

NOTE ON A GLACIER IN THE ARWA VALLEY, BRITISH GARHWAL. BY L. B. GILBERT, B. SC. (LONDON), EXECUTIVE ENGINEER, KUMAON PROVINCIAL DIVISION AND J. B. AUDEN, M. A. (CANTAB.), *Assistant Superintendent, Geological Survey of India.* (With Plates 15 to 21).

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### I.—INTRODUCTION.

After Mr. F. S. Smythe and his party had climbed Mount Kamet in June 1931, they turned their attention to the area west of Kamet, and ascended the Arwa valley in order to explore the peaks forming the boundary between British and Tehri Garhwal. In the London 'Times' of September 24th, 1931, Mr. Smythe published an article entitled 'The Conquest of Kamet' from which the following is an extract:—

<sup>1</sup> As in Northern Sikkim, there are traces in Garhwal of a former glacial age when glaciers extended far down the lower valleys. Himalayan glaciers are for the most part retreating, but some are advancing in Northern Garhwal. One glacier debouching into the Arwa valley has advanced

so far that the valley is in danger of being choked by it. Were it to advance 200 or 300 yards farther the valley stream would be dammed, and as the valley is flat for several miles a large lake would be formed. The bursting of the dam would be disastrous to Badrinath, and other villages in the Alakhnanda valley, and might even result in serious floods far down on the plains. This glacier should be watched.'

This paragraph attracted the attention of the officers of the Public Works Department in the United Provinces, on account of the possible danger involved, by a flood, both to the pilgrims who visit Badrinath, to the various bridges and buildings situated along the pilgrim route, and, in addition, to the head-works of the Upper Ganges canal at Hardwar. The memory of the 10,000 million cubic feet of water which swept down the Alakhnanda consequent on the collapse of the landslip dam at Gohna, in 1894, has caused the Government engineers the more certainly to take cognisance of information concerning actual or potential river blockages.

Consequently, at the suggestion of the first writer, a joint inspection of the Arwa valley was made by the authors in June, 1932.

Just prior to their visit, Captain Birnie, a member of the Kamet Expedition, published an account of the Arwa glaciers in the *Himalayan Journal*.<sup>1</sup> Attached to this account was a map on the scale of half an inch to one mile of the glaciers and peaks at the upper or western end of the Arwa valley. Captain Birnie made no mention of any potential blockage in the Arwa valley, nor did it appear from his map that any of the glaciers marked therein would be likely in the near future to cause trouble. The authors, therefore, expected to find the glacier mentioned by Mr. Smythe lower down the Arwa river in the area to the east of that included in Captain Birnie's map. This proved to be so, and was confirmed on the return of the second author to Calcutta, after an absence of six months, when access could be had to the *Geographical Journal*, Volume LXXIX (1932). On page 6, Mr. Smythe gives a detailed description of this glacier.

The lower part of the Arwa river flows from west to east, joining the Saraswati river near Ghastoli, at Lat. 30° 52' 30" : Long. 79° 28', about 10 miles from Badrinath. The area is covered by Survey of India degree sheet No. 53N. The glacier in question occurs about two miles up the Arwa river from its confluence with the Saraswati, and flows

<sup>1</sup> *Himalayan Journal*, Vol. IV, pp. 35-45, (1932).

from the south. The barometric height of the valley bottom at the eastern side of the glacier was 13,720 feet.

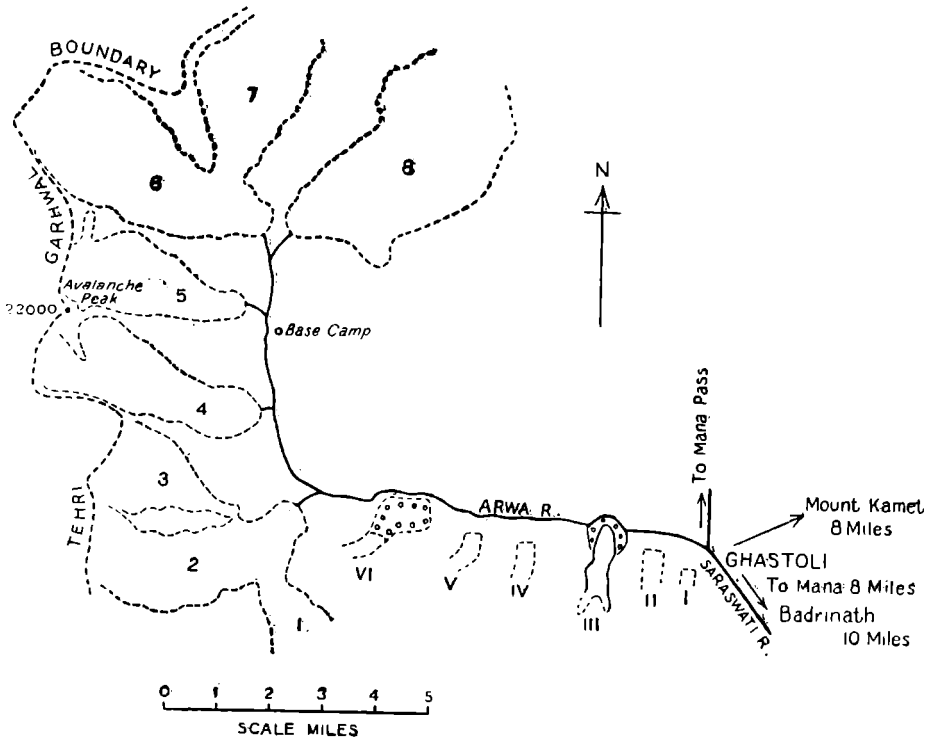


FIG. 1. Sketch Map of the Arwa glaciers.

(Glaciers Nos. 1 to 8 are taken from the map in *Geogr. Journ.*, Vol. LXXIX, p. 7. This map differs considerably from that published in *Himalayan Journal*, Vol. IV, p. 44. Glaciers Nos. I to VI of the lower Arwa valley are approximately marked from notes taken in 1932.)

The authors left Ranikhet by the pilgrim route, *viâ* Dwarahat and Karnaprayag, and reached the glacier on 15th June. Sporadic rain and low cloud hampered their examination, which was completed in three days. On the 19th, they moved camp to height 15,400. The night of the 20th June was spent at the base camp of 16,300 feet, established by the Kamet Expedition in 1931, about 10 miles up from Ghastoli. The authors wish to record their cordial appreciation of the help given by Pandit B. D. Nautiyal, Supervisor.

## H.—GENERAL DESCRIPTION OF VALLEYS.

The signs of possible former glacial action below Badrinath are not very definite. At milestone, 172 miles 6 furlongs<sup>1</sup>, the granulites are polished, but show no striæ, and remnants

**Below Badrinath.** of pot holes suggest that the polishing was probably due to river action at a time when the river had not eroded to its present level.

The rock surfaces at mile 175 furlongs 6 are more typical of glacial action, showing the presence of downward-directed striæ. Nevertheless, the shape of the valley here, even allowing for later modification by river erosion, is not at all typical of glacial action. The overlapping spurs in the valley between these two distance marks are definitely a feature characteristic of river rather than of glacial action.

Numerous dip-slope surfaces of the bedded quartz-biotite granulites give deceptive impressions of polishing. These are, however, generally plane and not curved surfaces and are seldom parallel to the sides of the valley.

Looking up the Alaknanda river from the P. W. D. bungalow at Badrinath (Plate 15), there is seen an excellent U-shaped valley, without overlapping spurs, and of

**Above Badrinath.** simple outline. This was at first taken without hesitation to be of glacial origin. Subsequently, it was seen that to some extent the U-shape was due to the inclination of slopes of talus coming down from the valley sides. The simplicity of the valley course, the width of the valley, and the old moraine-like hummocks upon which the bungalow rests, are, however, strong indications that a glacier formerly descended the Alaknanda at least as far as Badrinath, depositing a terminal moraine there. It is very probable that the original valley was U-shaped, but that it has been later modified by talus to give a secondary U within the primary one. Above the Mana falls, and south of Musapani, are seen old lateral moraines on the west side of the Saraswati river, which have been subsequently slightly dissected by occasional streams flowing from the western slopes. North of Musapani, and also on the west side of the Saraswati, there are small hanging glaciers whose snouts lie some 2,000 feet above the main valley bottom. These send down little moraine. Old moraine below

<sup>1</sup> Miles measured along the pilgrim track from Hardwar. Badrinath is at mile 183.

these glaciers, belonging to the now vanished Saraswati glacier, has been partially covered up by recent talus.

It should be emphasised that there is little purity in the type of rock detritus in any of the valleys visited. Moraine matter interdigitates with talus, while the present river has deposited gravels, with water-rounded boulders, and bedded micaceous silts. The river has often cut into its own deposits, leaving small river-erosion forms within the larger enclosing glacial valley.

Water-rounding of boulders, particularly of biotite-gneiss and tourmaline-granite, is marked, even to within two miles below the debouching of the rivers from the glaciers. Associated with these gravels is angular debris from talus fans and from moraines.

On turning from the Saraswati into the east-west Arwa valley there is seen, on the south side, a series of remarkably steep hanging glaciers. No glaciers are seen on the north side, the only noticeable feature being talus fans fed from gulleys in the highly jointed granite. Similar talus fans occur on the south side, alternating and interdigitating with moraines from the hanging glaciers.

**Arwa valley.**

Six glaciers occur on the south flank of the valley along its east-west stretch, east of the portion included in Captain Birnie's map. These are given in Roman numerals so as not be confused with those figured by Captain Birnie.

Counting from the east, the snout of No. I glacier lies high up within its hanging valley. That of No. II has descended slightly, but is still about 1,000 feet above the main valley bottom, without any appreciable moraine fan, and need not be further considered. No. III is the glacier with which this report is directly concerned, and will be described in detail in a later section. Seen from the east, at river level (Plate 16), the moraine of this glacier blocks any view of the upstream side of the main valley, having crossed the whole width of the valley except for 778 feet. The snouts of numbers IV and V are high, not having forsaken their lateral hanging valleys. The base of the moraine of No. VI occurs at height 15,000 ft., about  $1\frac{1}{2}$  miles east of the snout of combined glaciers, 1, 2 and 3 in Captain Birnie's map, and calls for more comment. Its moraine, like that of No. III, has spread right across the main valley, except for a few hundred feet, and is, indeed, more formidable in appearance than No. III moraine. This moraine, besides being so close to the north side of the valley,

has spread out eastwards down the main valley. On ascending, however, to its hummocky plateau surface, no trace of a glacier could be seen. No sign of ice was visible, except high up in the hanging valley, where it takes a bend to the south-west. The practical absence of falling stones, to be expected from the melting of stone-studded ice, had it been present,<sup>1</sup> and the absence of cracking, usual in ice which is adjusting itself to movement, lead to the supposition that the moraine of No. VI glacier is at present dead, having been forsaken by the retreating ice. The moraine of this glacier is little covered by shrub, grass or lichen, which may be explained partly by the altitude being unfavourable to plant growth, partly perhaps by supposing the retreat of the ice to have been recent. Mr. Smythe (*ibid.*, p. 6) notes 'three glaciers of considerable size debouching into the valley from the south.' In 1932 these glaciers, clearly Nos. IV, V and VI, were not actually debouching into the valley.

On coming to the area included in Captain Birnie's map, the snout of the combined glaciers 1, 2 and 3 was found well to the south of the river fed by the higher glaciers, as indicated on the map. The snout of glacier 4 ends in an ice cave opening out into a small lake a few hundred yards from the river which flows from glaciers 5, 6, 7 and 8, and is only about half a mile from the opposite E. N. E. hillside. On the map, it is shown as over two miles distant from this hillside. This was probably a mistake, the amount of morainic matter at the time doubtless having obscured the snout. This glacier has a relatively low gradient, and it is unlikely that its advance would be rapid. The existence of the very characteristic tan-brown lateral moraine dropped from its north flank<sup>2</sup>, some distance in advance of the present snout, rather suggests a retreat. This is, of course, no proof that the glacier may not at the moment be advancing. Even should advance be rapid, the gradient of the N. N. W.—S. S. E. valley, into which it would encroach, is sufficiently steep for any lake formed to be of negligible dimensions.

The remaining glaciers do not concern this report. It may perhaps be remarked that from a position at 17,300 feet, north-east

<sup>1</sup> Very occasionally stones did fall, but the moraine, in its upper part, is made up of stones so precariously tumbled together that such rare falling may be considered to be without significance as an indication of ice.

<sup>2</sup> The rock is a ferruginous micaceous shale; sometimes slate or phyllite.

of the 16,300 foot base camp, glacier 5 was seen to be accurately represented on the map, 6 was recognised, but 8 seems to require some correction.

### Secular Changes.

It can be asserted with considerable confidence that a glacier originally descended the Saraswati and Alaknanda valleys as far as Badrinath. Consequently, the retreat of the ice has been great since the period of maximum glaciation.

Little can be said about the recent advance and retreat of the local glaciers in the Arwa valley. The valley is uninhabited, and only the lowest part is used by Bhotiyas as a grazing ground for sheep and goats. No information could be elicited from the Mana Bhotiyas concerning the behaviour of the glaciers. No. III has sometime advanced, and is still active. No. VI, of exactly similar type to No. III, has retreated. No. IV has in no distant past retreated. The collective evidence is therefore contradictory. Accurate measurements of a large number of glaciers over a considerable period are required before any consistency in advance and retreat can be detected.<sup>1</sup>

### III.—GLACIER NO. III, ARWA VALLEY.

#### I. Form.

As previously stated, glacier No. III occurs about two miles up the Arwa valley from its confluence with the Saraswati. It is fed by two very steep, hanging glaciers, which join in a cirque some distance above the conspicuous ice-fall in the constriction at the base of the hanging valley (Plate 18). What may perhaps be called the 'normal' extent of this glacier was doubtless similar to that of Nos. I, II, IV and V, the snout occurring at the constriction, and dropping a moraine in fan form at its base, into the main valley. At the present time, however, the snout has advanced over its moraine so as to rest only 778 feet from the opposite side of the valley at its level (Plate No. 16). The lower part of the glacier, which protrudes beyond the constriction, is inclined northwards at about  $11\frac{1}{2}^{\circ}$ . The ice of this lower advanced portion

<sup>1</sup> Such consistency may be found by a study of the 'Rapport pour 1014-28' of the Commission U. G. G. I. des Glaciers.

is so charged with boulders and dirt, and is so effectively covered by moraine matter, that, when first seen from the east, at valley bottom, it was momentarily mistaken for fine-grained laminated sediment interbedded with boulder moraine. The true conditions are best realised from view-points on the northern slopes of the valley, such as D1 or D2, from which radial crevasses and blue ice at the snout are at once evident (Plates 18, 19).

Two features may be stressed:—

- (a) The ice does not rest on the main valley floor, but on moraine which has been liberated in advance, by tip-heap deposition of boulders, both en-glacial and supra-glacial, from the melting of the snout and sides. The base of the ice is not discernible but, of the 450 feet combined thickness of ice and underlying moraine near the snout, 150 feet may be taken as a fair estimate for the ice, and 300 feet for the moraine.
- (b) The ice does not, as might have been expected, expand laterally after leaving the constriction, but occurs as a tongue, with roughly parallel sides, and of about the same width as that of the constriction. In this it differs from the ice which must recently have covered the moraine of glacier No. VI.

## 2. Question of recent advance.

The Survey of India Degree Sheet No. 53N shows, erroneously, a main longitudinal glacier in the Arwa valley terminating three miles up from Ghastoli. Mr. Smythe (*loc. cit.*, p. 6) suggests that the surveyors, looking probably from the east, took glacier No. III to be the snout of a longitudinal glacier in the main Arwa valley. From this it might be concluded that the original advance of glacier No. III occurred before 1864, the date of the commencement of the survey. Since all the side valleys, both to east and west of the Saraswati (Sarsuti) are shown with longitudinal glaciers similar to that in the Arwa valley, it is possible that this explanation does not hold. It is more probable that the surveyors adopted a uniform technique for representing valleys which they had orders not to spend time in visiting; (Dr. Longstaff, *ibid.*, p. 14).

The present condition of the moraine does no more than assign a certain, but not great age, to the original advance beyond the



constriction. It is partly covered with lichen, grass, and shrub. No rates of growth are known for the plants concerned, so that it is impossible to give a quantitative estimate. The grass, and even the shrubs, may be annuals. Lichens, on the other hand, usually grow slowly. Of more value is the density of growth. Only the lateral moraine, on the left or west side of the advanced tongue of ice, is closely covered and gives any impression of age. The greater part of the rest of the moraine is very sparsely covered. Over this latter moraine the ice has dropped boulders of perfectly fresh tourmaline granite<sup>1</sup>, completely free from plant growth. These may be seen in Plate 17 as three pale-coloured tongues descending from the ice. Recent advance of the ice is therefore suggested.<sup>2</sup> The moraine immediately at the snout appears to be slightly older than that just at the sides, which indicates that this year there may have been a slight lateral extension of ice near the snout rather than definite longitudinal advance. It cannot be inferred from this that there is no further danger of longitudinal advance. Such signs must mean little more than the capricious behaviour of the glacier in the year of observation. The part of the ice which happened to flow to the snout may, indeed, have been relatively poorly charged with boulders.

No definite indication of advance or retreat is given by the angle of the ice front. This angle varies from 40° to 70° in different parts of the snout. Melting is strong in June. Advance could only be proved if the angle of slope during such a time were vertical. The lack of verticality, on the other hand, does not necessarily indicate retreat, since such a condition may obtain in a glacier which is advancing slowly but at the same time is subject to rapid melting.

### 3. Modes of future advance.

Two modes of advance may be considered. The first, in which advance is gradual; the second, in which it is sudden and rapid. In considering the first mode of advance it is assumed that the Arwa river, when at its greatest volume, would be capable of dealing with the greater part of the moraine matter which would be tumbled into it. Large boulders might remain scattered in the bed of the

<sup>1</sup> These granites weather very rapidly. The perfect whiteness of a freshly split surface will tarnish within a few months.

<sup>2</sup> The *dak-coolie* of the Kamet expedition reported a slight retreat of the ice, but his evidence may be discounted, since the amount of retreat he figured would not have been sensible to any one except by instrumental observation or cairn sighting.

stream, as some do at the present time, but the smaller boulders would be swept away. Thereby any chance of the micaceous silt, held by the river, being retained by the smaller boulders and pebbles would be prevented. The ice rests on a considerable thickness of moraine, and it is possible to imagine that, in the event of slow advance, in proportion as the river swept the greater part of the toppling moraine away, so would the overlying ice, if at all overhanging, drop as blocks by splitting along crevasse joints. Advance of ice would, it is true, be expected to be most rapid in the early months of the year, when the river is not at its greatest volume. Nevertheless, such advance is, by the first supposition, slow. Whatever slight moraine blockages might occur during the spring along the south side of the river would probably be for the most part removed when the river increased in size and carrying power during the period of melting snows.

The second assumption is that of sudden and rapid advance of ice across the valley.

It is seen from the description that glacier No. III, although gently inclined in its lowest reach, is fed by very steep ice (Plate 18) at a relatively short distance behind the lowest ice-fall. Without wishing to stress the comparison with Kashmir glaciers, it may be considered that the Arwa glacier is of transverse rather than of longitudinal type,<sup>1</sup> one therefore in which a sudden and rapid advance may be expected. The Hassanabad glacier in the Hunza district and the Yengutsa glacier in the Nagir district of Kashmir are typical transverse glaciers and both are rapid movers; Hayden<sup>2</sup> reports the almost incredible distance of six miles in a single year for the advance of the Hassanabad glacier. Glacier No. III, Arwa valley, is, it is true, of very inferior dimensions compared to that at Hassanabad. Nevertheless, even allowing for the difference in scale, it is very probable that the inclination of its feeder glaciers and their closeness to the snout, would permit rapid advance in this Arwa glacier. The short distance of 778 feet which now separates the snout from the opposite side of the Arwa valley could be covered in a single season, when the river was at its lowest. If this were so, the river would at first percolate through the moraine which had been brought so suddenly across its

<sup>1</sup> *Rec. Geol. Surv. Ind.*, XXXV, pp. 125, 136, (1907).

<sup>2</sup> *Ibid.*, p. 135; Mason, *op. cit.*, LXIII, p. 234. (1930), questions the extreme rapidity of this advance, but accepts that in a single year it may have been as much as one mile. Even this is remarkable.

course. Subsequently, however, as the river increased in volume and silt content with the melting of the snows, there would be progressive retention of silt by the moraine, and decreased percolation. A lake would form under these conditions.

It is impossible to state which of these alternatives is the more likely.

#### 4. Magnitude of possible flood.

The largest flood would be produced by the glacier moving rapidly across the gap in the valley. It would, as indicated in Plate 21, form a dam some 400 feet high, but its width would not be great and the materials forming the dam would not be compacted as when a large landslip occurs. Such a dam would probably burst under the weight of water accumulated behind it and, assuming the worst that could happen, the water would just then be coming over the top of the dam.

The length of the lake which would be formed in these circumstances was determined by measuring the distance up the valley to a point which, as closely as could be determined by an Abney level, was at the height of the probable top of the dam. The width of the lake, both at river level and at full lake level, was determined roughly by means of a theodolite. The figures are:—

Length of lake . . . . .	7,900 feet.
Width at full lake level . . . . .	1,060 feet.
Width at river level . . . . .	745 feet.

The valley above the site of the glacier is comparatively flat for about a mile—actual observation showing a rise of 210 feet per mile. From that point, it rises twice as steeply so that the volume of water that would be impounded may be calculated:—

$$\begin{aligned} \text{Volume} & \left\{ \frac{5300 \times (400+190)}{2} + \frac{(2600 \times 190)}{2} \right\} \\ & \times \frac{1060+745}{2} \\ & = 1634, 881, 500 \text{ cubic feet.} \\ & \text{say } 1,640 \text{ million cubic feet.} \end{aligned}$$

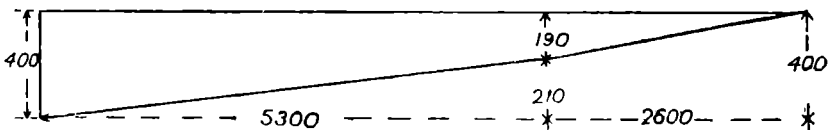


FIG 2.—Longitudinal section up Arwa valley.

When the Gohna dam was topped 10,000 million c.ft. of water were liberated in  $4\frac{1}{2}$  hours, the upper 380 feet of the dam being washed away during the process. But the Gohna lake was 4 miles long against a length of  $1\frac{1}{2}$  miles for the possible lake in the Arwa valley, and it is probable that the Arwa dam will fail under water pressure rather than be topped and scoured out. The Arwa lake would, therefore, be emptied in a much shorter time than  $4\frac{1}{2}$  hours, and that time might be fixed at  $2\frac{1}{2}$  hours. This means a discharge of about 200,000 cusecs. in the Arwa valley as against a discharge of 617,284 cusecs. from the Gohna lake. That is to say, the flood from the Arwa lake would have about one third the magnitude of that from the Gohna lake.

On page 16 of the printed report on the Gohna flood<sup>1</sup> are recorded the heights to which the river rose at different places in the Alaknanda valley. The possible Arwa lake would be fifty miles further away from those points and the heights to which the water would rise instead of being one third might be taken as one fourth the heights recorded for the Gohna flood, as indicated in the following table. If the water were to rise to these levels no damage would be done between Chamoli and Hardwar except that the suspension bridge at Karnaprayag would be washed away and small sections of the pilgrim route near Chamoli, Karnaprayag and Rudraprayag would be damaged,

Name of place.	Height (in feet) to which water rose in Gohna flood.	Height (in feet) to which water will rise assuming $\frac{1}{4}$ th the magnitude of Gohna flood.
Chamoli . . . . .	160	40
Nandprayag . . . . .	113	28
Karnaprayag . . . . .	130	33
Rudraprayag . . . . .	140	35
Srinagar . . . . .	42	11
Deoprayag . . . . .	70	18
Biasghat . . . . .	88	22
Lachmanjhula . . . . .	35	9
Rikhikesh . . . . .	18	5
Hardwar . . . . .	11	3

<sup>1</sup> This report is in the records of the U. P. Government.

Except for a low-lying approach to the suspension bridge at Chamoli and a steel girder bridge over the Alaknanda river in mile 143 furlong 2, the pilgrim route between Chamoli and Joshimath passes many hundreds of feet above the river and is quite out of reach of the anticipated flood.

The steel girder bridge just referred to is constructed in a rocky gorge and has a span of  $70\frac{1}{2}$  feet. Assuming a velocity of 30 feet per second for the flood, the rise in water level may be taken as  $200,000 \div (30 \times 70\frac{1}{2}) = 95$  feet. The bridge is only 64 feet above present water level and would therefore be destroyed.

It is between Badrinath and Vishnuprayag that the maximum damage would be done. There are in this valley two points of constriction, one at Bamini just below Badrinath where there is a steel girder bridge of 84 feet span, and one at Ghursil in mile 179 where there is a steel girder bridge of 40 feet span. The rise in flood level at these points would be:—

Bamini	$200,000 \div (30 \times 84) =$	.	.	.	.	.	.	.	80 feet.
Ghursil	$200,000 \div (30 \times 40) =$	.	.	.	.	.	.	.	167 feet.

Since the heights of the bridges above present water level are 32 and 60 feet respectively, they would both be destroyed.

There are some low-lying villages between Vishnuprayag and Hanumanchatti and the pilgrim route runs close above the river. Great damage would, therefore, be done both to the villages and to the road.

Much damage would also be done at Badrinath. At one place, opposite the hot spring, the river is only 60 feet wide. Here, the flood would rise to 111 feet, and later, there would be a backing up of water due to a rise of 80 feet at the Bamini bridge. This would mean the submersion of the houses on the river bank and of most of the town. During the flood of August 1931, when the river rose about 30 feet above its ordinary level, one house collapsed and many of the retaining walls on the river bank were washed away. A flood on the scale anticipated would bring down most, if not all, of the houses on the river bank, cut away a large slice of the foreshore, and possibly damage the temple.

Badrinath is built on the terminal moraine of the old glacier mentioned in an earlier section of this report, and the river has cut its way down through this moraine. The left bank is still protected by enormous boulders but the right bank, on which the town

stands, has been deprived of this protection by the activities of builders who have found in the boulders a convenient quarry for building-stone. Quite apart from any danger from abnormal flood, Badrinath needs the protection of a stone embankment and an apron of articulated cement-concrete blocks, else the scour action of the river even in normal annual flood, will gradually undercut and destroy all the buildings on its bank.

### 5. The probable time for the lake to fill.

On the 22nd June, when the snow-fed rivers were in flood, the discharge of the Arwa stream was found to be about 1,100 cusecs. Since rainfall is scanty, maximum discharge cannot be greater than 1,200 cusecs. As has been suggested, the glacier will probably close the gap in the valley at an early month in the year when the size of the stream is small, and the discharge at that time may safely be taken to be not more than 150 cusecs. Assuming the dam is formed early in March the following figures may be adopted :—

Discharge in March, 150 cusecs. or a total of 402 million c.ft.

Discharge in April, 300 cusecs. or a total of 778 million c.ft.

Discharge in May, 600 cusecs. or a total of 1,607 million c.ft.

Discharge in June, 1,200 cusecs. or a total of 3,110 million c.ft.

Even assuming that half the water is lost through percolation, it will be seen that  $\frac{402+778+1607}{2} = 1,393$  million c. ft. of water will have accumulated by the end of May, against a lake capacity of 1,640 million c.ft. On the assumptions made, the lake would be full and the dam would burst on the 3rd June. It is evident that inspections of the glacier should be made as early in May as possible if warnings are to be issued to villages in the danger zone.

It is true, and a remarkable fact, that both the floods in the Alaknanda valley of which there is any record took place in August; the Gohna flood on the 26th August, 1894 and the recent flood, the cause of which has never been precisely ascertained, on the 23rd August, 1931. But the lake area in the Arwa valley is a small one and would fill rapidly, and it is advisable to assume that measures would have to be adopted to issue the necessary warnings much earlier in the year.

## 6. Mapping.

The moraine and glacier were mapped from a prismatic compass and chain survey and the outlines of the valley and position of the ice falls filled in by obtaining bearings from known points. The results are shown on a scale of 800 feet to the inch in Plate 20.

A cross section of the valley on the axis of the glacier was obtained by reading horizontal and vertical angles on a theodolite from the ends of the base line BC. The cross section is plotted in Plate 21.

Photographs were taken from the points D1, D2, D3 and A.

To enable future observers to detect any movement in the snout of the glacier and determine the amount of that movement,

**Fixed points for future observations.** two sets of permanent marks were established:—

- (a) Cairn H was built in such a position that an observer standing with his back against the mark on boulder G looked over Cairn H along a line tangential to the snout of the glacier and parallel (as closely as could be judged) to the granite cliffs opposite. It should be possible to detect any movement in the snout of the glacier by repeating the observation after a fair lapse of time.
- (b) To allow of a more accurate determination of the movement of the snout its horizontal distance was measured by theodolite from a fixed point F on the opposite cliff. That distance was 778 feet and the angle it subtended at another fixed point E, which is 97 feet away from F, was  $32^{\circ} 5'$ .

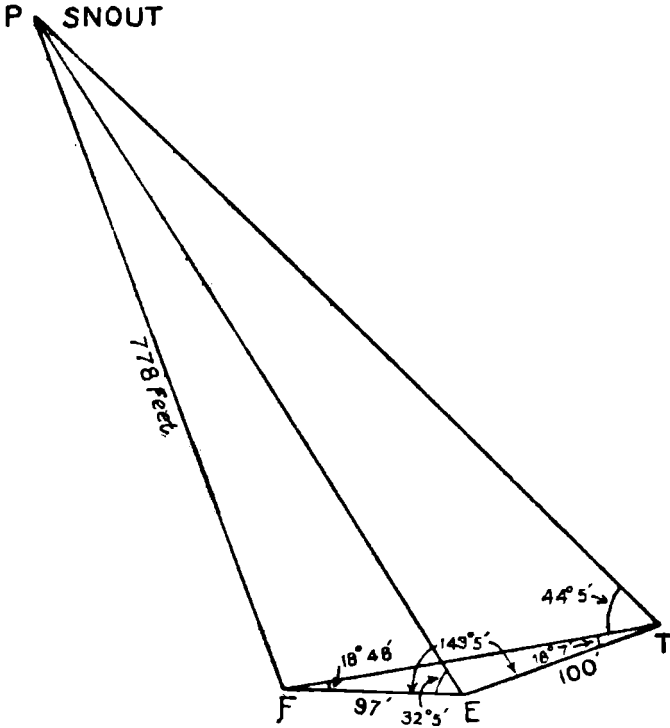


FIG. 3.—Diagram showing angles, measured in 1932, from fixed stations on to snout.

The results of these observations are indicated in the sketch given above. E T is a temporary base line (100 feet long) which had to be adopted because it was not possible to set up the theodolite at F. The movement of the snout would be measured by laying down any convenient temporary base line through E and observing horizontal angles as before.

#### IV.—CONCLUSIONS.

There is no immediate danger of the Arwa valley being blocked and of a lake being formed, but the glacier should be visited every spring for the next five years and the distance of the snout, from the granite cliff opposite, measured in the way indicated in section III (6). Should the glacier move abnormally fast and produce an unexpected blockage, indication of the movement should be obtained in a sudden shrinkage in the stream. Mana Bhotiyas cross the stream on their way up to and down from the pass and a



visit to the glacier will take them only two miles out of their way. The authors have asked the Rawal of Badrinath to arrange for the Bhotiyas to go to the glacier should they notice any abnormal shrinkage in the stream.

### V.—LIST OF STATIONS.

Station.	Situation.	Position of paint.
A Theodolite . . . Cairn Photograph . . . .	Bank of river by grass patch.	On top stone.
B } Theodolite . . . . 400' base line.	Bank of river . . . .	Do.
C } Theodolite . . . .	Small streamlet . . . .	Do.
D1 Photograph . . . Small cairn.	West of large boulder well up on talus.	Do.
D2 Photograph . . . Cairn	Well up hillside on plat- form west of gulley.	Do.
D3 Photograph . . . .	Well up hillside on in- clined platform east of gulley near its bifurca- tion.	Do.
E Theodolite . . . . .	Peg at foot of cliff. . . .	On cliff-face.
F Fixed point . . . . .	....	Do.
G } Tangent to snout . { Large boulder.	....	On vertical east face.
H } { Cairn,	On west side of small boulder just above 100 foot bank of river.	On top stone.

### LIST OF PLATES.

- PLATE 15.—View from P. W. D. Bungalow, Badrinath, looking north up Alak-  
nanda river. U-shaped valley.
- PLATE 16.—View from Station A facing  $267^{\circ}$ . Glacier No. III almost across main  
Arwa valley. Camera levelled.
- PLATE 17.—View from Station D3 facing  $233^{\circ}$ . Glacier No. III and Arwa valley.  
Three tongues of fresh moraine visible. Camera levelled.
- PLATE 18.—View from Station D2 facing  $170^{\circ}$ . Snout, ice fall, two feeding  
hanging glaciers. Glacier No. III. Camera levelled.
- PLATE 19.—View from Station D1 facing  $138^{\circ}$ . Glacier No. III. Camera levelled.
- PLATE 20.—Sketch map of Glacier No. III debouching into Arwa valley. Scale  
1 inch=800 feet.
- PLATE 21.—Cross section of Glacier No. III.

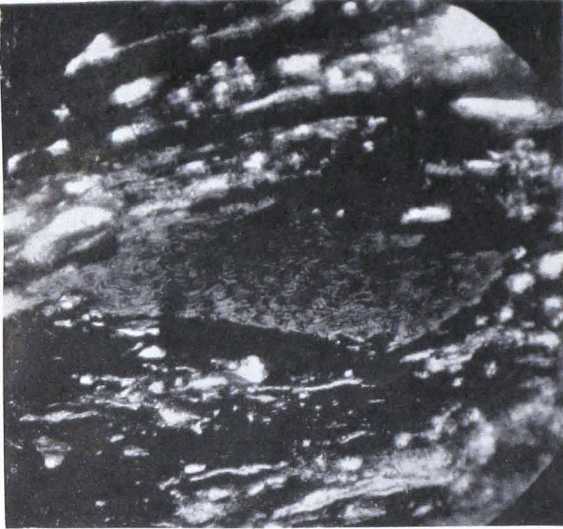


Fig. 1. Specimen 1. Cluster of Microspores. ( $\times 300$ ).

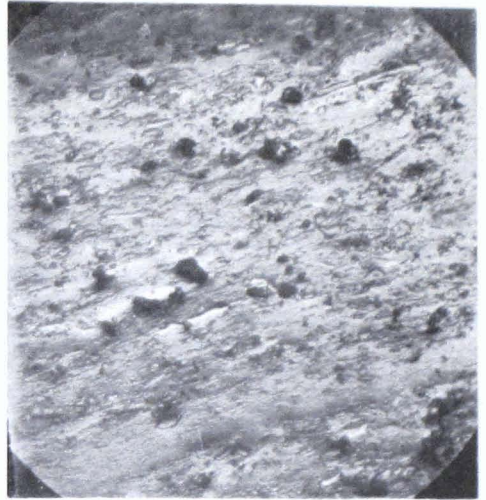


Fig. 2. Specimen 1. Durain. ( $\times 106$ ).

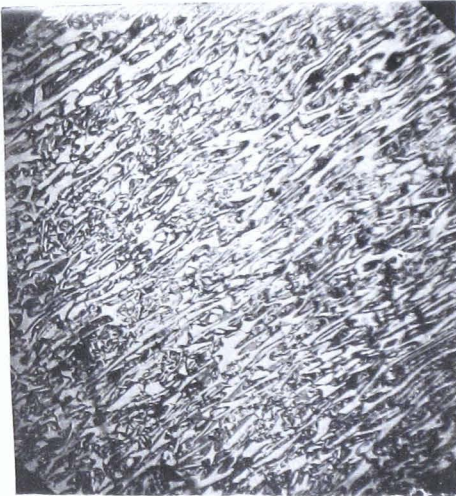


Fig. 3. Specimen 1. Fusain showing 'bogen' structure. ( $\times 106$ ).

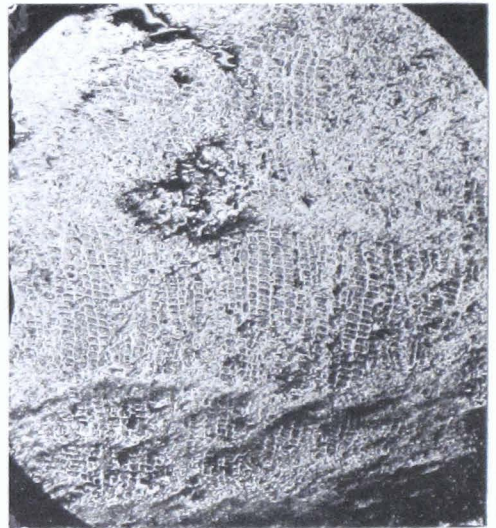


Fig. 4. Specimen 1. Fusain showing cell structure. ( $\times 38$ ).

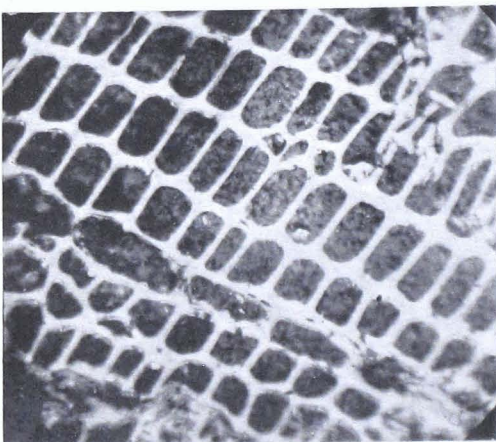


Fig. 5. Specimen 1. Fusain showing cell structure. ( $\times 228$ ).

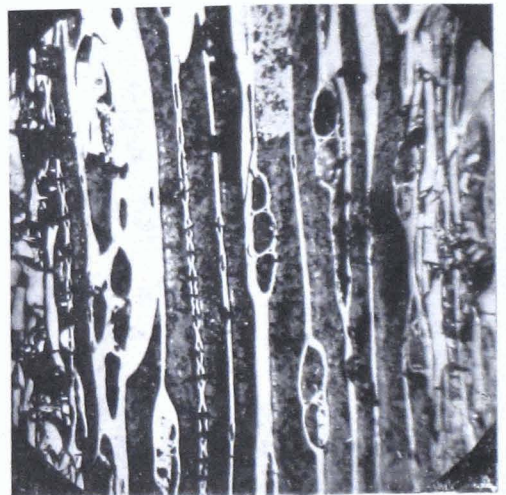


Fig. 6. Specimen 1. Fusain, showing wood ray and bordered pits. ( $\times 228$ ).

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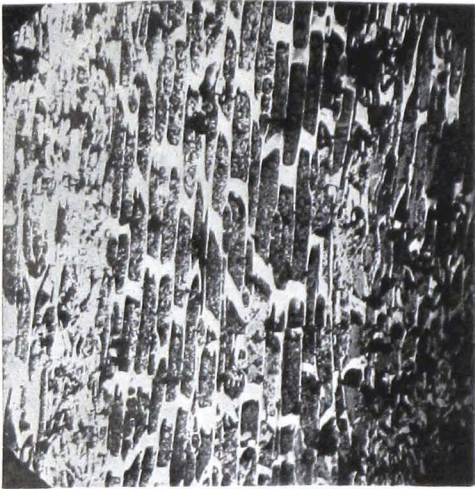


Fig. 1. Specimen 1. Fusain, showing thickening of horizontal walls of tracheids. ( $\times 106$ ).

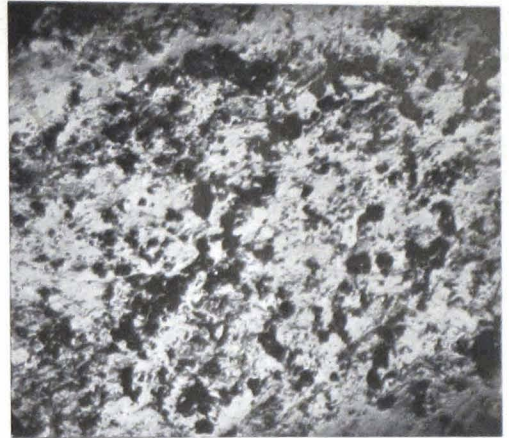


Fig. 2. Specimen 1. Durain. ( $\times 106$ ).

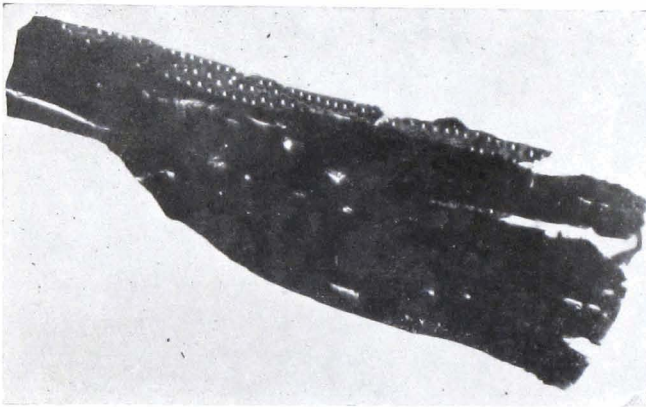


Fig. 3a. Specimen 1. Wood showing pluriseriate bordered pits. ( $\times 102$ ).

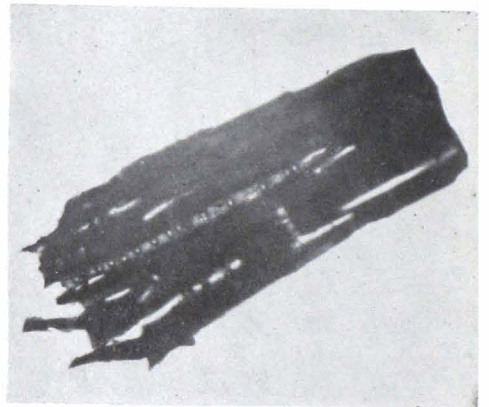


Fig. 3b. Specimen 1. Wood showing uniseriate bordered pits. ( $\times 86$ ).



Fig. 4. Specimen 2. Section showing fine bands of vitrain. ( $\times 65$ ).

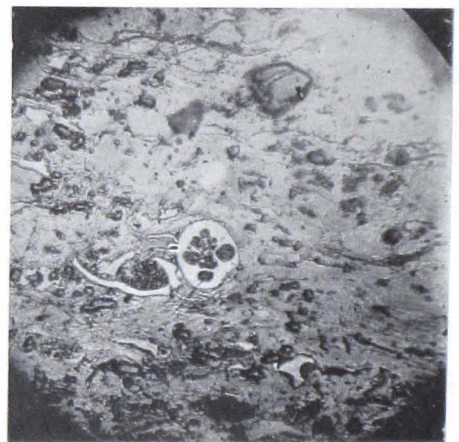


Fig. 5. Specimen 2. Durain with *Sclerotitis* sp. ( $\times 228$ ).

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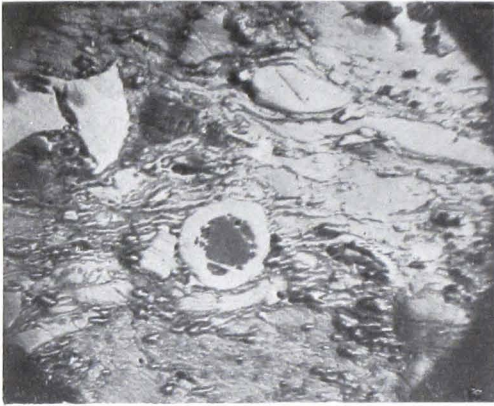


Fig. 1. Specimen 2. Durain with *Sclerotitis* sp. ( $\times 228$ ).

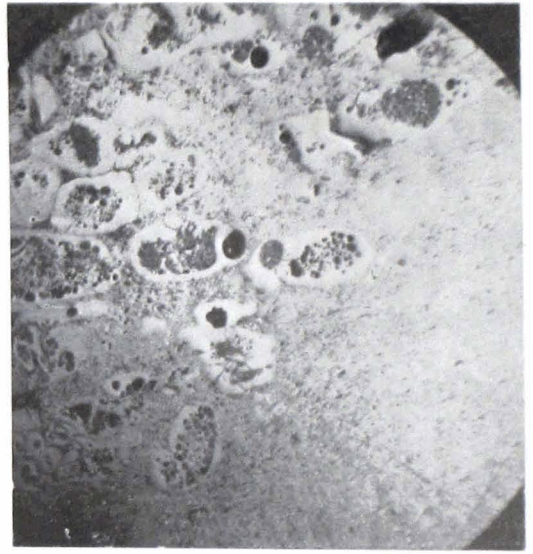


Fig. 2. Specimen 2. Vitrain with *Sclerotitis* sp. ( $\times 78$ ).

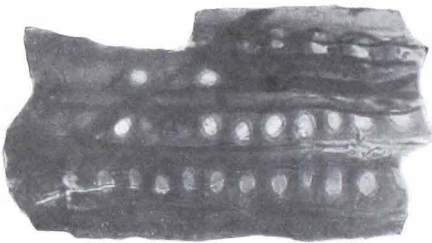


Fig. 3a. Specimen 2. Wood showing uniseriate bordered pits. ( $\times 270$ ).



Fig. 3b. Specimen 2. Wood showing biseriate bordered pits. ( $\times 270$ ).

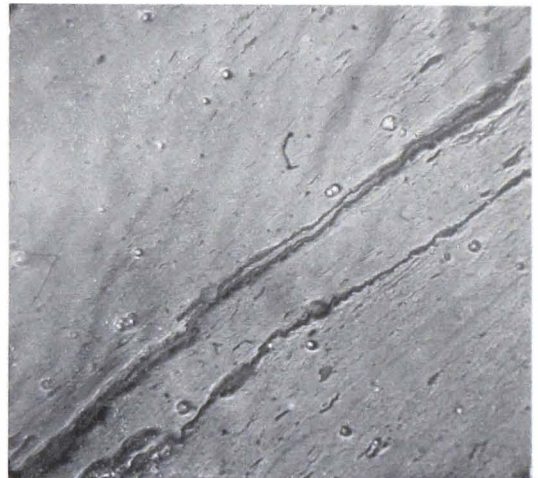


Fig. 4. Specimen 3. Cuticles and grains of pyrite. ( $\times 106$ ).



Fig. 5. Specimen 3. *Sclerotitis* sp. and its spores. ( $\times 96$ ).

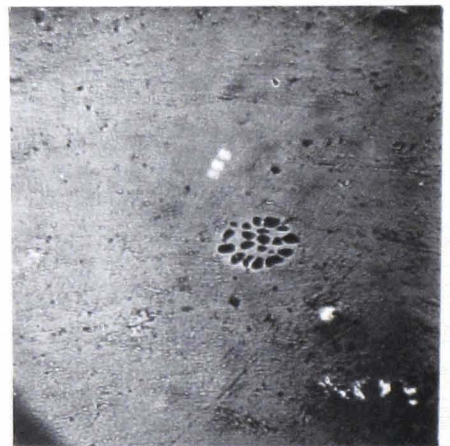


Fig. 6. Specimen 3. *Sclerotitis* sp. ( $\times 228$ ).

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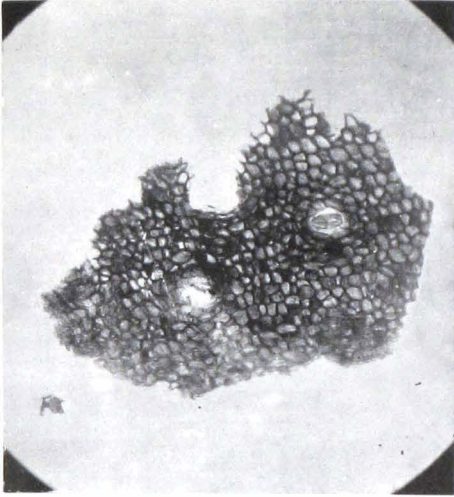


Fig. 1. Specimen 3. Cuticle showing stomatic opening.



Fig. 2. Specimen 4. Section showing cuticle. ( $\times 100$ ).

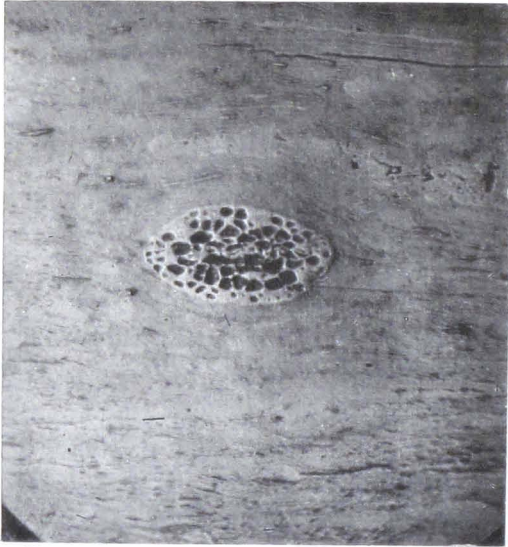


Fig. 3. Specimen 4. *Sclerotitis* sp. ( $\times 228$ ).

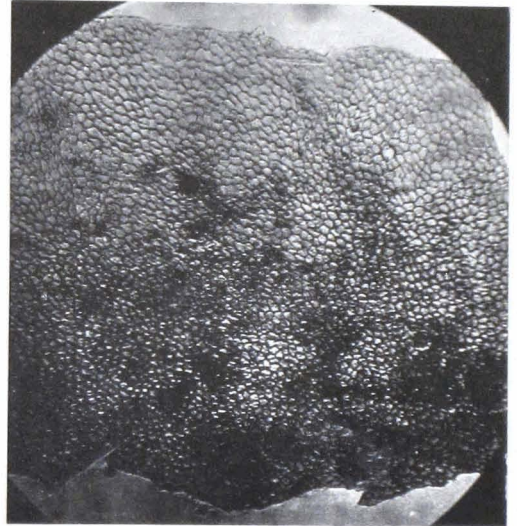


Fig. 4. Specimen 4. Cuticle. ( $\times 100$ ).

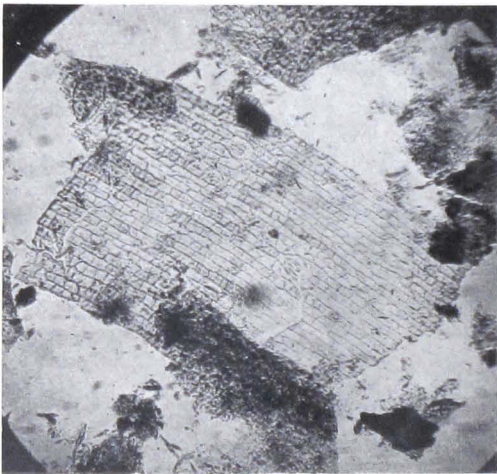


Fig. 5. Specimen 4. Cuticle. ( $\times 100$ ).

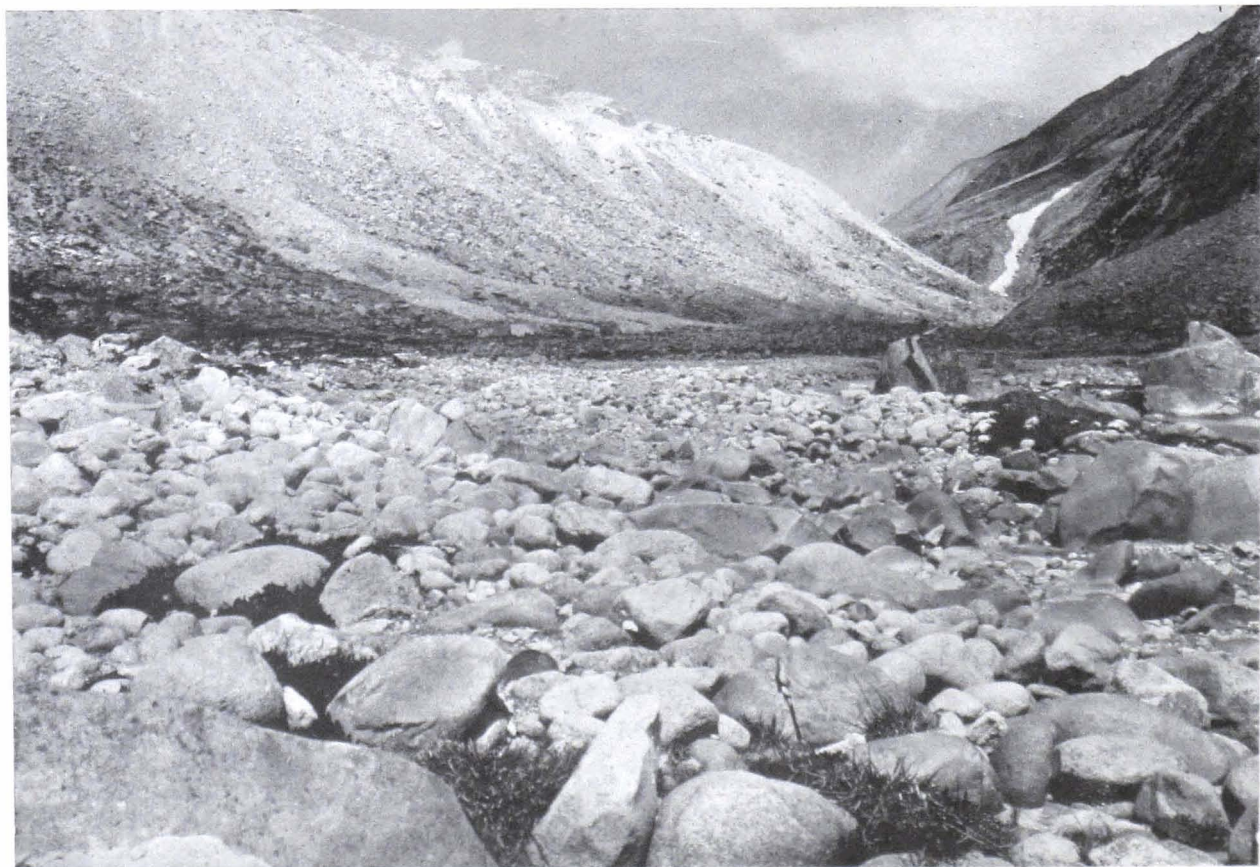


Fig. 6. Specimen 4. Pollen grains. ( $\times 100$ ).

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VIEW FROM P. W. D. BUNGALOW, BADRINATH, LOOKING NORTH UP ALAKNANDA RIVER.



VIEW FROM STATION A FACING 267°. GLACIER No. III ALMOST ACROSS MAIN ARWA VALLEY.

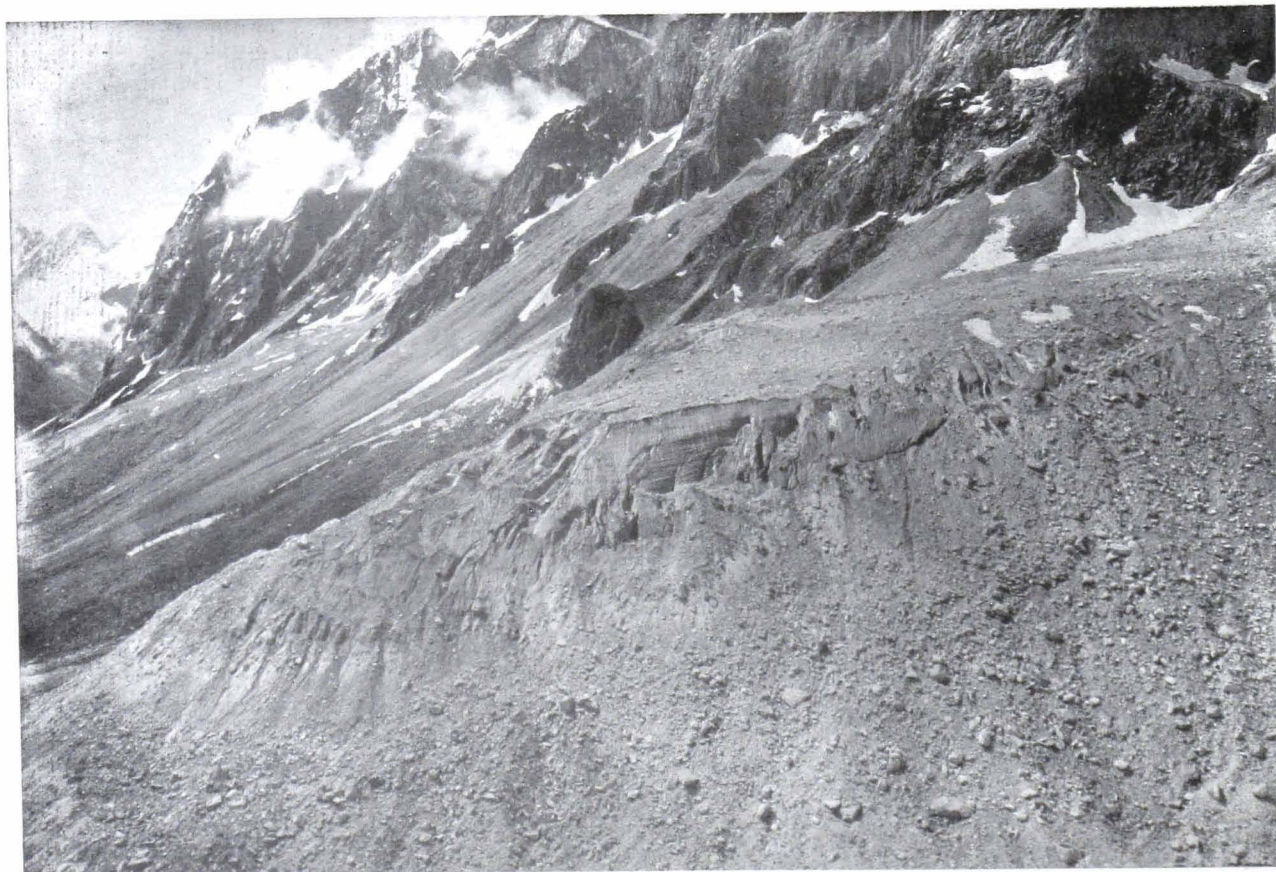


VIEW FROM STATION D3 FACING 233°. GLACIER No. III AND ARWA VALLEY. THREE TONGUES OF FRESH MORaine VISIBLE.





VIEW FROM STATION D2 FACING 170°. SNOUT, ICE FALL, TWO FEEDING HANGING GLACIERS. GLACIER No. III.



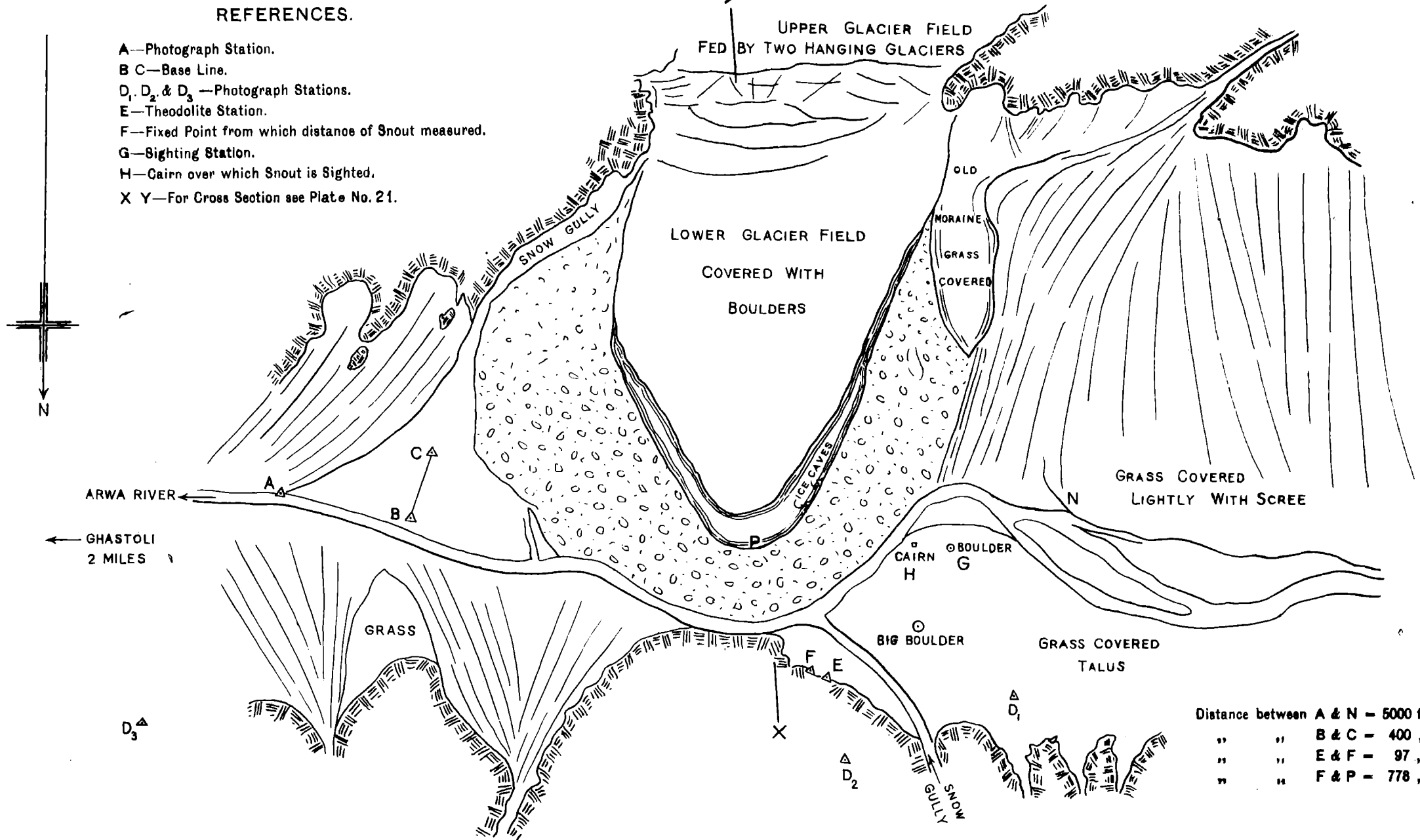
VIEW FROM STATION D1 FACING 138°. GLACIER No. III.

# GLACIER No. III. ARWA VALLEY. GARHWAL.

Scale 800 Ft = 1 Inch  
Ft 200 100 0 400 800 Ft.

REFERENCES.

- A—Photograph Station.
- B C—Base Line.
- D<sub>1</sub>, D<sub>2</sub> & D<sub>3</sub>—Photograph Stations.
- E—Theodolite Station.
- F—Fixed Point from which distance of Snout measured.
- G—Sighting Station.
- H—Cairn over which Snout is Sighted.
- X Y—For Cross Section see Plate No. 21.



Distance between	A & N	= 5000 ft.
" "	B & C	= 400 "
" "	E & F	= 97 "
" "	F & P	= 778 "

**GLACIER No. III.**  
**ARWA VALLEY, GARHWAL.**

CROSS SECTION ON X—Y.

