacopteris* " and taking the old specific name of McCoy they removed it from *Rhacopteris*, adopting instead the little used name *Aneimites* Dawson. Gothan (1915, p. 228) had the idea that the Australian specimens represented a compound leaf and would bring it together with an *Archæopteris* cf. *archetypus* Schmalhausen (best figures in Nathorst, 1904, pl. I, 2-4 ; II, 5). Gothan saw, in 1912, during a tour of some museums of Western Europe, samples of our Australian forms in the Botany School, Cambridge and noted in his daybook : " *Rhacopteris inæquilatera* Feistmantel—Australia no *Rh. inæquilatera.*" In 1931 he saw some more specimens in the collection of the Manchester Museum and after all, seeing no trace of composition of bigger fronds, he believed that as in *Rhacopteris* the whole frond is composed of only a series of pinnules as in *Cardiopteris* ; in consequence the idea of the reference to *Archæopteris* must be given up, but that to " *Aneimites* " too, the more so because this is a badly defined form-genus. If the determination as *Archæopteris* had been right the age of the *Rhacopteris* beds in Australia (Kuttung series) would be more probably upper Devonian than Carboniferous. That is really not probable, since the other plants occurring together with our species are clearly not Devonian, *e.g.*, the *Rhacopteris* cf. *transitionis* Stur (=*Rhacopteris intermedia* O. Feistmantel, 1876, Taf. 2, fig. 2 and the similar specimens figured under different names by Australian authors : *e.g.* ?*Sphenopteridum cuneatum* Walkom, 1934, pl. 18, fig. 2 ; *Rhacopteris meridionalis=intermedia* Dun. 1905, pl. 22, figs. 1, 2 and represented too in the Manchester collection). For the *Rhacopteris* of the old Lower Carboniferous form it is well known that they have nearly all pinnules of asymmetrical shape (" *inæquilatera* " Goeppert, " *Anisopteris* " Oberste-Brink). Though sometimes the Australian and the Indian specimens have a somewhat asymmetrical form, this as a rule is only slightly pronounced.

Among the species published from the Teilia Quarry (North Wales) by Walton is one named *Rhacopteris circularis*, which with its round circular pinnules is somewhat exceptional as a "*Rhacopteris*" in the enlarged sense of Schimper. A certain asymmetry is seen, but the circular form of the pinnules and their more or less typically radiating nerves diminish the impression of the "unequalness" of the pinnules. Walton has given an indication (1926, p. 208, footnote) that the specimen of Feistmantel (1890, pl. 4, fig. 1) should be brought together with his *Rhacopteris circularis*. Then we must do the same with the abundant specimens of the so-called *Rhacopteris inæquilatera etc.* from Australia. Indeed there is a good similarity between the two species, but we must say that the shape of the *Rhacopteris* from Australia etc. is not so well rounded as of the *Rhacopteris circularis*, so that specific identity cannot be accepted, the lateral margins of the pinnules being much more straight. It is certainly better to retain the old name *Rhacopteris ovata* of McCoy. On the other hand the occurrence of such forms as *Rhacopteris circularis*, which cannot be well separated from *Rhacopteris* as a whole, gives us the possibility of retaining the Australian and Indian Lower Carboniferous forms also in *Rhacopteris*.

From the characters first spoken of here, it seems rather clear that an identity with *Rhacopteris inæquilatera* Goepp. cannot be proved[1] because the species is a distinctly asymmetrical *Rhacopteris* ("*inæquilatera*"). That identity has been denied, *e.g.*, also by Walkom (1934, pp. 431-432); certainly he was right in doing so.

We must repeat here what has been noted by Gothan in Cambridge some 25 years ago (1912), that already then he rejected the idea of the identity of the two species. After all the species should be named: *Rhacopteris ovata* (McCoy) Walkom. It is true that the correctness of our determination should be definitely proved by finding a fertile *Rhacopteris*, which unfortunately is very rare and only till now found in two cases described by Stur and Walton, with the characteristic forked apex with a lot of sporangia on it.

It may be emphasized again that what is right for the Australian specimens is surely the same for our Indian ones figured on plates I and II. The Australian specimens are better preserved and therefore we started with the determination of those.

[1] If really the Australian *Rhacopteris* were the same species as *Rhacop. inæquilatera* Goepp., this name must be rejected, because the date of McCoy's species is as old as 1847.

III.—GEOLOGICAL AGE OF THE PO SERIES.

The Po Series (named after the village of Po in Spiti, 32° 3′ : 78° 23′) comprises some 2,000 feet of shales and quartzites forming the upper part of the Kanawar system (Hayden, 1904, p. 44; Burrard and Hayden, 1908, p. 233; Burrard and Heron, 1934, pp. 278, 302; Wadia, 1926, p. 100; Fox, 1931, p. 193). The series is divisible into two parts. The lower part consists mostly of dark-coloured shales which have been much altered by igneous intrusions, but locally the shales are unaltered and have yielded fragmentary leaf impressions. It was from this plant-bearing horizon, known as the Thabo stage, that Hayden collected nearly all the fossils described above.

The upper part of the series is called the **Fenestella** shales; it contains a rich marine fauna in which polyzoa and brachiopods preponderate. Among the marine animals a solitary specimen of *Rhacopteris ovata* (pl. I, figs. 1, 2) was also found, but as this is contained in a rolled pebble it is not possible to say whether it is of local origin or derived from the older (Thabo) horizon.

If we leave this rolled pebble out of consideration as being unreliable for stratigraphical purposes, we are left with two clearly marked fossiliferous horizons, a lower (Thabo stage) with plants, and an upper (Fenestella shales) with marine animals. It is important to note that in discussing the age of the Po Series as a whole geologists generally have paid no heed to the evidence of the plants which, as already stated, Zeiller had compared with species from the Culm (Lower Carboniferous) of Australia and Germany. The main purpose of this article is to discuss this palæobotanical evidence, but before we come to that it may be useful to state briefly the position as regards the Fenestella shales, which overlie the plant-beds.

(a) The age of the Fenestella shales.

The Fenestella shales have been at different times classed as Lower, Middle and Upper Carboniferous. In 1908 Hayden (in Burrard and Hayden, p. 233) regarded them as Upper Carboniferous but soon afterwards Middlemiss (1910, pp. 222-232) pointed out that the Fenestella shales of Spiti showed an exact parallel with the *Fenestella*-bearing series in the Lidar valley in Kashmir, which on several grounds was correlated with the Middle Carboniferous of Europe. Hayden (1910) agreed with this view, which is the one now generally accepted (Wadia, 1926, p. 100; Burrard and Heron, 1934, p. 302; Fox, 1931, p. 193). It should be remembered, however, that according to Diener (1915) the fauna of the Fenestella shales has a highly individual character, with many forms which are confined to these beds, so that they cannot at present be referred to any known Carboniferous horizon (Wadia 1926, p. 357). Fox (1931, p. 193) writes "The *Fenestella* series (shales) of the Lidar valley are found between the *Syringothyris* limestone (Lower Carboniferous) and the Panjal Agglomeratic Slate and Panjal traps. If the Agglomeratic Slate is the equivalent of the Salt Range glacial boulder bed, it is evident that the Thabo plant beds of the Po area are older than Middle Carboniferous and may be Culm in age".

(b) The age of the Thabo plant-beds.

The most important species of the Thabo stage are *Rhacopteris ovata* (McCoy) and *Sphenopteridium* cf. *furcillatum*. For a determination of the age of the series it is of no importance whether the latter specimen belongs to *Sph. furcillatum* or to *Sph. dissectum*; the significance as to the age, *i.e.* Lower Carboniferous, would be the same. The other more frequent species, *Rhacopteris ovata*, points to the same opinion and the *Rhacopteris* cf. *transitionis* of the Australian deposits too. If found anywhere in the world—America, Europe, Australia—no palæobotanist would hesitate a moment in identifying these strata as Lower Carboniferous characterized by true and clear "Archæopterids" in the sense of Gothan (Lehrbuch 1921) exposing the association *Cardiopteris-Rhacopteris-Sphenopteridium*. A younger age as well as an older one is to be excluded from discussion. So, too, a Middle Carboniferous age (Westfalian-Upper Namurian in the sense of Heerlen) cannot be accepted at all. Zeiller was quite right in his opinion on the age. Unfortunately the confidence of many geologists in fossil plants as indices of geological age is not great. But plants are worthy of consideration as well as the marine animals, though the horizons embraced by them may be bigger or more extended than in the case of marine fossils. So we may not be enabled to give indications about the more exact age within the Lower Carboniferous. In Europe they would be assigned most probably to the Visé formation (upper part of the Lower Carboniferous). On the other hand we see by our Indian fossils that in the Lower Carboniferous the character of the flora all over the earth was nearly the same and well recognisable, even if the species of the different regions are not exactly the same. The recognition of the Lower Carboniferous age in our case is much easier than it was in the determination of the age of the Chinese Lower Carboniferous plants (Gothan and Sze, 1933).

The fact that the *Rhacopteris* in Europe are not so frequent as they are in Australia and in the Thabo shales—*Rhacopteris* in Europe being an additional and rarer genus than *Cardiopteris* and *Sphenopteridium*—is certainly due to a local peculiarity of these Gondwana regions. The character of the flora as Lower Carboniferous is clearly proved in both regions.

IV.—SUMMARY AND CONCLUSIONS.

A small collection of fossil plants from the lower part (Thabo stage) of the Po Series in Spiti is described, and the bearings of the flora on the geological age of the beds are discussed. While a fuller knowledge of the flora is desirable, the evidence at present available points as distinctly as possible to a Lower Carboniferous age for the Thabo beds. If the overlying Fenestella shales are of Middle Carboniferous age, the Po Series should be regarded as covering the period from Lower to Middle Carboniferous.

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VI.—EXPLANATION OF PLATES.

The photographs are all from untouched negatives. The original specimens are preserved at the Geologial Survey of India, Calcutta.

PLATE 16, FIGS. 1, 2.—*Rhacopteris ovata* McCoy Walkom (=*Rh. inæquilatera* Fstm. non Goepp.). From a bed with marine fossils (Fenestella shales), ½ mile N. N. E. of Po, Spiti. Fig. 1, nat. size; Fig. 2 × 2. K3/294. (Page 196).

FIGS. 3, 4.—*Rhacopteris ovata* McCoy Walkom (=*Rh. inæquilatera* Fstm. non Goepp.). Thabo stage, 1¼ miles S. W. of Thabo, Spiti. Fig. 3 nat. size; Fig. 4 × 2. K3/293. (Page 198).

PLATE 17, FIGS. 1, 2.—*Rhacopteris ovata* McCoy Walkom (=*Rh. inæquilatera* Fstm. non Goepp.). Locality and horizon as above. Fig. 1 nat. size; Fig. 2 × 2. K3/293. (Page 198).

FIGS. 3, 4.—*Rhacopteris ovata* McCoy Walkom (=*Rh. inæquilatera* Fstm. non Goepp.). Locality and horizon as above. Fig. 3 nat. size; Fig. 4 × 2. K3/293. (Page 198).

PLATE 18, FIGS. 1, 2.—*Sphenopteridium ? furcillatum* Ludwig sp. Locality and horizon as above. Fig. 1 nat. size; Fig. 2 × 2. K/293. (Page 197).

FIG. 3.—*Sphenopteris* sp. Locality and horizon as above. × 2. K3/293. (Page 198).

POLISHED AND THIN SECTION TECHNIQUE IN THE LABORATORY OF THE GEOLOGICAL SURVEY OF INDIA. BY J. A. DUNN, D.Sc., D.I.C., F.G.S., M.M.G.I., F.N.I., *Petrologist, Geological Survey of India.* (With Plates 19 and 20.)

CONTENTS.

I.—INTRODUCTION.

All thin rock sections for Geological Survey of India officers were made by hand until recently. The four section-cutters, who each averaged four sections per day, acquired such skill that there was little incentive to modernise the method, especially as some of these men accompanied officers of the Survey during the touring season and made sections in camp, thus permitting petrological work to be done on the spot. Lately there has been a large increase in the number of sections required during those months of the year when officers are at headquarters, and, as this is also the period when section-cutters proceed on leave, it became increasingly difficult to keep up with the demand for thin sections. Much time had also been taken up recently in making polished sections. It was, therefore, decided to mechanise the methods.

Since the introduction in recent years of the study of ore minerals by reflected light, polished sections at the Geological Survey have been made on cloth laps. With the change in the method of making thin sections it was decided at the same time to introduce the Graton-Vanderwilt method of polishing on lead laps. Machines for both thin and polished sections, as well as for other purposes, were all constructed as parts of the one scheme.

The apparatus has been designed in collaboration with Mr. A. Lacamp of the Mathematical Instrument Office of the Survey of India, where the machines were made. To Mr. Lacamp must be given the credit for the ultimate results which, after a few minor initial difficulties, have proved eminently satisfactory.

Briefly, the section-cutting machinery is erected on two well braced steel frame tables (Plate 19, fig. 1), each 6 feet long and 2 feet 6 inches wide. On one table, arranged from right to left, are: (*a*) polishing machine, (*b*) cloth lap, and (*c*) fine grinding disc for thin sections. On the other table, in line with and to the left of the first, and again arranged from right to left, are: (*a*) coarse grinding disc, (*b*) emery wheels, and (*c*) sample grinder; there is space on this table for other small apparatus. Further to the left is a rock-cutting machine, using an armature-steel disc mounted with diamond dust —this machine is a remodelled rock-cutting machine, using carborundum powder, which had been almost completely worn out but was given a fresh lease of life with new bearings, shafting, pulleys, etc. A $2\frac{1}{2}$ H. P. motor, previously available, supplies the power, driving all the above machines from the one main shaft. The design of the bearing brackets for the main shaft, seen on Plate 19, fig. 1, was necessitated by exigencies of space.

Each disc is driven off a countershaft with loose and fixed pulleys. The vertical spindles of the discs have ball-bearings below, with an adjustment for taking up wear; the top conical bearings are of gun metal. To prevent 'grabbing', the disc for fine grinding has concentric grooves cut in its surface eccentrically to the disc centre and spaced half an inch apart; this is unnecessary on the coarse disc. Both discs are $9\frac{1}{2}''$ in diameter. The polishing machine will be described later.

II.—THIN SECTION TECHNIQUE.

For the most part thin sections are made in the laboratory according to the usual procedure. The rock fragment is ground on one side to a smooth surface, then fixed with Canada balsam to the glass slide. To make handling easier during grinding, the slide is fixed with paraffin wax to a small square of thick glass, and ground down first on the coarse, then on the fine grinding disc. When necessary they are finished by hand on a glass plate. Covers are fixed with liquid balsam and the usual labels attached. The rate at which sections can be made by each section cutter is now at least three times that of the old speed. In addition the amount of carborundum used has shown a reduction.

For delicate work, such as rocks which break up readily, the fragments are usually heated in balsam for some time, until the pores are filled, before grinding. Recently, in special cases, bakelite resinoid has been used. This material, labelled R-0014, sold by Messrs. Bakelite Limited, Tyseley, Birmingham 11, England, is of the consistency of thin treacle and is further thinned by alcohol in the proportion of 1 : 1. Acetone or other similar solvents of the phenol formaldehyde (bakelite), may be used, but I prefer alcohol. Nine specimens at a time are treated; each fragment is placed in a small cube-shaped tin with $1\frac{1}{2}''$ sides and the bakelite-alcohol solution poured over it. The fragment is soaked in the solution, if necessary under vacuum, for one hour (the vacuum must be applied slowly, otherwise the solution froths over), then placed in a constant temperature oven at 70-80°C. for 6-8 hours, until the consistency of the liquid is so thick that it drips very slowly. The specimen is then taken out, laid on a tin plate and returned to the oven at 70-80°C. overnight (about 16 hours), when the bakelite acquires a hardness rather greater than that of hard rubber and all the solvent has been driven off, but polymerisation is still incomplete. The temperature is now raised to 100°C. for 8 hours and the bakelite becomes extremely hard. These times vary with the age of the bakelite-resinoid, as also does the ultimate hardness of the bakelite. The curing should never be hastened by too rapid heating, as bubbles may form and the bakelite becomes brittle, whilst the mineral particles are not held so strongly. If, after subsequent grinding of one side of the fragment, all the pore spaces are not quite filled, the process may be repeated. However, so long as the pore spaces are well lined with a wall of bakelite this is usually sufficient. I have made excellent sections of kaolin by this method, using, of course, kerosene as lubricant during grinding. Sections of kaolinised granites from Mawchi, Burma, which could not be made by the older methods, were quite successfully made with bakelite.

Sections of sands or powdered rock may also be made by means of bakelite, using the liquid variety known as bakelite-cement, G-5280, a thick treacly liquid. An old section-glass with matte surface is broken in half, the sand or rock powder poured on as a thin layer, then gently covered with bakelite. The heat treatment is the same as before, but the first stage, at 70°C., is rather shorter.

The resulting layer of sand and bakelite on glass is then rubbed down to a smooth surface and fixed in the usual way with balsam to the microscope slide. The piece of glass is now uppermost and is ground away; the bakelite and sand is then reduced to the usual section thickness. The tendency is for the bakelite to shrink slightly and the strain set up at the surface between the grain and bakelite grips the grain tightly. Under the microscope this strain in the bakelite at the interface can be clearly noticed as a thin birefringent film, whilst the rest of the bakelite is isotropic. The resulting section is equal to any normal rock section, but one must become familiar with the colour of the bakelite.

The above technique of the treatment of bakelite is similar to that used by Mr. Paul Bird of Columbia University, to whom I am indebted for demonstrating his method to me. I have also to thank Mr. G. H. Tipper, Mineral Adviser to the High Commissioner for India, for obtaining much information on the application and properties of bakelite.

III.—POLISHED SECTION TECHNIQUE.

The preparation of polished sections is performed in two stages: (*a*) mounting the specimens in bakelite, (*b*) grinding and polishing.

Mounting in bakelite.

In the past a fragment of the specimen has been chipped off and ground down with carborundum and water to a suitable size, about $\frac{3}{4}''$-$1''$ diameter and $\frac{1}{8}''$ thick. As it is probable that coarse grinding with carborundum causes considerable sub-surface shattering, requiring long polishing to remove the shattered surface layer especially where hard minerals, like quartz, are also present, the surface to be polished will, in future, as far as possible, be cut by means of the diamond disc.

Sometimes specimens are very friable, and fragments of tin ores in particular have to be soaked in bakelite before any grinding is done. But even where the specimen is not friable, it is advisable in the majority of cases to soak the specimen in bakelite after the fragment has been ground to the required size. The method of impregnation and curing is precisely similar to that used for thin sections.

After curing is complete the surplus bakelite on the surface to be polished is carefully removed down to the merest film, and is finally removed with rewashed 200-minute carborundum using a zinc plate on which fine grooves, spaced $\frac{1}{4}''$ apart, are cut. The specimen is then ready for mounting.

The bakelite used for mounting is bakelite moulding powder of which several varieties were tried, a brown variety (×20) proving the most satisfactory. Other plastic materials, such as the cellulose acetate powders Cellomold and Rhodoid, should serve, although rather softer than bakelite. Owing to absorption of moisture by the fibre filling in the bakelite during the rains in India it is preferable to mount the specimens immediately before polishing. The bakelite is pressed around the specimen in a mould, a section across which is shown in fig. 1.

A is a hard steel cylinder carefully machined with a slight funnel taper in the internal diameter at the top, *i.e.*, the top is $\frac{1}{32}''$ more in diameter than it is $\frac{3}{4}''$ lower. There is also a taper at the bottom into which is fitted a steel plug, B, which has been machined to give a perfect contact. The cylinder is next screwed into a heavy steel base, C. The temperature of the whole mould is then raised to 160°C., checking it carefully with a thermometer placed inside the mould. The specimen, D, is then quickly dropped in, a measured amount of bakelite powder, E, poured over it, a shaped brass plug, F, placed on top (a small tapped hole in the top of this plug, into which a thin threaded rod loosely fits, permits quick and accurate insertion), and finally the plunger, G, inserted. The whole is quickly placed under a rock breaker, in lieu of a press, and the plunger screwed down to the utmost pressure that two men can apply—at least three tons. The cellulose acetate plastic powders require much less pressure and a lower temperature. The whole operation, from the moment the bakelite is dropped in, takes only a few seconds. The mould is then left for four minutes, the press opened, and the mould cooled in water.

The use of the brass plug F prevents the bakelite from squeezing up along the sides of the cylinder as brass has a higher co-efficient of expansion than steel. The one defect in the mould shown is that the base, C, should be thicker; B need not be so thick. A further improvement would be to wind the mould with an electric heating element so that the heat would be retained whilst the pressure is being applied. It would also be preferable to construct a special press of two steel plates connected by strong bolts and with a screw or hydraulic jack.

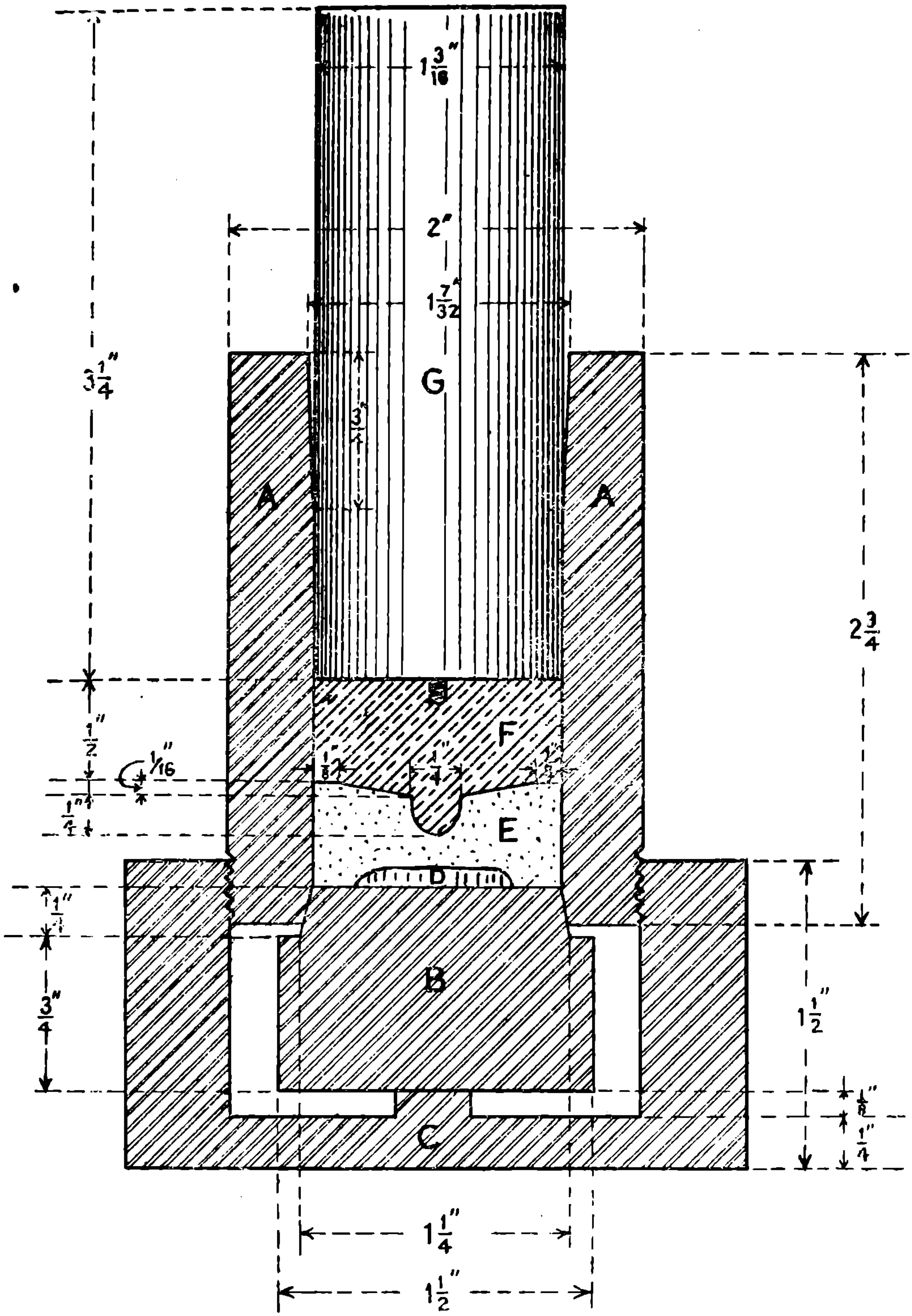

FIG. 1.—Mould for making bakelite mounts.

The resulting bakelite mount in which the specimen is set is a cylinder, shaped like a draught-piece, $1\frac{3}{16}''$ diameter and about $\frac{1}{2}''$ thick. On the reverse side of the specimen the greater part of the centre is concave and has a $\frac{1}{4}''$ diameter cup in the centre; the raised edge prevents the mount from rocking on the microscope stage later, and the concave surface gives a recess for the painting of registered numbers.

When small fragments of ore or fine concentrates are to be mounted, they are first placed in the bottom of a small flat-bottomed shallow porcelain dish, say $1\frac{1}{4}''$ diameter and $\frac{1}{4}''$ deep (the dish is first greased), and bakelite cement, G-5280, poured over them. The bakelite is cured in the usual way, as for rock sands, until it is extremely hard. The 'button' of bakelite and ore powder is removed from the dish simply by chipping off the solidified meniscus, when the 'button' falls away at once. This is then ground down to the requisite size and mounted as for ordinary specimens in the mould as described above.

A very few minerals are affected by the heat treatment necessary with the above method. In such cases a blank of plaster-of-paris may be prepared, slightly larger than the size of the specimen, and the mount made over it. The plaster is then dug out, the specimen inserted and held in place either by sealing wax, balsam, golaz, Spence metal (pyrites and sulphur) or some such low temperature alloy as Wood's metal (50 per cent. Bi, 25 per cent. Pb, 12·5 per cent. Sn and 12·5 per cent. Cd, with melting point 68°C.)—the latter material is used at Harvard University, but is susceptible to etch reagents. Recourse to this procedure is, fortunately, rarely necessary.

After removing surplus bakelite and bevelling the edge slightly with sandpaper the specimen is ready for the polishing machine.

IV.—THE POLISHING MACHINE.

Metallographers may be inclined to look upon this method of polishing as unnecessarily complicated. But the material which the petrologist is treating is vastly different from the alloys, in which the individual constituents have a fairly homogeneous hardness. In an ore specimen, extremely hard minerals may be in juxtaposition to soft minerals; the rates of polishing vary enormously, and, with cloth-polishing, relief between adjacent minerals may be so considerable that other minerals occurring along the interfaces may be completely obscured. Photographic difficulties at high magnification become pronounced. The method now described provides an almost perfect plane surface with a minimum of relief between hard and soft minerals. Manual attention is also reduced to a minimum during polishing.

Polishing with water as a lubricant on plates and on cloth is of the rolling grain type, *i.e.*, the polishing medium polishes by rolling along and abrading the surface. This results in soft minerals being gouged out more quickly than hard. By using soft laps, such as lead, the abrasive becomes fixed in the metal and polishes by finely cutting the minerals, and it is not possible for soft minerals to be worn away much below the adjacent hard minerals.

The principle of the method was worked out by J. W. Vanderwilt[1] and used first in the Graton-Vanderwilt machine at Harvard. During 1934-35 I had spent some time studying methods of polishing in Germany, Paris, the United States, Canada, and Australia. I concluded that the Vanderwilt method was undoubtedly the best method for polishing ore sections, and I examined machines of this type at Harvard, Toronto, the Mines Department Ore Dressing Laboratory at Ottawa, the Lake Shore Mine at Kirkland Lake in Northern Ontario, and at Melbourne University. Most of these machines are expensive, but the Lake Shore apparatus impressed me by its simplicity, particularly if it could be made more compact and rigid. On returning to Calcutta, and after discussion with Mr. Lacamp, we evolved the machine shown in text. fig. 2 and in Plate 19, fig. 2. This consists of a lap, 13″ diameter, revolving anti-clockwise at 170 r.p.m. Above it, on either side of the centre, and spaced 7″ apart, are two revolving heads also rotating anti-clockwise, but at 184 r.p.m. Through bushings close to the periphery of each of these heads pass three spindles which each press, with the aid of lead weights, on to a bakelite-mounted specimen resting on the lap, the lower ends of the spindles fitting into the cup in the back of the bakelite mount. In addition, each spindle passes through the centre of a brass weight which is fitted over the bakelite mount—the reason for this latter weight will be discussed later. As we were unable to afford the cost of patterns for castings, the greater part of the frame was fabricated from steel pipes and T-joints.

[1] J. W. Vanderwilt, "Improvements in the polishing of ores", *Econ. Geol.* 23, 292 (1928).

If lap and heads both move anti-clockwise and at the same revolutions per minute, the linear speed of any cutting particle with respect to the mount surface, assuming that the latter did not rotate on its spindle, would be the same over the whole surface of the lap from centre to outer edge. On this view the lap wear would be even. As it happens, the revolving lap exerts a turning moment on the

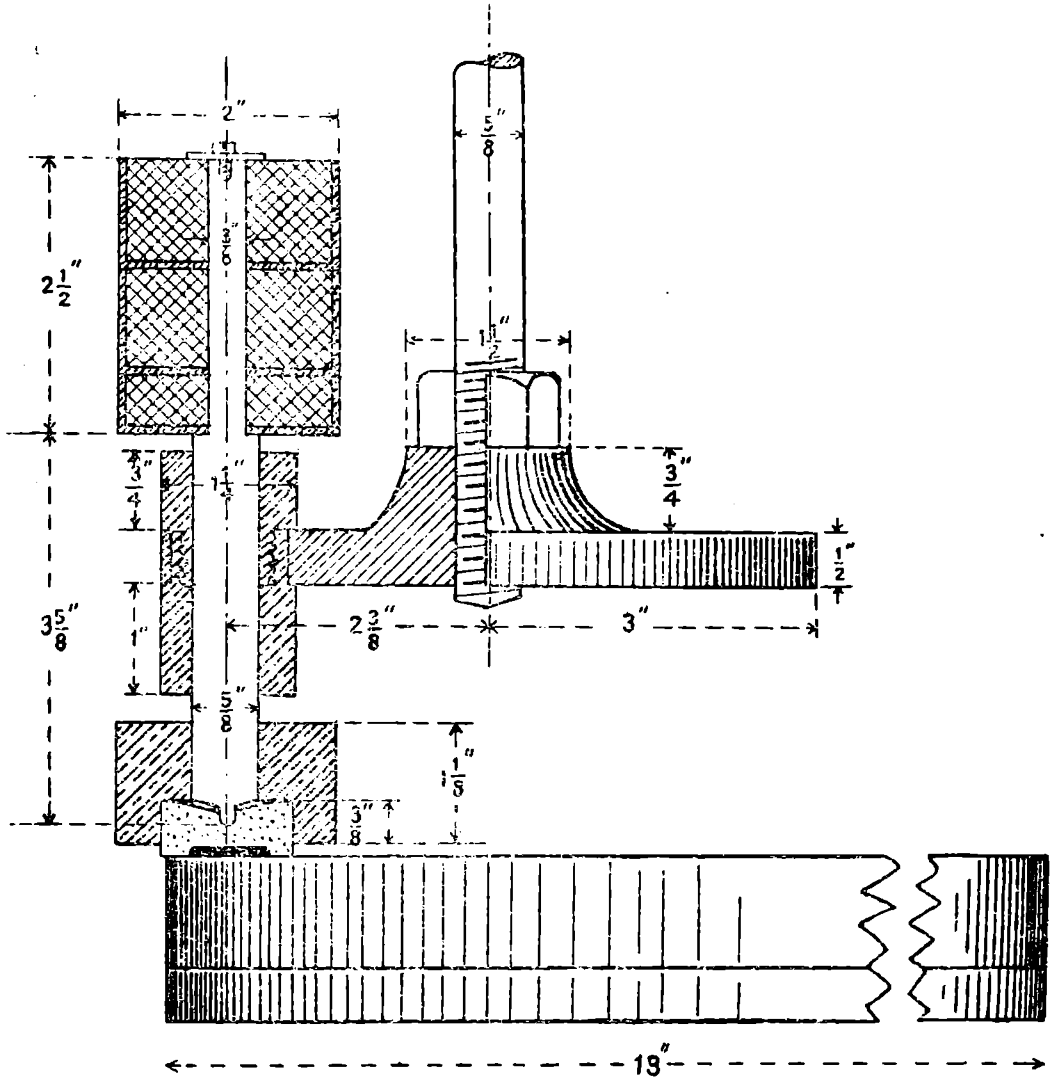

FIG. 2.—Section through weighted spindle and mounted specimen.

specimen mounts and rotates them anti-clockwise on their own axes, the spindles, hence the ultimate tendency is for the linear speed of any abrasive grain with respect to the mineral surface to be less at the outer edge of the lap than at the centre, and the lap will tend eventually to become dish-shaped. Allowance was made for this tendency by making the r.p.m. of the revolving heads slightly greater than the r.p.m. of the lap.

It will be seen that there are at least three various movements: the lead lap moving anti-clockwise under the specimen; the specimen moved by the revolving head also anti-clockwise (*i.e.*, in the same direction as the lap on the outer edge but at little more than half its linear speed, and in opposed directions towards the centre of the lap where the latter's linear speed is reduced to *nil*); and the rotation of the specimen itself around the spindle as a result of the anti-clockwise moment imparted by the lap. Any particular polishing grain has, therefore, a very complicated and always varying direction of movement relative to any point on the surface of the specimen. Polishing by this method is by reduction of microscopic scratches of constantly diminishing size and the above movements ensure that the scratches are ever varying in direction.

When installed the driving motor was rated at 600 r.p.m. but in actual fact its speed proved to be 720 r.p.m. The polishing machine was designed for rotation of the lap at 200 r.p.m., hence its actual speed became 240 r.p.m. and that of the heads 260 r.p.m. This proved too fast, and there was an apparent tendency for the specimens to roll around on their edge, as the machine was not at first designed with the lower brass weights into which the specimens and spindles are now fitted. The fact that the central driving spindle of each of the two revolving heads was not in perfect adjustment with respect to the lap but permitted a difference in height of about $\frac{1}{64}''$ between the revolving heads and the outer edge and centre of the lap, added to the tendency of the weights to lift. A smaller pulley on the counter shaft reduced the speed of the lap to 170 r.p.m. and the heads to 184 r.p.m.; in addition brass weights were fitted immediately over the specimens, still permitting the latter to revolve, however. This completely cured the trouble. Whereas originally the tendency had been for the specimens to polish from the outer edge inwards, they now polish from the centre outwards (the surface from coarse grinding is rarely perfectly flat)—a highly satisfactory result, indicating that the polished surface approaches a plane and not an obvious flat cone as before. This tendency to form a conical surface has been found in this method of polishing elsewhere and has been explained by the lap dishing as a result of slightly greater wear in the centre. Although dishing is undoubtedly a contributary cause, the main explanation is more probably that given above, *i.e.*, with high speed and centralised weighting of the specimen mount the latter tends to roll around on its edge rather than maintain perfect flat contact with the lap, particularly if the adjustment between lap surface and revolving heads is not perfect. The lower brass weight distributes additional weight around the edge of the specimen. It is also advisable after each change of lap during the three stages of polishing to insert the same mount under the same brass weight and spindle; each brass weight and spindle has its own idiosyncrasies which it is preferable to maintain throughout polishing.

It is obvious that with these weighted heads six specimens must be polished at a time in order to eliminate vibration; if a less number is required one head must be fully loaded with three specimens.

The polishing process is divided into three stages, a different lap being used for each stage: (*a*) a cast iron lap using abrasive of average size 8-10 microns and maximum size 15 microns; (*b*) a lead lap using abrasive of not more than an average size of 3-6 microns; (*c*) a lead lap using abrasive of maximum size 1 micron. In each case the lubricant consists of one part nujol to three parts kerosene, the proportion advised by Vanderwilt. I am doubtful whether the kerosene does any real work as a lubricant, as Vanderwilt believes, at any rate not in the tropics, for it evaporates within a few minutes of spreading it on the lap, leaving the nujol alone to do the work. Its value lies in thinning down the nujol, permitting the latter to spread with great rapidity on the lap surface, thus providing a remarkably thin and even film to hold the polishing powder. The abrasives are sized in the laboratory by a method to be described later, and are made up in tubes for use ready mixed with the lubricant. An amount which could be heaped on to the little fingernail is applied by means of soft tissue paper (toilet paper is ideal) and is sufficient for a full day's polishing.

Each lap is grooved concentrically to eliminate 'grabbing'. In the iron lap the grooves are $\frac{1}{16}''$ wide, $\frac{1}{16}''$ deep, with round bottoms to facilitate cleaning, and are spaced $\frac{1}{4}''$ apart. The grooves in the lead laps were also spaced evenly at first, but in spite of the higher r.p.m. of the heads to allow for the tendency to greater wear in the centre, slight dishing took place. To compensate this tendency the groove spacings were made wider in the centre than at the edge. The following are the radii of the grooves, starting from the centre hole which is $\frac{9}{16}''$ radius: $\frac{31}{32}''$, $1\frac{13}{32}''$, $1\frac{27}{32}''$, $2\frac{9}{32}''$, $2\frac{23}{32}''$, $3\frac{3}{32}''$, $3\frac{15}{32}''$, $3\frac{27}{32}''$, $4\frac{7}{32}''$, $4\frac{1}{2}''$, $4\frac{13}{16}''$, $5\frac{1}{8}''$, $5\frac{3}{8}''$, $5\frac{5}{8}''$, $5\frac{7}{8}''$, $6\frac{3}{32}''$, $6\frac{9}{32}''$, $6\frac{7}{16}''$ (edge of lap). At the centre of each lap there is a $1\frac{1}{8}''$ diameter hole $\frac{1}{2}''$ deep and the specimens project slightly over the edge of this depression as well as over the outer edge of the lap, thus permitting complete and even wear over the whole lap. The laps have to be refaced at long intervals, whenever necessary, as the grooves become worn down.

The first polish on the iron lap takes up to one hour. The type of polishing on this lap is partly due to rolling grains and partly to cutting. The lap should retain a reflecting surface from a minute or so after starting, with a suggestion of greasiness, and should give a slight greasy smear on the fingers when touched. With each fresh group of specimens the grooves should be brushed with a stiff brush and every few days they should be completely cleaned out with soap and water. The correct amount of oil on the surface is rapidly judged by experience; with too much oil the surface of the specimen becomes badly scratched. On the iron lap better results are obtained by using more oil than is used on the lead laps.

Hard minerals, such as pyrite, attain quite a good polish on the iron lap; softer minerals, such as galena, may be covered with scratches, whilst others, such as chalcopyrite and sphalerite, may be covered with minute pits giving a matte surface. It is useless prolonging the time with the hope of increasing the polish on minerals like chalcopyrite, for the pits cannot be removed on the iron lap. It should be remembered that, on the iron lap, we are polishing partly by rolling grains, a mechanically different process from the polishing by fixed grains on the lead lap. By using a rather dry surface hard minerals may be polished on this lap, but it should be remembered that harsh treatment will deeply pit and effect the subsurface of brittle minerals like pyrrohotite and cholcopyrite, particularly with the rise in temperature of a dry lap. It is safer to be content with a flat surface on the specimen, and with removal of deep scratches and pits.

It is a good idea, in many cases, to clean the lap and use a finer abrasive, of say 6-8 microns, after the first stage. Alternatively, I have found that rubbing for less than a minute on a zinc plate with 8-10 micron abrasive and water has an excellent effect in removing any remaining coarse scratches.

The specimen should now be carefully examined with a lens. If any minerals present show a tendency to come away along cleavages or intergrain surfaces, the specimen surface should be covered with a thin film of bakelite resinoid solution in alcohol. In applying this solution, drop the liquid on one spot, then let it spread over the surface, scrape off excess, then cure as before. After curing, the specimen should be polished on the iron lap for the briefest possible time just to remove the bakelite film; it is very important that this polishing stage should not be unduly prolonged, otherwise sub-surface shattering will go below the bakelite resinoid penetration and re-impregnation will be necessary.

In one day of six hours thirty specimens have been polished on the iron lap without making any particular effort to hasten the work.

The next stage is on the first lead lap, and the surface of this should be slightly less greasy than that of the iron lap, *i.e.*, just sufficiently greasy to leave a faint trace of oil on the fingers when touched. With too much oil the specimen surface becomes scratched, and relief between hard and soft minerals will appear; with too little, the lap surface is roughened as a result of grabbing and the specimen surface may also be damaged. The best procedure I find is to first smear the thinnest possible film of lubricant over the lap surface with the fingers, then apply the abrasive paste with toilet paper, evenly. This avoids excess oil. The amount of abrasive must be a minimum, no more than can be piled on the little finger-nail. During the first hour until the correct film of nujol is acquired, one or two inspections are advisable, but after that a smear of oil with the finger once an hour is about sufficient. The grooves should be brushed out occasionally and the surface wiped once a day. About once a fortnight the lap should be thoroughly cleaned with either soap and water or with fairly strong sodium hydroxide; a quick wipe with very dilute nitric acid (one part strong nitric in ten parts of water) will help to keep the surface in condition and remove excess abrasive. Above all, *perfect cleanliness* is essential. Atmospheric dust, particularly around grinding machinery, is coarser than the polishing powder used, and it is therefore imperative that the machine be covered. Once a coarser powder has been used on the lead lap it should be theoretically impracticable to use a finer abrasive without re-machining the surface of the lap, but I have found that a careful wipe with dilute nitric acid removes the coarse material sufficiently to give suitable results with the finer powder, providing that the difference in size is not considerable.

Once the machine is started the lead lap can be left alone for two to three hours, apart from adding an occasional smear of lubricant with the finger. The opportunity may be taken at this time to examine the progress of polishing. Some specimens may be completed and others may be added in their places, but usually six hours is necessary. The rate of polishing is, of course, that of the hardest mineral present; any relief from the iron lap must be eliminated on the lead lap before polishing of the softer minerals can be commenced. Frequent starting and stopping of the lap should be avoided, because it is at such times that most of the scratches appear on the specimen.

For many minerals the polishing is complete at this stage, but for easily scratched minerals, like galena, the final lead lap must be used with the finest possible abrasive of maximum grain size 1 micron. Scratches arise usually from fine specks of mineral or bakelite breaking away.

As abrasives I have used both emery and carborundum on the cast-iron and first lead lap with satisfaction. On the final lead lap I much prefer tin oxide whenever possible, as it polishes most minerals so readily, but I find that tin oxide is quite useless on certain iron oxides as it pits them badly, even destroying any polish that they might previously have acquired. The reason for this is obscure; it may be due to some combined chemical and percussive action under pressure. When it is noticed that a mineral is not steadily improving in polish another powder should be used. In the case of the iron ores I find that either emery or " Shamva metallographic powder " is suitable—the latter is somewhat coarse, but fortunately the hardness of the iron oxides does not necessitate the finest powders.

Between each stage the specimen should be cleaned with cotton wool. Finally it should be cleaned with xylol, but should not be touched with the fingers.

Certain minerals, such as pyrrhotite and sphalerite, are very difficult to polish because, being brittle, pitting is severe in the early stages. Indeed, a satisfactory surface can rarely be obtained with pyrrhotite. With galena, it is often difficult to remove the final scratches, but a few seconds on a cloth lap will complete the polish without materially affecting the relief.

For storage the sections are placed in shallow drawers (one inch deep) on the bottoms of which green baize is spread; the polished surface is faced downwards to minimise tarnish and the registered numbers are uppermost. The numbers are painted on the mounts immediately after they are moulded.

A few words as to difficulties. There were the usual troubles attendant on first starting up new shafting, pulleys and belts, but all were eliminated in a week or so. The polishing machine pulleys and belts gave the most trouble because of the great weight of the lap, but its idiosyncrasies were soon understood and corrected. After a few days the specimens acquired a spasm of 'grabbing' on the lead lap and throwing off, damaging the surface of the lap. One possible cause after another was eliminated until it was found that the revolving heads had moved out of adjustment. They were in as nearly perfect adjustment as possible when first started, and I have been unable to understand even now how the adjustment had altered; the new adjustment required new holes to be drilled and tapped in the frame to take new holding screws. This trouble also forced me to examine minutely the action of the specimens, spindles and weights during rotation, leading to the discovery that the specimens tended to roll on their edge. The addition of brass weights fitting over the bakelite mounts completely eliminated this. If designing another of these machines I would have the weighted spindles inclined a minute fraction outwards at the lower end so that the weights would tend to be forced down rather than up during rotation. Better still, the weights could be replaced by strong springs.

A contributory cause of lifting of the weights was that the recess in the back of the specimen mounts, as first made, was V-shaped, as in fig. 3(*a*); this shape permitted the spindle ends to ride up on the side of the recess. Mounts with a vertical sided cup were later used as in fig. 3(*b*), and mounts already made were drilled. In this

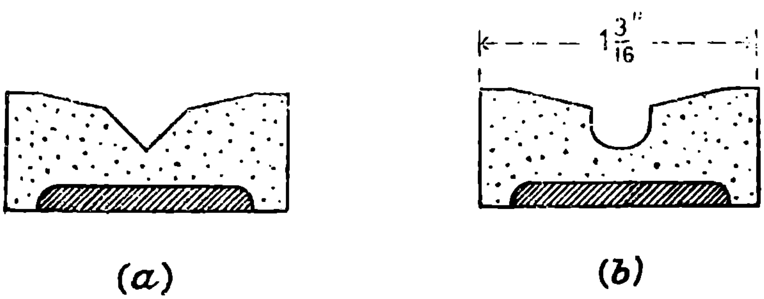

FIG. 3.—Section through mounts.

respect others may find it useful to know that carbon tetrachloride is an excellent lubricant for drilling bakelite.[1]

A further improvement would be in the laps themselves. As designed, each of these is cast on to an iron base or turntable, which is screwed to the vertical spindle. It would be preferable, and cheaper, to have the one turntable, on which can be laid different plates or laps—one of cast iron and two of lead—adjusted for horizontality from below by three set-screws passing through the turntable.

V.—SIZING THE ABRASIVES.

Apart from as perfect a machine finish as possible on the laps, the most important item is the use of well sorted abrasives. The best and finest of the usual commercial abrasives are badly sized; for example, in 200 minute carborundum, the average size was 12-15 microns, a considerable proportion extended down to 1 micron, whilst a number of occasional grains were even as large as 60 microns. At any stage in polishing most grains below the average are doing no work, whilst larger grains are undoing all the polishing by deeply scratching the surface. It was quite impossible to use the commercial powders as sold. Magnesia can be used as bought, for the grain size is ·75-1 micron, but this is only suitable for the final stage for soft minerals, and would require an impossible time for polishing hard minerals. The same may be said of Tonerde.

An apparatus was fitted up exactly on the lines of that used by J. W. Vanderwilt,[2] see Plate 20, fig. 1; starting from the reservoir (1) on the left, the suspended abrasive passes through a continuous siphon consisting of a series of sealed jars (2-7) increasing successively in diameter, so that the current of water is reduced from jar to jar, and finally emerges into jar No. 8. The sludge which settles is successively finer in each jar. The inlet tube of each jar is taken to within a short distance of the bottom; the outlet tube takes off from about one inch below the bottom of the cork. The water above the outlet should be clear in each jar, acting as a visible check on convection currents, for if these are present the water above the outlet becomes turbid, indicating the possibility that coarser grains

[1] Shop and Laboratory, Vol. 1 (5), p. 8, published by the Mico Instrument Co., Cambridge, Massachussetts, (1937).

[2] J. W. Vanderwilt, " A laboratory method for grading abrasives ", *Econ. Geol.*, 24, pp. 853-859, (1929).

are being carried over. Passing through the cork of each jar is a third tube which just reaches the base of the cork and is closed at the top end by rubber tubing and a pinchcock; these tubes facilitate the withdrawal of air from the jars when first starting the siphon. Pinchcocks and T-pieces are inserted also in the tubing connecting the first three jars in order to start the siphon with the minimum difficulty. The tubing used is 7 mm. bore, except the last, which is 5 mm., to give a better control of the current. The current is controlled from the end of this last tube and varies from 60 to 180 drops per minute depending on the specific gravity of the abrasive being sorted. I find that it is quicker to put all the powder available through first with a strong current, then collect the sludge in jars 3-8 and put it through with a slow current. Any sludge in the water in jar 8 is allowed to settle as much as possible and the water returned to the circuit; the final rate of current is such as to give powder of 1 micron or less in jars 7 and 8 varying up to 6 microns in jar 3. At the end, the finest sludge has to be settled by adding 1 c.c. of nitric acid to 1 litre of water.

The water in the reservoir is kept stirred by a small paddle driven by a length of fishing twine off a small pelton wheel connected to the tap. It could be left going all night with a laboratory attendant to come along every few hours to refill the reservoir.

Table 1 gives details of the jars and of the size of emery particles which settle in them when the current is 100 drops per minute.

TABLE 1.

Jar.	2	3	4	5	6	7
Diameter of jar . . .	2½″	3″	4″	5″	6″	7″
Height between inlet and outlet tubes.	6″	2½″	4″	5″	7″	10″
Height of inlet tube above bottom of jar.	9″	2½″	1″	¼″	¼″	¼″
Size of emery settled in each jar.	+8μ	+5μ	+4μ	+3μ	+2·5μ	+1·5μ

Two points need attention: (*a*) there must be no sharp kinks or depressions in the rubber tubing connecting each jar, and (*b*) the corks must be sealed with paraffin wax and held down with string, otherwise the head of water will force them off and the whole operation be destroyed. Thoroughly clean jars at the start are obviously essential.

The proportion of abrasive to water was 60 grams to one litre of water, but with accumulation of coarse material in the reservoir this increases considerably. In rewashing the sludge from jars 3-8, the consistency is kept more or less constant in the reservoir.

This procedure may seem to be a troublesome method of obtaining well-sized abrasives, but it is the only method of accurately sorting such small particles. The usual forms of elutriator do not permit of sufficiently quiet settling to give well-graded powders of these minute dimensions. Anyway, the excellent results in polishing fully justify the trouble taken and it should be remembered that a very little powder goes a long way in polishing.

VI.—THE ORE MICROSCOPE ASSEMBLAGE.

Plate 20, fig. 2, shows the ore microscope, arc lamp, cooling cell and lenses as fitted up for use at the Geological Survey of India. This assemblage is more or less a permanent fixture on green baize, and when not in use is covered with a glass frame, permitting it to be brought into use in a few seconds.

The microscope is a Reichert. Two of these ore microscopes were purchased some years ago; I would much prefer the Leitz MOP model. Two things are essential for this work, excellent polarising and perfect definition at high magnification, properties which the Leitz model possesses in advance of any other make of ore microscope which I have handled. However, by removing parts of the Reichert and using an arc lamp instead of the attached incandescent bulbs, the Reichert has proved quite satisfactory, at least so far as polarisation effects are concerned, but definition at high magnification leaves much to be desired.

Clear polarisation effects can only be obtained with intense illumination. For this reason I use an arc lamp, and with the analyser out reduce the light intensity with several screens. Naturally, mineral colours will vary with the screens used, but as the screens are constant the eye becomes adjusted to their effects.

The technique of ore examination is almost entirely optical. With care perhaps 70 per cent. of the ore minerals can be identified by hardness, type of surface, cleavage, colour, reflectivity, reflection pleochroism, internal reflection, twinning, and bi-reflectence colours, or the possibilities are reduced to a minimum. When necessary, recourse is had to Short's series of etch tests or to other special etch tests in the case of the oxides. If there is still doubt, microchemical tests, following Short, are done on the sulphides,[1] and on the scheme suggested by Watson for the oxides.[2] The reagents are kept handy and ready for use. Microchemical tests are often a trial of patience in the hot weather and rains in this country; one is dealing with drops $\frac{1}{16}''$ to $\frac{1}{8}''$ diameter, which dry within a few seconds in the hot weather, whilst the handling of minute quantities of deliquescent salts in the rains is a difficulty.

For microchemical tests a minute amount of mineral powder is excavated by means of a dental hammer drill. Originally a rotating dental drill was used, but a percussive type was obviously desirable for hard minerals. I was about to have a magnetic vibrating needle made according to an excellent pattern designed by Mr. Spencer Mann of Melbourne University, when Dr. Heron suggested adapting an ordinary dentist's mallet. By fitting fine gramophone needles, this has proved eminently satisfactory.

For steadiness, Dr. M. Haycock of Ottawa fits the rotating needle to a stand over the microscope stage and raises the mineral up to the needle, which has previously been brought into focus. However, the mallet type can be held remarkably steadily without any difficulty, but perhaps age will later change my opinion.

VII.—THE MICROSCOPE CAMERA.

The large horizontal type of polarising metallographic camera was beyond the means at our disposal. The cheaper forms of camera, which are attached to the microscope tube, are unsatisfactory, as slight change in focus is unavoidable when changing the screen for the plates. A new design was submitted to the Mathematical Instrument Office, where it was made. The camera consists of a bed of 17-ply wood screwed to four legs each with adjustable pin-pointed feet which can be locked. The camera bellows is fixed to the centre of the bed and slides on a stout brass column to one side.

[1] M. N. Short, "Microscopic determination of the ore minerals", *U. S. Geol. Surv.*, Bull. 825, (1931).

[2] J. A. Watson, "Colour reactions in the microchemical determination of minerals", *Miner. Mag.*, XXIV, pp. 21-34, (1932).

Through the centre of the bed passes a removable brass nose-piece designed to give considerable lateral movement and yet permit no light to pass except that coming through the microscope. The laterally movable lower part of this nose-piece is made to fit lightly but snugly over the microscope tube and is lined with felt.

To take a photo the nose-piece is pulled out from inside the camera, the latter is placed centrally over the microscope and the nose-piece pushed in and down over the microscope tube—an operation taking a few seconds. The ground glass is slid on and the usual operations gone through.

The camera is remarkably stable; there is not the slightest vibration so long as one keeps reasonably still, and the results have been eminently satisfactory. My only complaint is that the D. C. lighting available in Calcutta prevents the use, without considerable trouble, of a more suitable form of intense illumination than the arc lamp, in which the wandering of the bright spot sometimes gives rise to a dark patch in one quadrant of the field whilst an exposure is being made.

For plates I prefer anti-halo chromo isolar when available, otherwise isochrome, sold by Agfa. Considerable use is made of colour screens, particularly of blue, orange and red. An intense illumination is used, keeping the exposure around 10 seconds for ordinary light and up to say 1 minute for crossed nicols or with deep colour screens, because I find that the longer the exposure the greater is the effect on the plate of any light reflected from internal parts of the microscope.

VIII.—EXPLANATION OF PLATES.

PLATE 19, FIG. 1.—Section machines assembled on tables.

FIG. 2.—Polishing machine (celluloid cover raised), one weighted spindle and specimen removed and resting on table. Cloth lap to left, with trough removed; the cloth lap is used for removing tarnish and polishing rocks.

PLATE 20, FIG. 1.—Apparatus for grading abrasive powders.

FIG. 2.—Ore microscope and apparatus, with camera in position.

MARBLE AND DOLOMITE OF GHUNDAI TARAKO, NORTH-WEST FRONTIER PROVINCE. BY A. L. COULSON, D.Sc., D.I.C., F.G.S., F.N.I., *Superintending Geologist, Geological Survey of India.*

CONTENTS.

I.—INTRODUCTION.

Previous production recorded.

In the returns of mineral production in the North-West Frontier Province, production of limestone has been recorded intermittently in past years from Ghundai Tarako (34° 13′ : 72° 25′), a hill forming part of the boundary between the Swabi tahsil of the Mardan district and the Buner tract of Swat. The main peak of the ridge has an elevation of 1,673 feet above sea-level.

Former paper.

My various reports submitted to the Government of that Province concerning the marble and limestone occurrences I visited in the Mullagori country of the Khyber Agency and in the Swabi tahsil of the Mardan district, have been summarised in my paper on "Marble of the North-West Frontier Province" (Coulson, 1936). This present paper is supplementary to the former, but for purposes of comparison, frequent reference has been made to opinions concerning the quality of the Khyber and Swabi marble expressed therein. To the best of my knowledge, there has been no previous record of the Ghundai Tarako marble, apart from the brief mention made in my previous paper (Coulson, 1936, p. 342). I visited the Ghundai Tarako in April, 1937, and this paper has been delayed in order to include the analyses of the various samples I collected, which have kindly been made for me in the Laboratory of the Geological Survey of India.

Date of visit.

II.—GEOLOGICAL NOTES.

The ridge of Ghundai Tarako is composed of altered grey limestones, probably Carboniferous in age, similar to the limestones responsible for the Shahidmena (34° 9′ : 71° 17′) and Kambela Khwar (Khyber) and the Maneri (34° 8′ : 72° 28′) (Swabi) marble. As before, the metamorphism has been caused by the intrusion of epidioritic and amphibolitic rocks and it is possible that the process has been aided by the intrusion of the Buner granite. What appear to be granitic veins may be seen in the south-east end of the ridge.

Marble formed by metamorphism of grey Carboniferous limestone.

This Buner granite, a biotite-granite with 74·30 per cent. of silica, crops out over a very large area in the Swabi tahsil of the Mardan district and the Buner tract of Swat to the north and north-east of Ghundai Tarako, and it is possibly associated in origin with the soda-granite suite of Shahbazgarhi (34° 14′ : 72° 10′) and Patigate Sar (34° 9′ : 71° 22′), which I have described elsewhere [Coulson, 1936, (1)]. I propose to discuss these acidic rocks and the muscovite-granite of Malakand (34° 34′ : 71° 56′) in a separate paper.

Buner granite.

The general strike of the Ghundai Tarako varies from N.W.-S.E. to N.N.W.-S.S.E. There is a definite cross-jointing. The dip is usually about 45° to the north-east or N.N.E., but it changes. Thus at the south-east end of the ridge, the dip is to the S.S.E.

Strike and dip.

The amphibolitic and epidioritic dykes vary in size, but instead of anastomising as in the case of the Maneri marble, they usually have a strike transverse to that of the limestone, *i.e.*, N.E.-S.W. Sometimes they are three or four feet across; at others they have thicknesses up to 12-15 feet or more. On the whole, one does not meet many basic rocks (certainly less than at Maneri) and this is one of the reasons why I think the Buner granite has had a fair amount to do with the metamorphism. In the case of the metamorphism of the limestones to the south-west of Amankot (34° 16′ : 72° 26′), a few miles N.N.E. of Ghundai Tarako, there has been infiltration of siliceous material from the granite with the formation of calc-schists. It will be remembered that I suggested (1936, p. 333) that as yet unexposed masses of the biotite-aegirite-arfvedsonite-granite may have assisted in the metamorphism of the limestone to marble at Shahidmena.

Amphibolitic rocks.

III.—ANALYSES.

Analyses of Ghundai Tarako marble and dolomite.

The following are the results of the analyses of nine samples of the marble and dolomite of the Ghundai Tarako ridge, selected during a thorough inspection from south to north (Table 1):—

TABLE 1.—*Analyses of limestone, marble and dolomite from Ghundai Tarako, Mardan and Swat.*

Column number.	I	II	III	IV	V	VI	VII	VIII	IX
Rock number.	51/191	51/192	51/193	51/194	51/195	51/196	51/197	51/198	51/199
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	0·24	0·74	0·60	0·52	0·16	0·20	0·94	0·54	0·56
$Fe_2O_3+Al_2O_3$	0·24	0·50	0·70	0·40	0·35	0·20	0·45	0·40	0·46
Ca O	31·58	53·32	32·27	54·57	52·90	53·20	50·55	54·40	53·75
Mg O	20·98	1·74	19·92	0·58	2·64	2·50	4·07	1·05	1·56
Loss on ignition	46·36	42·86	46·21	43·31	43·72	43·57	44·15	42·94	43·12
H_2O	0·18	0·32	0·25	0·23	0·27	0·33	0·13	0·34	0·20
S	..	..	..	0·02	..	..	..	..	..
TOTALS	99·58	99·48	99·95	99·63	100·04	100·00	100·29	99·67	99·65
Specific gravity	2·88	2·73	2·73	2·74	2·73	2·73	2·73	2·74	2·72

I. (51/191) Grey-white dolomite, south-eastern end of Ghundai Tarako. Buner, Swat.
II. (51/192) Banded grey recrystallised limestone, north of previous specimen, around spur, Buner, Swat.
III. (51/193) Grey dolomite, south-western end of Ghundai Tarako, Swabi tahsil, Mardan district.
IV. (51/194) White saccharoidal marble, a quarter of a mile S.S.W. of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
V. (51/195) White saccharoidal marble, just south-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
VI. (51/196) White marble, west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
VII. (51/196) White marble, a little north-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
VIII. (51/198) Greyish white marble, north-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
IX. (51/199) Saccharoidal white marble, three furlongs N.N.W. of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.

Analyses of other marble and dolomite.

In Table 2, analyses of other marble and dolomite are given for comparison :—

TABLE 2.—*Analyses of marble and dolomite from the Khyber, Mardan, Jodhpur, Italy and the Kurram.*

Column number.	I	II	III	IV	V	VI
Rock number.	49/462	49/485	49/475	42/562	..	49/456
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2 . .	0·02	0·06	0·04	0·46	*trace*	2·04
$Fe_2O_3 + Al_2O_3$	0·10	0·18	0·05	0·04	0·11	0·84
CaO . .	54·60	54·40	55·86	56·08	55·64	30·77
Mg . .	1·61	0·88	0·33	0·90	0·41	20·42
Loss on ignition	43·86	43·69	42·58	43·28	44·17	43·86
P_2O_5 . .	..	..	..	..	*trace*	..
TOTALS .	100·19	99·21	98·86	100·76	100·33	97·93
Specific gravity	2·72	2·70	2·71	2·73	..	2·90

I. (49/462) White saccharoidal marble, lower quarry, Shahidmena, Mullagori country, Khyber Agency, North-West Frontier Province (Coulson, 1936, p. 335).

II. (49/845) White saccharoidal marble, $1\frac{1}{4}$ miles W.S.W. Lowaramena, Kambela Khwar, Mullagori country, Khyber Agency, North-West Frontier Province (Coulson, 1936, p. 337).

III. (49/475) White marble, Maneri, Swabi tahsil, Mardan district, North-West Frontier Province (Coulson, 1936, p. 341).

IV. (42/562) Marble, Makrana, Jodhpur State, Rajputana (Heron, 1935, p. 326).

V. (——) Marble, Carrara, Italy (Heron, 1935, *ibid*).

VI. (49/456) White crystalline dolomite, Zeran Tangi, east of Parachinar, Kurram Agency, North-West Frontier Province (Coulson, 1936, p. 344).

All samples of excellent quality.

It will be noted from a study of the figures in these tables that all the samples of limestone, marble and dolomite from Ghundai Tarako are of excellent quality; in no case does their silica content exceed one per cent. or their combined iron and alumina 0·75 per cent.

According to the analyses in Table 1, two grey stones from the southern end of the ridge are dolomites in composition. Only one of these (51/191), however, has the high specific gravity characteristic of that rock. Though green and yellow serpentinous marble with 7·34 per cent. of magnesia was recorded from Maneri, I noted none of this handsome coloured stone bordering the basic dykes intrusive into the marble of Ghundai Tarako. The grey limestone and the white saccharoidal and finely crystalline samples of marble from Ghundai Tarako are of quality equal to the best at Shahidmena, in the Kambela Khwar, or at Maneri, and compare favourably with the Makrana marble of Jodhpur and the best Italian marble.

Presence of dolomite.

Quality of Ghundai Tarako marble equal to that of Khyber and Maneri marble.

IV.—QUARRYING NOTES AND RECOMMENDATIONS.

Abundant marble of good quality is available at Ghundai Tarako, but care should be taken in the selection of sites for development. Thus rainwater containing ferruginous salts from the decomposition of the basic dykes has been responsible for a lot of iron-staining, which has penetrated a fair distance into the marble in places. There also seemed to be cubes of pyrite in some of the white marble. This mineral would, of course, have to be carefully avoided as marble containing it will stain by oxidation of the pyrite. The percentage of sulphur found in specimen 51/194, however, amounted only to 0·02.

Superficial iron-staining.

The Ghundai Tarako marble has been worked in the past by local *Khattacks* and taken by donkeys to neighbouring villages such as Nawe Kalai (34° 13′ : 72° 20′), Shekh Jana (34° 13′ : 72° 21′) Spinkani (34° 14′ : 72° 22′) and Shewa (34° 15′ : 72° 21′) to burn for lime. The cost of a *pari*, a heap of pieces of stone of about four cubic yards (six feet long by six feet wide by three feet high), delivered in Shekh Jana[1], which operation apparently takes one man about four days to complete, was quoted as Rs. 7. To Nawe Kalai, but a mile further, the cost was stated to be Rs. 10, as the operation takes six days. This indicates the primitiveness of the methods of extraction and transport so far used and it is obvious that the surface of the marble has only been scratched.

Former working of marble.

[1] Shekh Jana is only about 4½ miles west of Ghundai Tarako.

Cross-jointing.

The cross-jointing might at times be mistaken for the dip. Thus near the main peak, the chief joints dip to the south-west. However, the foliation of such of the banding as the marble possesses strikes N.W.–S.E. and dips into the hill, *i.e.*, north-east.

Best sites for development near main peak.

The main peak region seems to offer the best sites for quarrying. This area would have to be tested to see how far marble of good quality goes up the hill. It seems probable that nearer the summit, the marble is not so well recrystallised. The amount I saw of the Swat side of the ridge would seem to indicate that the best marble runs on the south-west, or Mardan, side.

Large blocks of white marble not available.

According to the local workers, the largest-sized blocks of white marble that can be extracted would be about two to three feet in length. This is a disadvantage when the marble is quarried for statuary purposes, though not so important for minor building purposes; but it is highly possible that as quarrying proceeds along the dip into the ridge and atmospheric agencies have had no opportunity to accentuate the jointing, much larger blocks will be available.

Transport facilities.

The Ghundai Tarako is a mile to the east of the canal road along the Machai branch of the Upper Swat canal, where it is crossed by the Wuch Khwar between the 230 and 235 hundred-foot marks.[1] To the north-west, this unmetalled canal road joins the Mardan-Rustam metalled road at Hamzakot, which is 17 miles from Mardan and 13 miles from the Wuch Khwar. To the S.S.E., the same canal road joins the Mardan-Swabi road at Gohati, which is 24 miles from Mardan, 5 miles from Swabi and 3½ miles from the Wuch Khwar. Thus if the marble of Ghundai Tarako were developed, 13 miles of unmetalled canal road would have to be metalled to enable the marble to be transported to Hamzakot and then by the 17 miles of metalled road to Mardan; alternatively, 3½ miles of canal road would have to be metalled to allow the marble to be brought to Gohati and thence by the 24 miles of metalled road to Mardan; to both these must be added the making of one mile of metalled road from the Wuch Khwar to Ghundai Tarako. It would, however, be advisable to make a new road from

[1] There are no mileposts along this road, the length of the distributaries and canals being measured in multiples of one hundred feet.

Ghundai Tarako for just over three miles across the Wuch Khwar and then by the side of the Nawe Kalai Minor distributary canal to mile 20·6 on the Mardan-Swabi road; this would bring the marble within 24 miles of Mardan as opposed to the 30 miles by Hamzakot and 27½ miles by Gohati.

V.—SUMMARY AND CONCLUSIONS.

The North-West Frontier Province is well supplied with excellent white statuary marble and has illimitable quantities of banded marble suitable for building purposes. In my previous paper (Coulson, 1936, p. 344), I doubted whether any of the deposits at Shahidmena, Kambela Khwar and Maneri would alone be able to keep up the regular supply of say 600 tons (9,000 cubic feet) of first class statuary marble as this would entail the monthly removal of about 40 by 28 by 10 feet of stone, allowing only 25 per cent. wastage. I considered

Advisable to develop all deposits of marble in the Khyber and Mardan.

" that for the best development of the marble industry in the North-West Frontier Province, it is advisable to develop simultaneously the Shahidmena, Kambela, Khwar and Maneri deposits. Also every possible care should be taken to extract the less valuable, banded, relatively impure marbles at the same time as the pure white marble, which at all times will command a market. By doing so, large quantities of good quality, banded marble, suitable for tiles, facing and general building purposes, which otherwise would be wasted, will be sold in addition to the statuary marble."

These remarks still hold good, with the qualification that possibly the largest quantities of statuary marble will be found in the Ghundai Tarako. The special attention of the Government of the Frontier Province is invited to the analyses given in section III of this paper, which show the excellence of the marble available and also indicate the presence of dolomite.

Finally it must be remembered that careful selection of sites for development should be made, taking into consideration the type of stone required. It is reiterated that possibly the best sites will be found in the neighbourhood of the main peak on the Mardan side of the Ghundai Tarako.

VI.—ACKNOWLEDGMENTS.

I wish to thank the Deputy Commissioner of the Mardan district for his interest in my work in his district.

I was accompanied by Salar Jung Khan, the Khan Sahib of Naranji, during my investigation of the Ghundai Tarako marble and the neighbouring hills to the N.N.E.

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MISCELLANEOUS NOTE.

Quarterly Statistics of Production of Coal, Gold and Petroleum in India: January to March, 1937.

Coal.

—	January.	February.	March.	Quarterly total for each Province.
	Tons.	Tons.	Tons.	Tons.
Assam	15,602	15,600	20,007	51,209
Baluchistan	701	432	552	1,685
Bengal	433,982	525,254	562,811	1,522,047
Bihar	1,021,518	1,168,523	1,201,936	3,391,977
Orissa	2,958	4,995	3,568	11,521
Central Provinces	144,277	138,842	114,680	397,799
Punjab	14,353	11,875	18,644	44,872
TOTAL	1,633,391	1,865,521	1,922,198	5,421,110

Gold.

—	January.	February.	March.	Quarterly total for each Company.
	Ozs.	Ozs.	Ozs.	Ozs.
The Mysore Gold Mining Co., Ltd.	8,209	7,397	8,214	23,820
The Champion Reef Gold Mines of India Ltd.	5,902	5,328	5,900	17,130
The Ooregum Gold Mining Co. of India Ltd.	4,341	4,239	4,301	12,881
The Nundydroog Mines Ltd	9,654	8,716	9,645	28,015
TOTAL	28,106	25,680	28,060	81,846

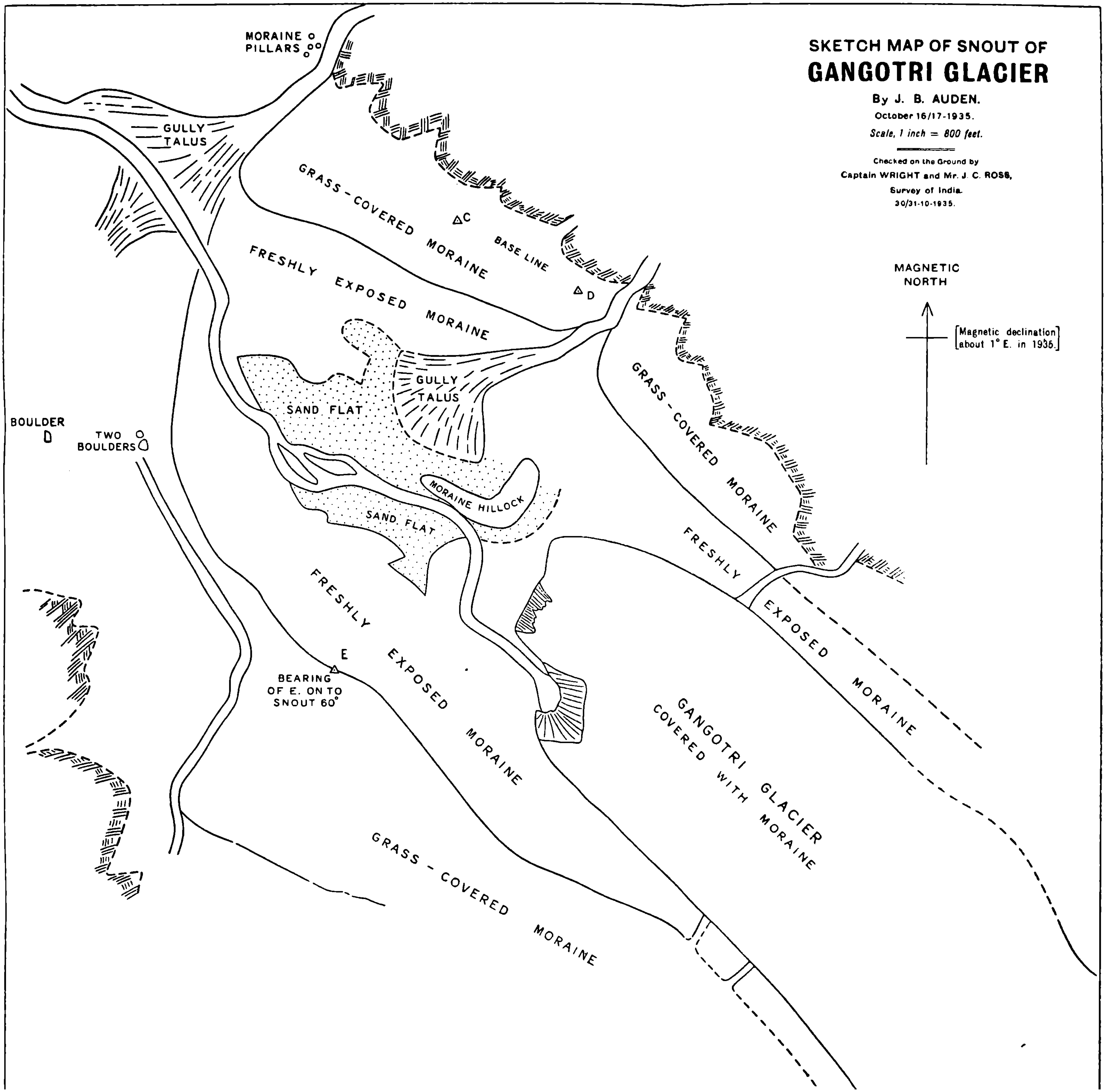
Petroleum.

—	Crude Petroleum.	Total gasolene* from natural gas.
	Gallons.	Gallons.
Assam	16,434,174	*Nil.*
Burma	63,734,133	2,619,596
Punjab	965,880	131,055
TOTAL	81,134,187	2,750,651

* These figures represent the total amounts of gasolene derived from natural gas at the well-head. Of these amounts a portion is sold locally as 'petrol' and the remainder is mixed with the crude petroleum and sent to the refineries. The figures given in the two columns, therefore, together represent the total 'raw products' obtained. These remarks apply to the similar totals quoted in previous *Records*.

A. M. HERON.

MGIPC--M--VIII-4-11—18-1-38—800.


SKETCH MAP OF SNOUT OF
GANGOTRI GLACIER
By J. B. AUDEN.
October 16/17-1935.
Scale, 1 inch = 800 feet.
Checked on the Ground by
Captain WRIGHT and Mr. J. C. ROSS,
Survey of India.
30/31-10-1935.
MAGNETIC NORTH
[Magnetic declination about 1° E. in 1935.]
MORAINE PILLARS
GULLY TALUS
GRASS-COVERED MORAINE
C
BASE LINE
D
FRESHLY EXPOSED MORAINE
GULLY TALUS
SAND FLAT
MORAINE HILLOCK
SAND FLAT
BOULDER
TWO BOULDERS
GRASS-COVERED MORAINE
FRESHLY EXPOSED MORAINE
FRESHLY EXPOSED MORAINE
E
BEARING OF E. ON TO SNOUT 60°
GANGOTRI GLACIER COVERED WITH MORAINE
GRASS-COVERED MORAINE

By permission of the Surveyor General of India.

G. S. I., Calcutta.

MAP OF THE GANGOTRI AREA.

Scale: $\frac{3}{4}$ inch = 1 mile (1: 95,040).

J. B. Auden, Photo. *G. S. I., Calcutta.*

GENERAL VIEW OF GANGOTRI GLACIER, WITH SATOPANTH PEAKS.

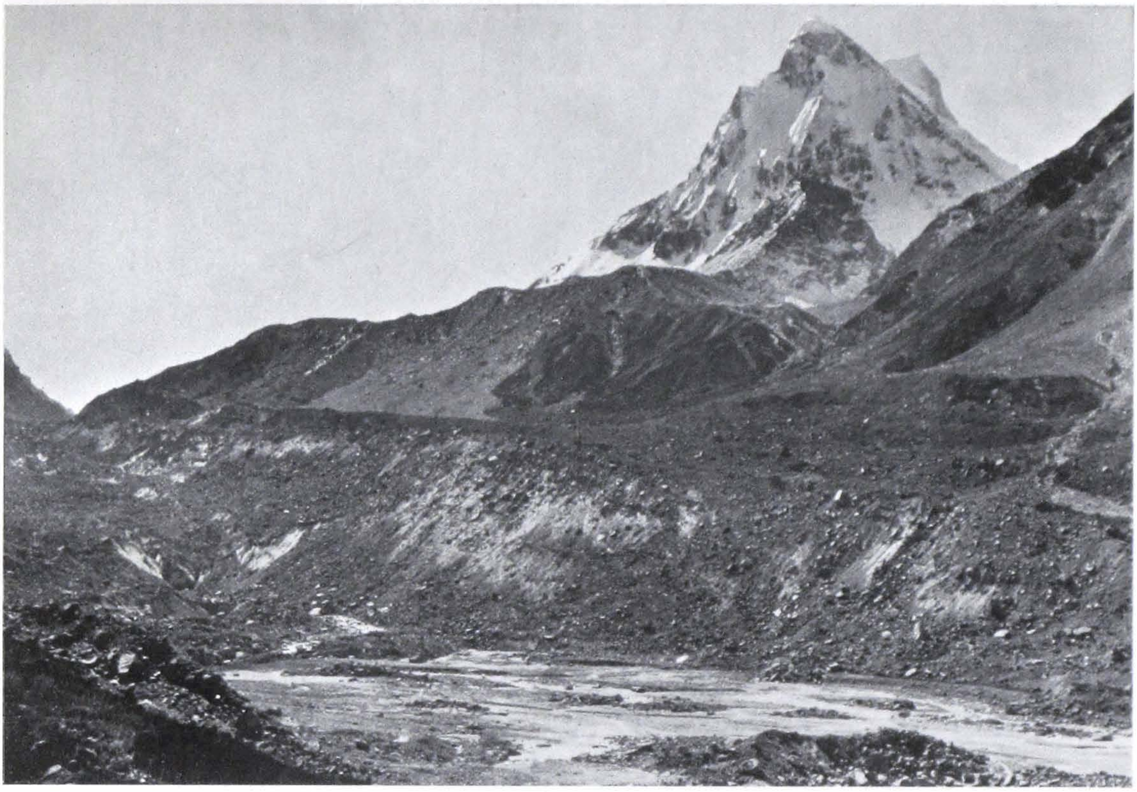
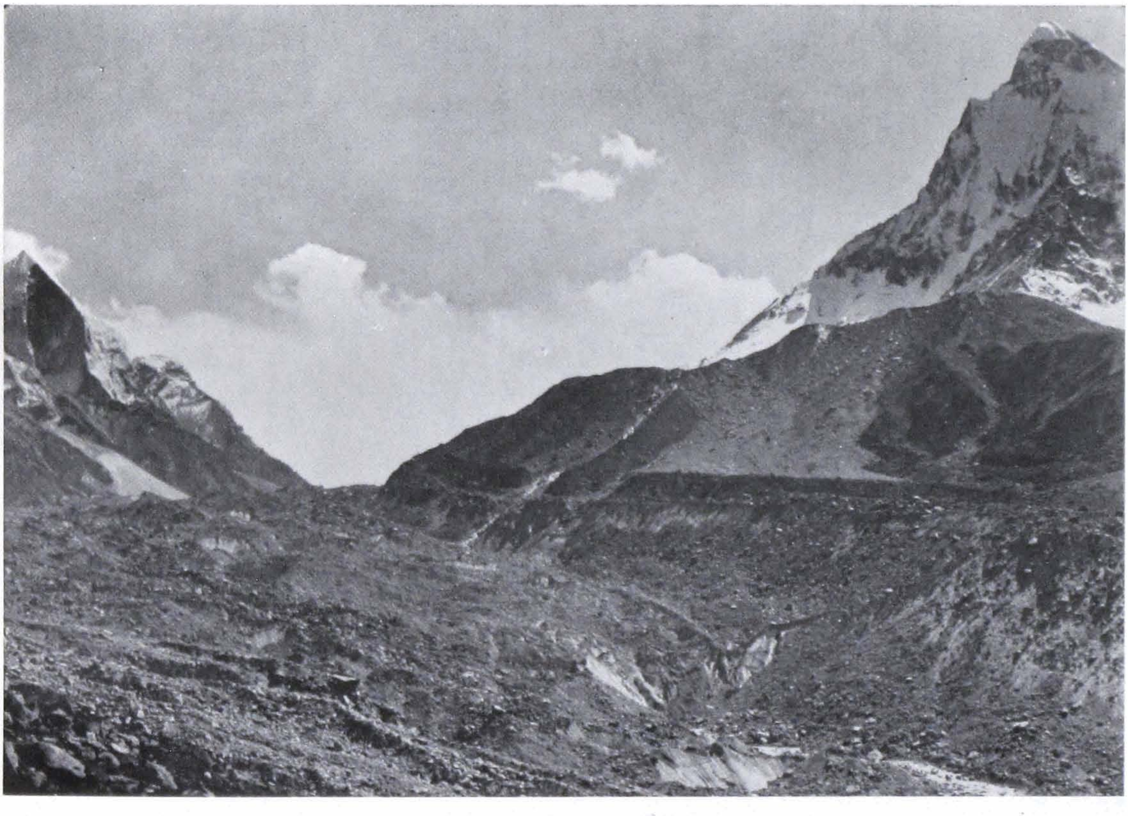
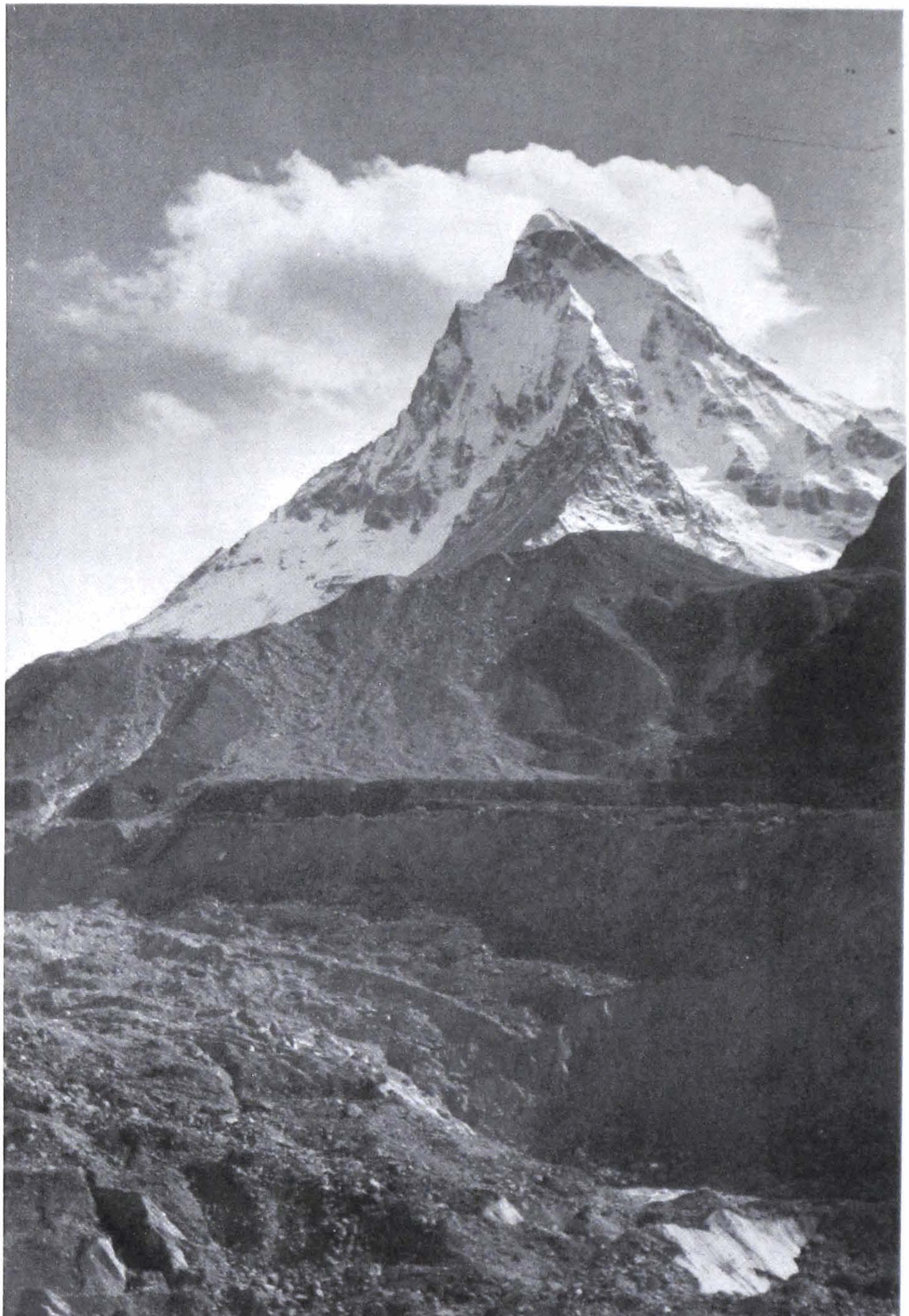


FIG. 1. VIEW OF GANGOTRI SNOUT AND SAND FLAT FROM CAIRN B, LOOKING SOUTH-EAST.



J. B. Auden, Photos. *G. S. I., Calcutta.*

FIG. 2. VIEW OF GANGOTRI SNOUT FROM CAIRN C, LOOKING TOWARDS 155°.



J. B. Auden, Photo. *G. S. I., Calcutta.*

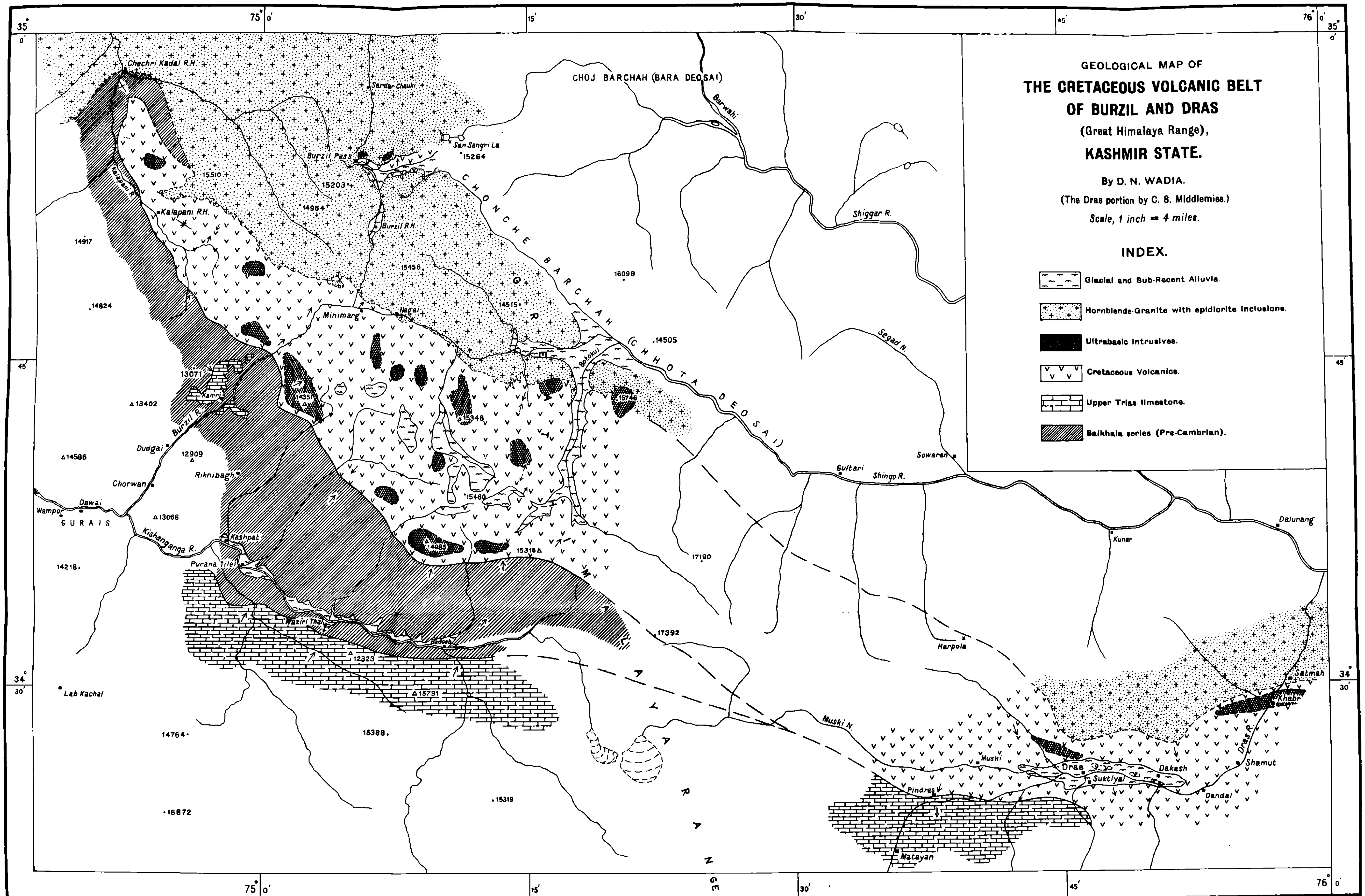
VIEW OF GANGOTRI SNOUT AND SHIVLING FROM CAIRN D, LOOKING TOWARDS 175°.

FIG. 1. VIEW OF GANGOTRI SNOUT FROM CAIRN E, LOOKING TOWARDS 60°.

J. B. Auden, Photos. *G. S. I., Calcutta.*

FIG. 2. VIEW DOWN BHAGIRATHI VALLEY SHOWING HIGH LEVEL MORAINE AND TALUS FANS.

Records, Vol. 72, Pl. 8.



A. K. Chandra, Lith.

Litho., G. S. I., Calcutta.

D. N. Wadia, Photo. G. S. I., Calcutta.

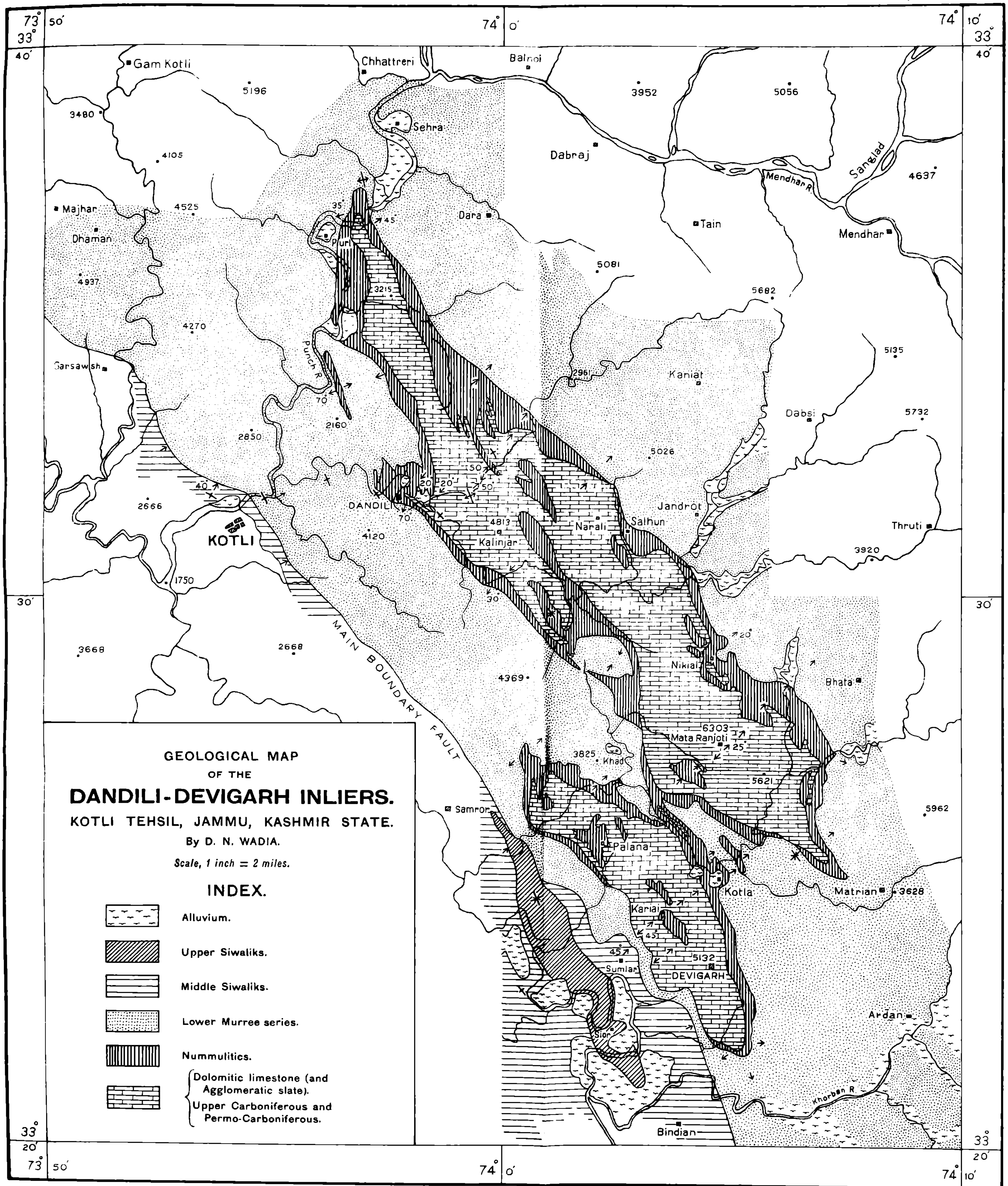
HEAD OF THE BURZIL VALLEY. THE SCREE CONCEALS CRETACEOUS LIMESTONE INTERCALATIONS IN VOLCANIC TUFFS.

FIG. 1. SILLS OF DOLERITE AND GABBRO, PASHWARI, BURZIL VALLEY.

D. N. Wadia, Photos. *G. S. I., Calcutta.*

FIG. 2. VOLCANIC AGGLOMERATIC CONGLOMERATE, NEAR MINIMARG, NAGAI VALLEY.

Records, Vol. 72, Pl. 11.



GEOLOGICAL MAP OF THE DANDILI-DEVIGARH INLIERS.

KOTLI TEHSIL, JAMMU, KASHMIR STATE.

By D. N. WADIA.

Scale, 1 inch = 2 miles.

INDEX.

- Alluvium.
- Upper Siwaliks.
- Middle Siwaliks.
- Lower Murree series.
- Nummulitics.
- Dolomitic limestone (and Agglomeratic slate). Upper Carboniferous and Permo-Carboniferous.

S. N. Guine, Lith.

Litho., G. S. I., Calcutta.

Records, Vol. 72, Pl. 12.

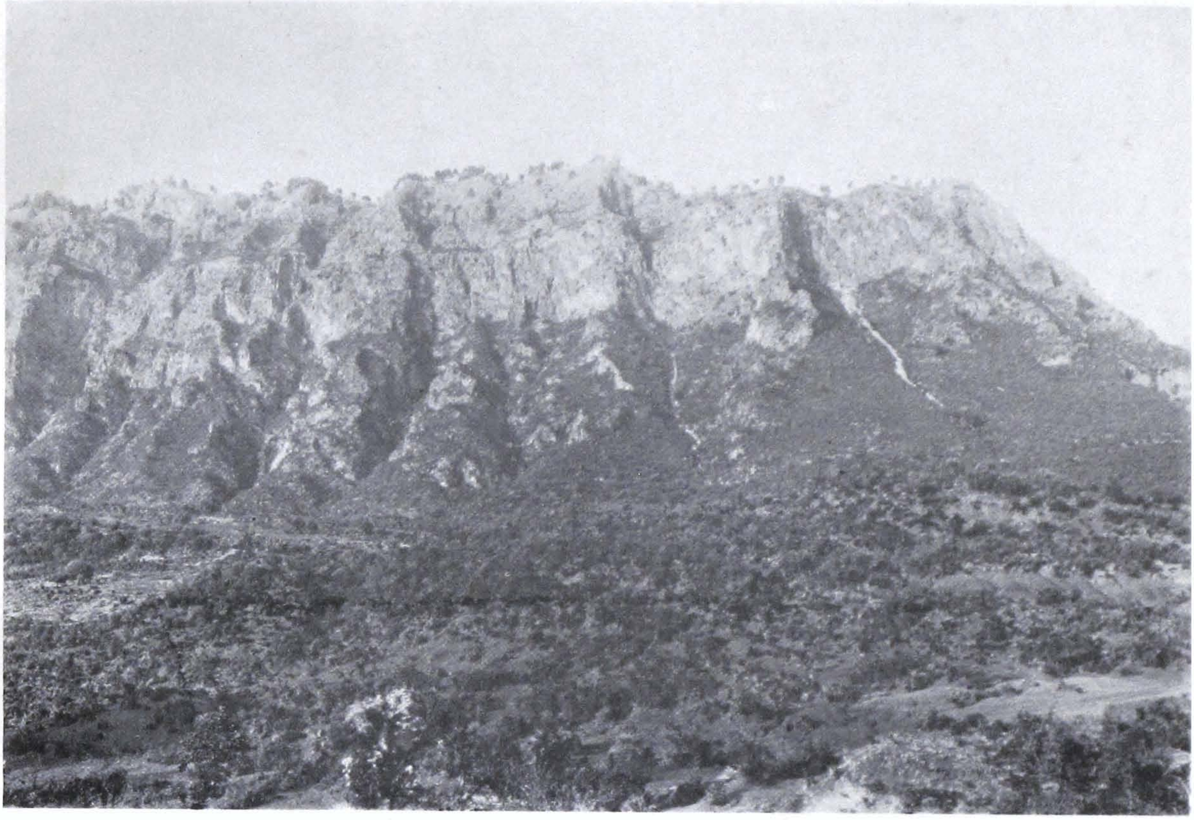


FIG. 1. CLIFF OF 'GREAT LIMESTONE,' DANDILI, KOTLI.

D. N. Wadia, Photos. *G. S. I., Calcutta.*

FIG. 2. 'GREAT LIMESTONE' CLIFFS—A FAULT-SCARP—NEAR SUMLAR VILLAGE, NORTH OF KOTLI *DUN*.

Records, Vol. 72, Pl. 13.

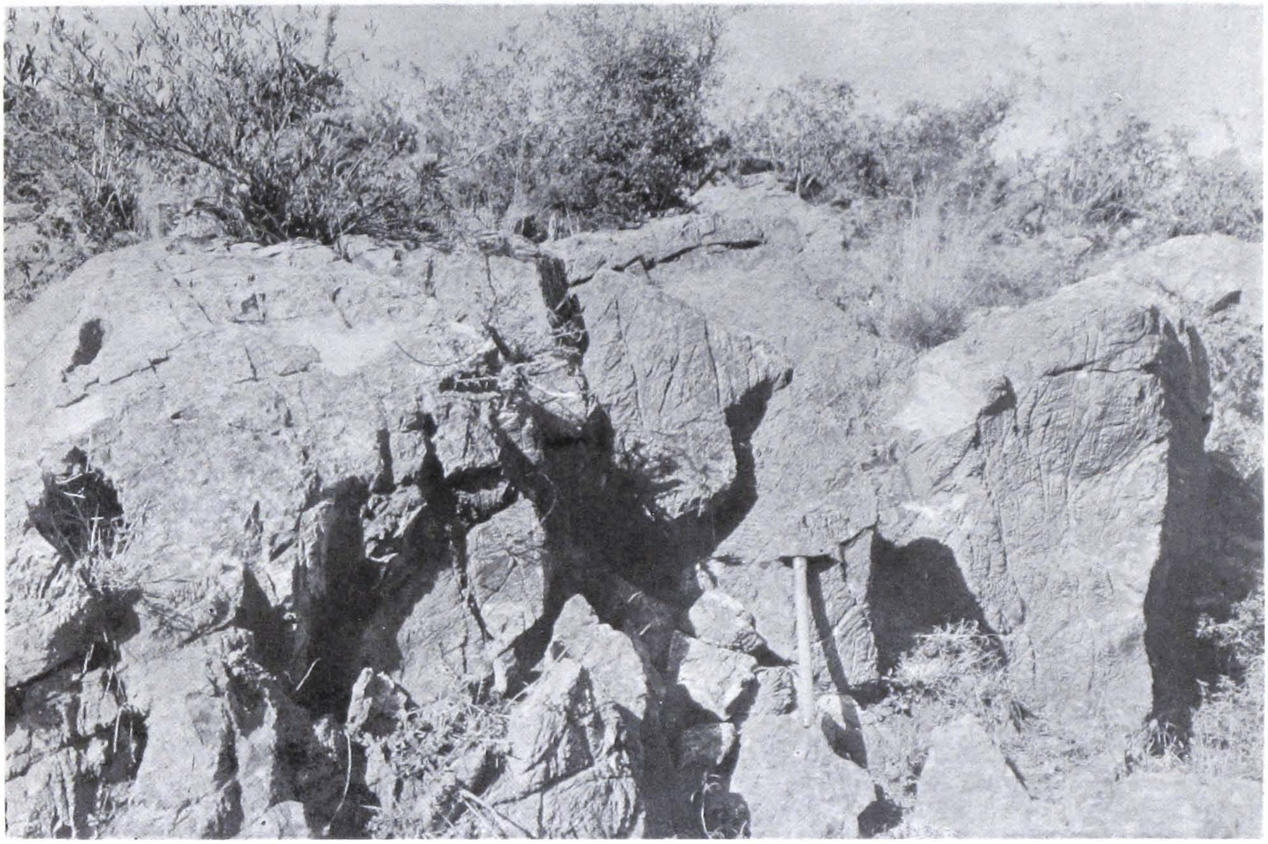
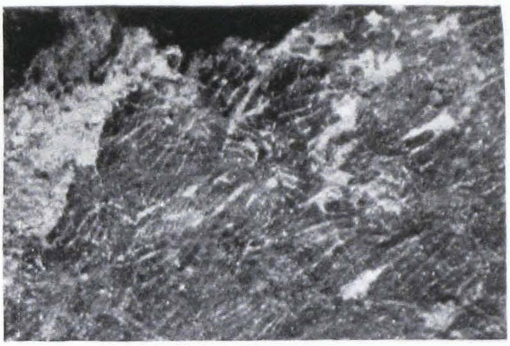


FIG. 1. WEATHERING OF "GREAT LIMESTONE". OUTCROP NEAR KAMROTI VILLAGE, KOTLI.

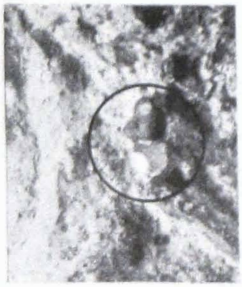
D. N. Wadia, Photos. *G. S. I., Calcutta.*

FIG. 2. MINOR FOLD IN "GREAT LIMESTONE" WITH A SHELL OF THE NUMMULITICS CARRYING BAUXITE, KAMROTI VILLAGE.

Records, Vol. 72, Pl. 14.

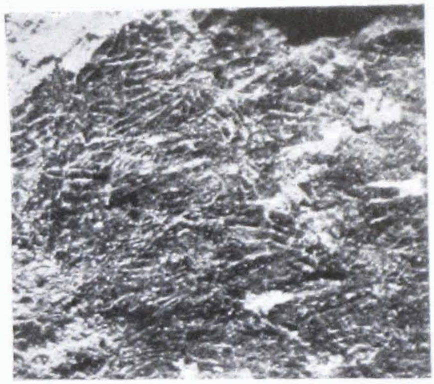


1. (× 11$\frac{1}{5}$).

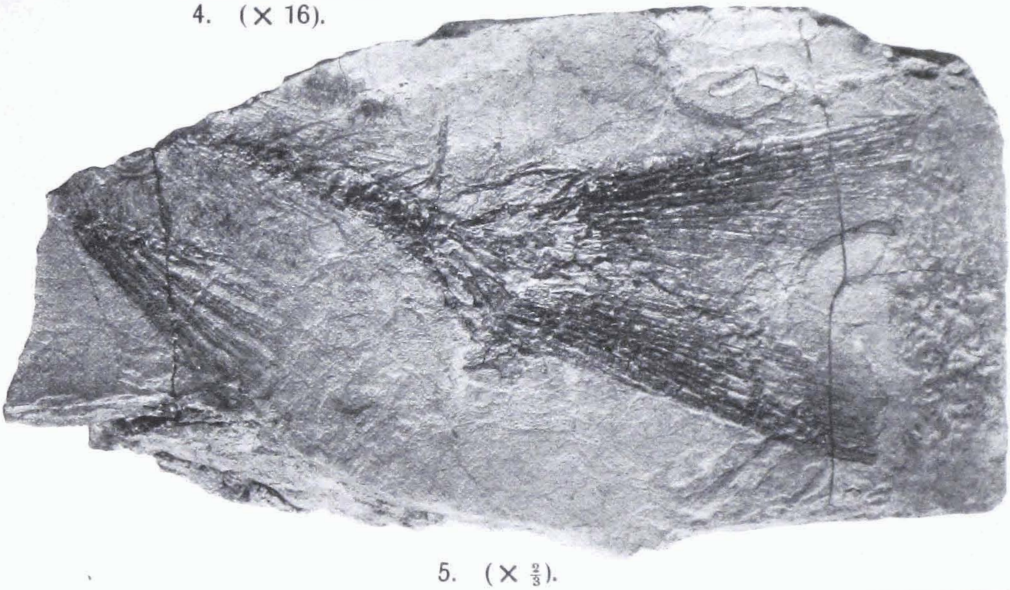


3. (× 5$\frac{3}{5}$).

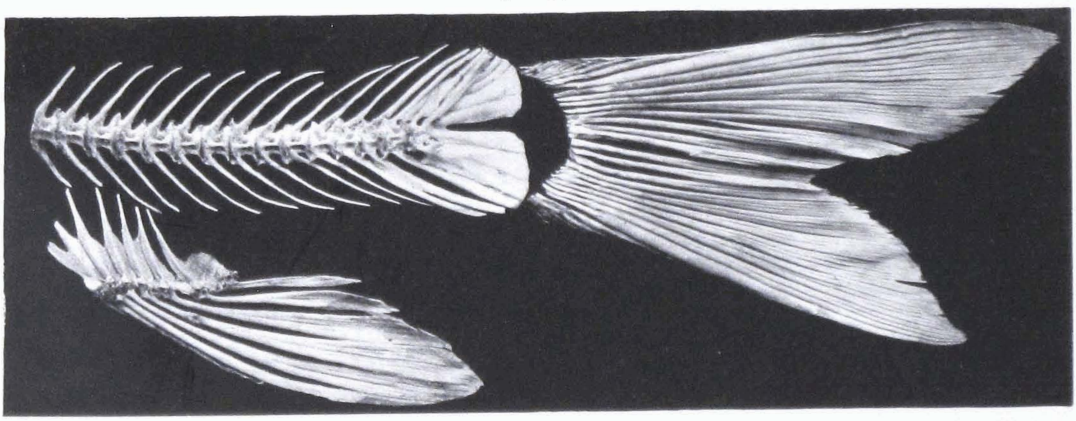
4. (× 16).



2. (× 11$\frac{1}{5}$).



5. (× $\frac{2}{3}$).

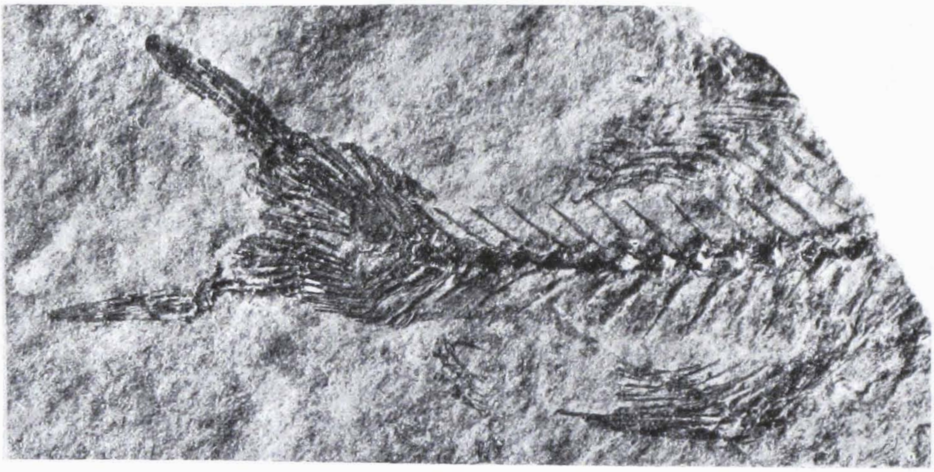


6. (× *ca* $\frac{3}{5}$).

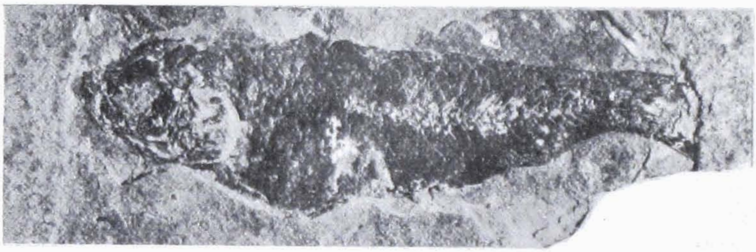
FOSSIL FISH REMAINS FROM THE KAREWAS OF KASHMIR.

S. C. Mondal, Photos. *G. S. I., Calcutta.*

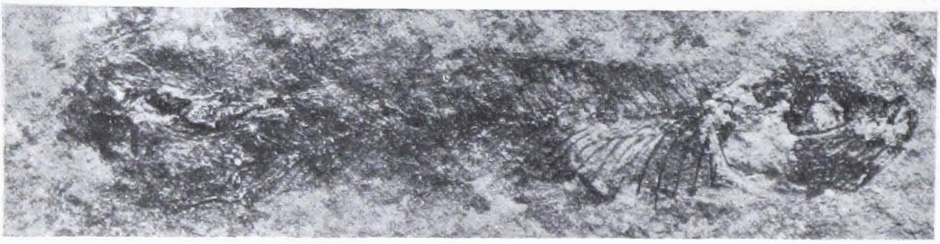
1. (× 3).



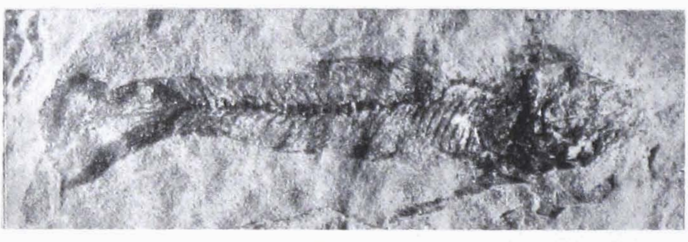
2. (× 3).



3. (× 1½).



4. (× 4½).



5. (× 3).

6. (× 3).

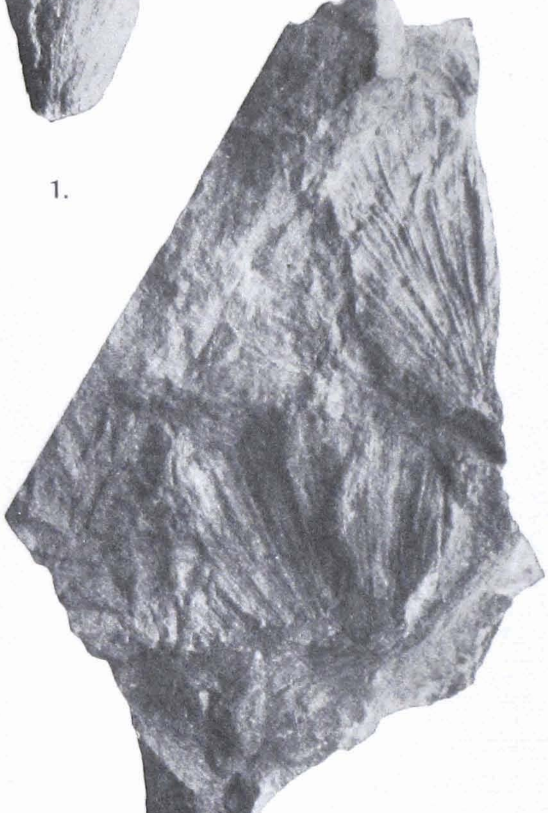
S. C. Mondul, Photos. *G. S. I., Calcutta.*

FOSSIL FISH REMAINS FROM THE SALINE SERIES.

1.

2. (× 2).

3.



4. (× 2).

S. N. Das, Photos. *G. S. I., Calcutta.*

FIGS. 1—4. RHACOPTERIS OVATA (McCoy) WALKOM.

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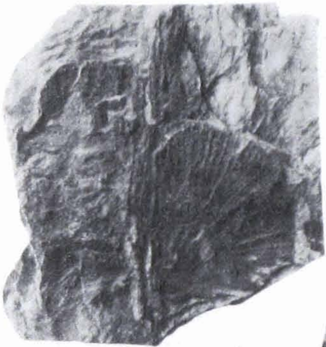
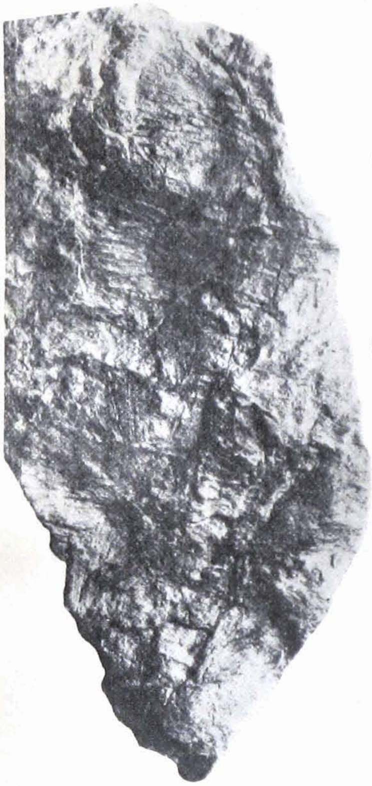
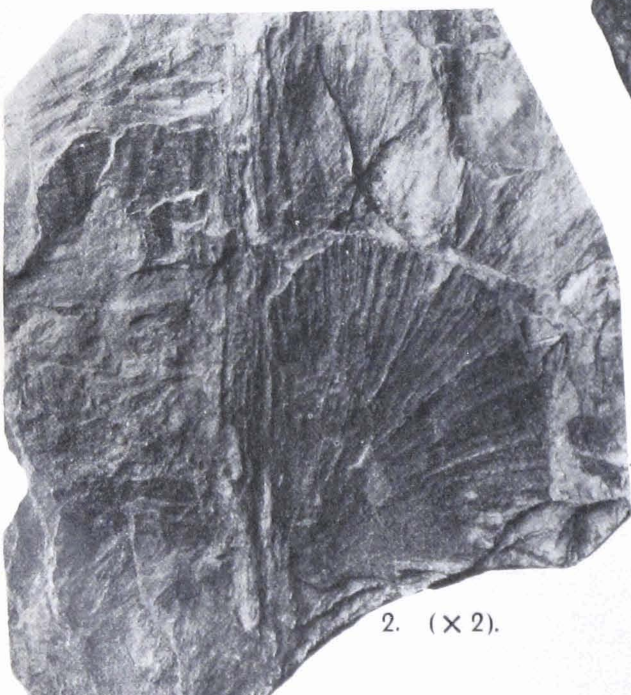


1.



3.



2. (× 2).

4. (× 2).

S. N. Das, Photos. *G. S. I., Calcutta.*

FIGS. 1—4. RHACOPTERIS OVATA (McCoy) WALKOM.

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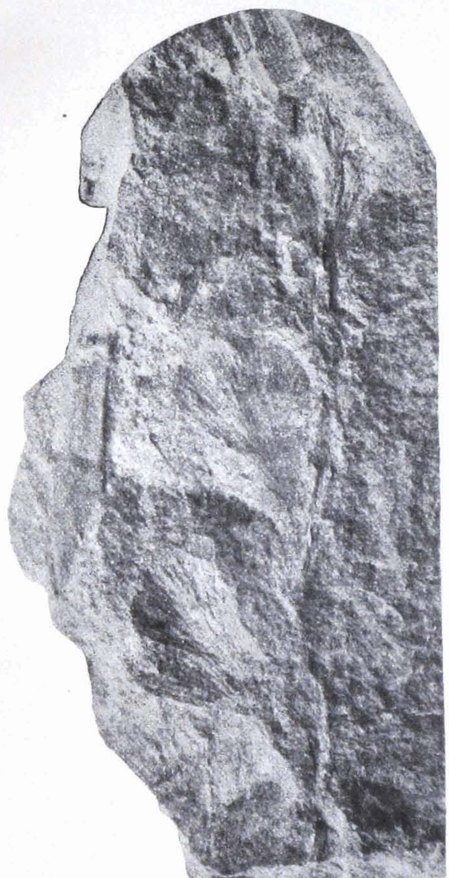
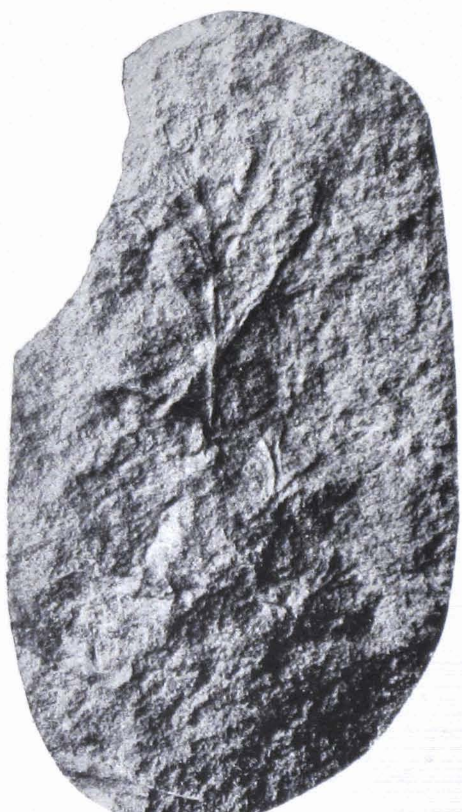
1.



2. (× 2).



3. (× 2).

S. N. Das, Photos. *G. S. I., Calcutta.*

SPHENOPTERIDIUM (?) FURCILLATUM LUDWIG *sp.*

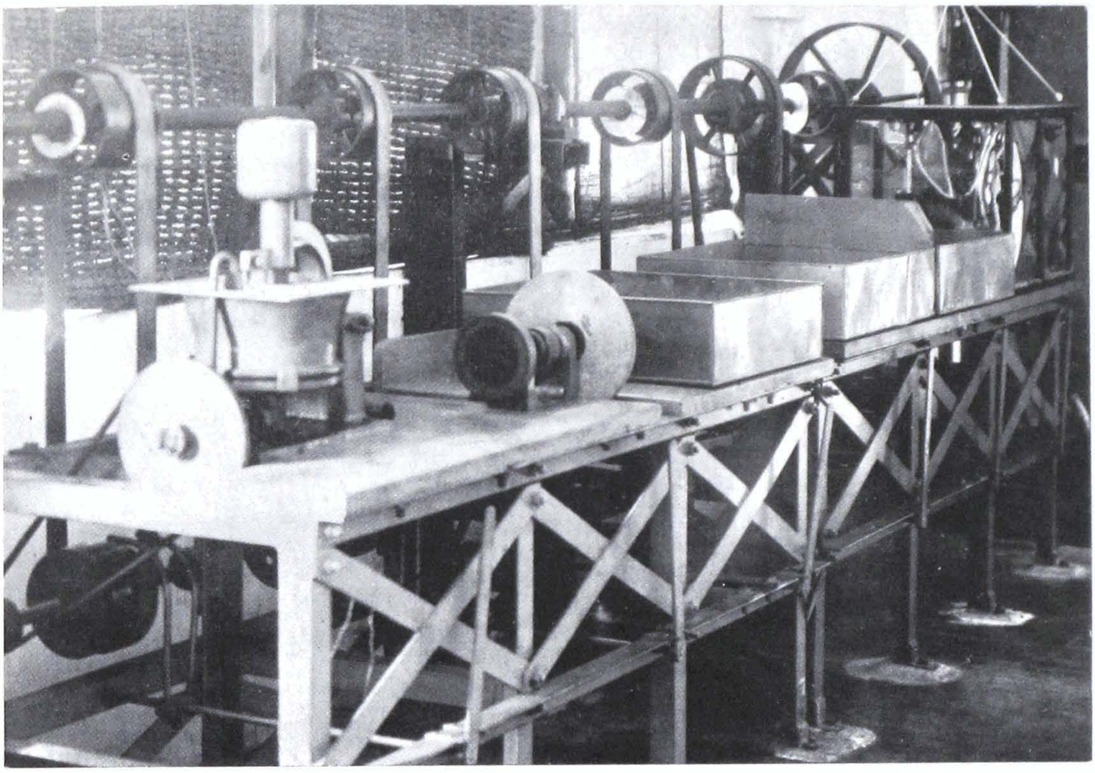
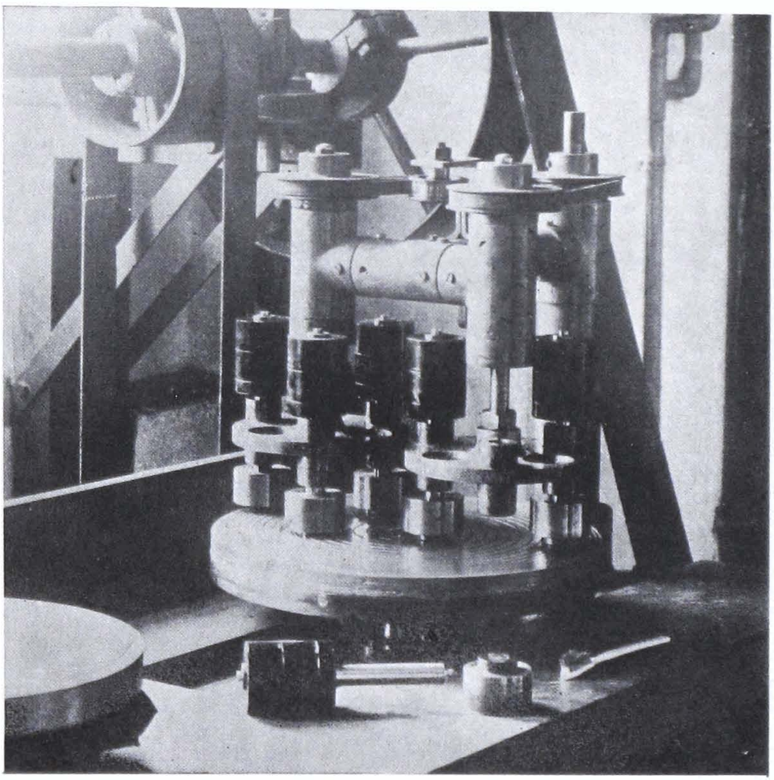


FIG. 1. SECTION MACHINES ASSEMBLED ON TABLES.



S. N. Das, Photos. G. S. I., Calcutta.

FIG. 2. POLISHING MACHINE (CELLULOID COVER RAISED), ONE WEIGHTED SPINDLE AND SPECIMEN REMOVED AND RESTING ON TABLE. CLOTH LAP TO LEFT, WITH TROUGH REMOVED; THE CLOTH LAP IS USED FOR POLISHING ROCKS.

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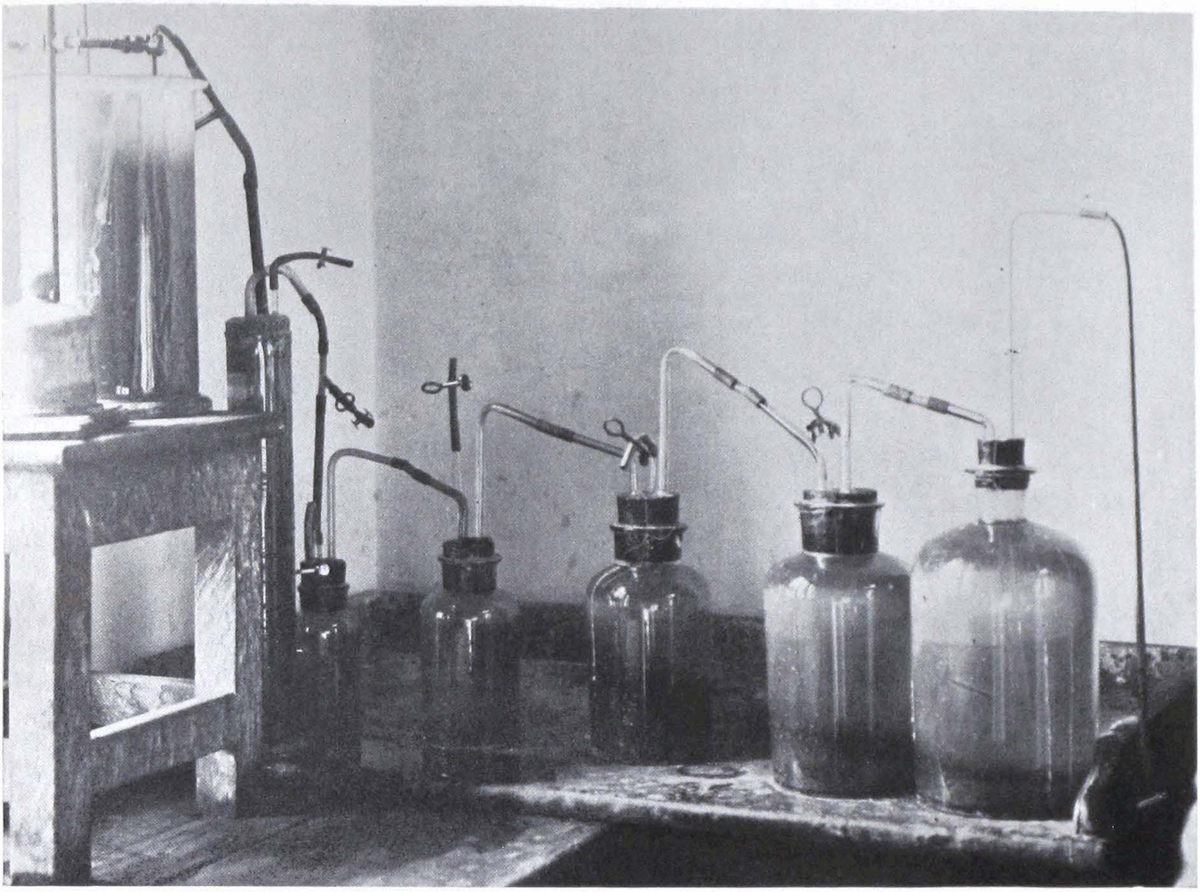
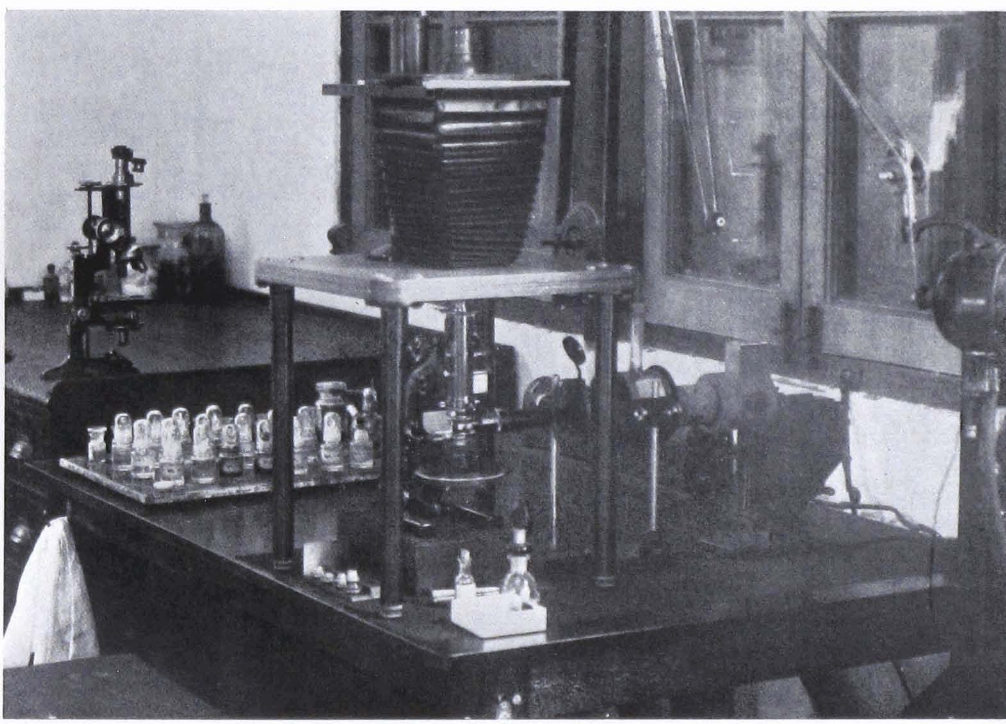


FIG. 1. APPARATUS FOR GRADING ABRASIVE POWDERS.



S. N. Das, Photos. *G. S. I., Calcutta.*

FIG. 2. ORE-MICROSCOPE AND APPARATUS, WITH CAMERA IN POSITION.

RECORDS OF THE GEOLOGICAL SURVEY OF INDIA.

VOL. I, 1868.

Part 1 (out of print).—Annual report for 1867. Coal-seams of Tawa valley. Coal in Garrow Hills. Copper in Bundelkhund. Meteorites.

Part 2 (out of print).— Coal-seams of neighbourhood of Chanda. Coal near Nagpur. Geological notes on Surat collectorate. Cephalopodous fauna of South Indian cretaceous deposits. Lead in Raipur district. Coal in Eastern Hemisphere. Meteorites.

Part 3 (out of print).—Gastropodous fauna of South Indian cretaceous deposits. Notes on route from Poona to Nagpur *viâ* Ahmednuggur, Jalna, Loonar, Yeotmahal, Mangali and Hingunghat. Agaté-flake in pliocene (?) deposits of Upper Godavary. Boundary of Vindhyan series in Rajputana. Meteorites.

VOL. II, 1869.

Part 1 (out of print).—Valley of Poorna river, West Berar. Kuddapah and Kurnool formations. Geological sketch of Shillong plateau. Gold in Singhbhum, etc. Wells at Hazareebagh. Meteorites.

Part 2 (out of print).—Annual report for 1868. Pangshura tecta and other species of Chelonia from newer tertiary deposits of Nerbudda valley. Metamorphic rocks of Bengal.

Part 3 (out of print).—Geology of Kutch, Western India. Geology and physical geography of Nicobar Islands.

Part 4 (out of print).—Beds containing silicified wood in Eastern Prome, British Burma. Mineralogical statistics of Kumaon division. Coal-field near Chanda. Lead in Raipur district. Meteorites.

VOL. III, 1870.

Part 1 (out of print).—Annual report for 1869. Geology of neighbourhood of Madras. Alluvial deposits of Irrawadi, contrasted with those of Ganges.

Part 2 (out of print).—Geology of Gwalior and vicinity. Slates at Chiteli, Kumaon. Lead vein near Chicholi, Raipur district. Wardha river coal-fields, Berar and Central Provinces. Coal at Karba in Bilaspur district.

Part 3 (out of print).—Mohpani coal-field. Lead-ore at Slimanabad, Jabalpur district. Coal, east of Chhattisgarh between Bilaspur and Ranchi. Petroleum in Burma. Petroleum locality of Sudkal, near Futtijung, west of Rawalpindi. Argentiferous galena and copper in Manbhum. Assays of iron ores.

Part 4 (out of print).—Geology of Mount Tilla, Punjab. Copper deposits of Dalbhum and Singhbhum: 1.—Copper mines of Singhbhum: 2.—Copper of Dalbhum and Singhbhum. Meteorites.

VOL. IV, 1871.

Part 1 (out of print).—Annual report for 1870. Alleged discovery of coal near Gooty, and of indications of coal in Cuddapah district. Mineral statistics of Kumaon division.

Part 2 (out of print).— Axial group in Western Prome. Geological structure of Southern Konkan. Supposed occurrence of native antimony in the Straits Settlements. Deposit in boilers of steam-engines at Raniganj. Plant-bearing sandstones of Godavari valley, on southern extensions of Kamthi group to neighbourhood of Ellore and Rajmandri, and on possible occurrence of coal in same direction.

Part 3 (out of print).—Borings for coal in Godavari valley near Dumaguden and Bhadrachalam. Narbada coal-basin. Geology of Central Provinces. Plant-bearing sandstones of Godavari valley.

Part 4 (out of print).—Ammonite fauna of Kutch. Raipur and Hengir (Gangpur) Coal-field. Sandstones in neighbourhood of first barrier on Godavari, and in country between Godavari and Ellore.

Vol. V, 1872.

Part 1 (out of print).—Annual report for 1871. Relations of rocks near Murree (Mari), Punjab. Mineralogical notes on gneiss of South Mirzapur and adjoining country. Sandstones in neighbourhood of first barrier on Godavari, and in country between Godavari and Ellore.

Part 2 (out of print).—Coasts of Baluchistan and Persia from Karachi to head of Persian Gulf, and some of Gulf Islands. Parts of Kummummet and Hanamconda districts in Nizam's Dominions. Geology of Orissa. New coal-field in south-eastern Hyderabad (Deccan) territory.

Part 3 (out of print).—Maskat and Massandim on east of Arabia. Example of local jointing. Axial group of Western Prome. Geology of Bombay Presidency.

Part 4 (out of print).—Coal in northern region of Satpura basin. Evidence afforded by raised oyster banks on coasts of India, in estimating amount of elevation indicated thereby. Possible field of coal-measures in Godavari district, Madras Presidency. Lameta or intra-trappean formation of Central India. Petroleum localities in Pegu. Supposed eozoonal limestone of Yellam Bile.

Vol. VI, 1873.

Part 1.—Annual report for 1872. Geology of North-West Provinces.

Part 2 (out of print).—Bisrampur coal-field. Mineralogical notes on gneiss of south Mirzapur and adjoining country.

Part 3 (out of print).—Celt in ossiferous deposits of Narbada valley (Pliocene of Falconer): on age of deposits, and on associated shells. Barakars (coal-measures) in Beddadanole field, Godavari district. Geology of parts of Upper Punjab. Coal in India. Salt-springs of Pegu.

Part 4 (out of print).—Iron deposits of Chanda (Central Provinces). Barren Islands and Narkondam. Metalliferous resources of British Burma.

Vol. VII, 1874.

Part 1 (out of print).—Annual report for 1873. Hill ranges between Indus valley in Ladak and Shah-i-Dula on frontier of Yarkand territory. Iron ores of Kumaon. Raw materials for iron-smelting in Raniganj field. Elastic sandstone, or so-called Itacolumyte. Geological notes on part of Northern Hazaribagh.

Part 2 (out of print).—Geological notes on route traversed by Yarkand Embassy from Shah-i-Dula to Yarkand and Kashgar. Jade in Karakash valley, Turkistan. Notes from Eastern Himalaya. Petroleum in Assam. Coal in Garo Hills. Copper in Narbada valley. Potash-salt from East India. Geology of neighbourhood of Mari hill station in Punjab.

Part 3 (out of print).—Geological observations made on a visit to Chadderkul, Thian Shan range. Former extension of glaciers within Kangra district. Building and ornamental stones of India. Materials for iron manufacture in Raniganj coal-field. Manganese-ore in Wardha coal-field.

Part 4 (out of print).—Auriferous rocks of Dhambal hills, Dharwar district. Antiquity of human race in India. Coal recently discovered in the country of Luni Pathans, south-east corner of Afghanistan. Progress of geological investigation in Godavari district, Madras Presidency. Subsidiary materials for artificial fuel.

Vol. VIII, 1875.

Part 1 (out of print).—Annual report for 1874. The Altum-Artush considered from geological point of view. Evidences of 'ground-ice' in tropical India, during Talchir period. Trials of Raniganj fire-bricks.

Part 2 (out of print).—Gold-fields of south-east Wynaad, Madras Presidency. Geological notes on Khareean hills in Upper Punjab. Water-bearing strata of Surat district. Geology of Scindia's territories.

Part 3 (out of print).—Shahpur coal-field, with notice of coal explorations in Narbada regions. Coal recently found near Moflong, Khasia Hills.

Part 4 (out of print).—Geology of Nepal. Raigarh and Hingir coal-fields.

Vol. IX, 1876.

Part 1 (out of print).—Annual report for 1875. Geology of Sind.

Part 2 (out of print).—Retirement of Dr. Oldham. Age of some fossil floras of India. Cranium of Stegodon Ganesa, with notes on sub-genus and allied forms. Sub-Himalayan series in Jamu (Jammoo) Hills.

Part 3 (*out of print*).—Fossil floras in India. Geological age of certain groups comprised in Gondwana series of India, and on evidence they afford of distinct zoological and botanical terrestrial regions in ancient epochs. Relations of fossiliferous strata at Maleri and Kota, near Sironcha, C. P. Fossil mammalian faunæ of India and Burma.
Part 4 (*out of print*).—Fossil floras in India. Osteology of Merycopotamus dissimilis. Addenda and Corrigenda to paper on tertiary mammalia. Plesiosaurus in India. Geology of Pir Panjal and neighbouring districts.

VOL. X, 1877.

Part 1 (*out of print*).—Annual report for 1876. Geological notes on Great Indian Desert between Sind and Rajputana. Cretaceous genus Omphalia near Nameho lake, Tibet, about 75 miles north of Lhassa. Estheira in Gondwana formation. Vertebrata from Indian tertiary and secondary rocks. New Embydine from the upper tertiaries of Northern Punjab. Observations on under-ground temperature.
Part 2 (*out of print*).—Rocks of the Lower Godavari. 'Atgarh Sandstones' near Cuttack Fossil floras in India. New or rare mammals from the Siwaliks. Aravali series in North-Eastern Rajputana. Borings for coal in India. Geology of India.
Part 3 (*out of print*).—Tertiary zone and underlying rocks in North-West Punjab. Fossil floras in India. Erratics in Potwar. Coal explorations in Darjiling district. Limestones in neighbourhood of Barakar. Forms of blowing machine used by smiths of Upper Assam. Analyses of Raniganj coals.
Part 4 (*out of print*).—Geology of Mahanadi basin and its vicinity. Diamonds, gold, and lead ores of Sambalpur district. 'Eryon Comp. Barrovensis', McCoy, from Sripermatur group near Madras. Fossil floras in India. The Blaini group and 'Central Gneiss' in Simla Himalayas. Tertiaries of North-West Punjab. Genera Chœromeryx and Rhagatherium.

VOL. XI, 1878.

Part 1.—Annual report for 1877. Geology of Upper Godavari basin, between river Wardha and Godavari, near Sironcha. Geology of Kashmir, Kishtwar, and Pangi. Siwalik mammals. Palæontological relations of Gondwana system. 'Erratics in Punjab.'
Part 2 (*out of print*).—Geology of Sind (second notice). Origin of Kumaon lakes. Trip over Milam Pass, Kumaun. Mud volcanoes of Ramri and Cheduba. Mineral resources of Ramri, Cheduba and adjacent islands.
Part 3 (*out of print*).—Gold industry in Wynaad. Upper Gondwana series in Trichinopoly and Nellore-Kistna districts. Senarmontite from Sarawak.
Part 4.—Geographical distribution of fossil organisms in India. Submerged forest on Bombay Island.

VOL. XII, 1879.

Part 1 (*out of print*).—Annual report for 1878. Geology of Kashmir (third notice). Siwalik mammalia. Siwalik beds. Tour through Hangrang and Spiti. Mud eruption in Ramri Island (Arakan). Braunite, with Rhodonite, from Nagpur, Central Provinces. Palæontological notes from Satpura coal-basin. Coal importations into India.
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Part 2.—Geological notes. Palæontological notes on lower trias of Himalayas. Artesian wells at Pondicherry, and possibility of finding sources of water-supply at Madras.

Part 3.—Kumaun lakes. Celt of palæolithic type in Punjab. Palæontological notes from Karharbari and South Rewa coal-fields. Correlation of Gondwana flora with other floras. Artesian wells at Pondicherry. Salt in Rajputana. Gas and mud eruptions on Arakan coast on 12th March 1879 and in June 1843.

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Part 2 (out of print).—Nahan-Siwalik unconformity in North-Western Himalaya. Gondwana vertebrates. Ossiferous beds of Hundes in Tibet. Mining records and mining record office of Great Britain: and Coal and Metalliferous Mines Act of 1872 (England). Cobaltite and danatite from Khetri mines, Rajputana; with remarks on Jaipurite (Syepoorite). Zinc-ore (Smithsonite and Blende) with barytes in Karnul district, Madras. Mud-eruption in island of Cheduba.

Part 3 (out of print).—Artesian borings in India. Oligoclase granite at Wangtu on Sutlej, North-West Himalayas. Fish-plate from Siwaliks. Palæontological notes from Hazaribagh and Lohardagga districts. Fossil carnivora from Siwalik hills.

Part 4 (out of print).—Unification of geological nomenclature and cartography. Geology of Arvali region, central and eastern. Native antimony obtained at Pulo Obin, near Singapore. Turgite from Juggiapett, Kistnah district, and zinc carbonate from Karnul, Madras. Section from Dalhousie to Pangi, *viâ* Sach Pass. South Rewah Gondwana basin. Submerged forest on Bombay Island.

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Part 2 (out of print).—Geology of Travancore State. Warkilli beds and reported associated deposits at Quilon, in Travancore. Siwalik and Narbada fossils. Coal-bearing rocks of Upper Rer and Mand rivers in Western Chutia Nagpur. Pench river coal-field in Chindwara district, Central Provinces. Boring for coal at Engsein, British Burma. Sapphires in North-Western Himalaya. Eruption of mud volcanoes in Cheduba.

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Part 4 (out of print).—Gold-fields of Mysore. Borings for coal at Beddadanol, Godavari district, in 1874. Supposed occurrence of coal on Kistna.

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Part 2 (out of print).—Synopsis of fossil vertebrata of India. Bijori Labyrinthodont Skull of Hippotherium antilopinum. Iron ores, and subsidiary materials for manufacture of iron, in north-eastern part of Jabalpur district. Laterite and other manganese-ore occurring at Gosulpore, Jabalpur district. Umaria coal-field.

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Part 2 (out of print).—Fossiliferous series in Lower Himalaya, Garhwal. Age of Mandhali series in Lower Himalaya. Siwalik camel (Camelus Antiquus, nobis ex Falc. and Caut. MS.). Geology of Chamba. Probability of obtaining water by means of artesian wells in plains of Upper India. Artesian sources in plains of Upper India. Geology of Aka Hills. Alleged tendency of Arakan mud volcanoes to burst into eruption most frequently during rains. Analyses of phosphatic nodules and rock from Mussooree.

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Part 2 (out of print).—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruption rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-beds of Salt-range. Gondwana Homotaxis.

Part 3 (out of print).—Geological sketch of Vizagapatam district, Madras. Geology of Northern Jesalmer. Microscopic structure of Malani rocks of Arvali region. Malanjkhandi copper-ore in Balaghat district, C. P.

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Part 4 (out of print).—Points in Himalayan geology. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaon, Section II. Iron industry of western portion of Raipur. Notes on Upper Burma. Boring exploration in Chhattisgarh coal-field (Second notice). Pressure Metamorphism, with reference to foliation of Himalayan Gneissose Granite. Papers on Himalayan Geology and Microscopic Petrology.

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Part 2 (out of print).—Indian Steatite. Distorted pebbles in Siwalik conglomerate. "Carboniferous Glacial Period." Notes on Dr. W. Waagen's "Carboniferous Glacial Period". Oil-fields of Twingoung and Beme, Burma. Gypsum of Nehal Nadi, Kumaun. Materials for pottery in neighbourhood of Jabalpur and Umaria.

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Part 4 (*out of print*).—Geological sketch of Naini Tal; with remarks on natural conditions governing mountain slopes. Fossil Indian Bird Bones. Darjiling Coal between Lisu and Ramthi rivers. Basic Eruptive Rocks of Kadapah Area. Deep Boring at Lucknow. Coal Seam of Dore Ravine, Hazara.

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Part 2 (*out of print*).—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Naméka Ruby-Mine in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State. Salt-spring near Bawgyo, Thibaw State.

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Part 3 (*out of print*).—Geology of Sherani Hills. Carboniferous Fossils from Tenasserim. Boring at Chandernagore. Granite in Tavoy and Mergui.

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Part 2 (out of print).—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwal.

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Part 2 (out of print).—General report for 1905. Lashio Coal-field, Northern Shan States. Namma, Mansang and Man-se-le Coal-fields, Northern Shan States, Burma. Miscellaneous Notes.

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