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SURVEY OF INDIA

PROFESSIONAL PAPER No. 25

THE REPRESENTATION OF GLACIATED REGIONS ON MAPS OF THE SURVEY OF INDIA

MAJOR KENNETH MASON, M.C., R.E.
SUPERINTENDENT, SURVEY OF INDIA.

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BRIGADIER R. H. THOMAS, D.S.O.
SURVEYOR GENERAL OF INDIA

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BY

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Survey of India.

India. SURVEY OF INDIA dept.

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HEAD BASIN OF NALIFKIN GLACIER, FEDCHENKO GLACIER, WESTERN PAMIRS.

Photo. Finsterwalder — By courtesy Notgem.d.Deut.Wissen.

THE REPRESENTATION OF GLACIATED REGIONS ON MAPS OF THE SURVEY OF INDIA

Introduction.—The following paper is the result of a feeling on the part of several officers of the Survey of India that the representation of glacier features on our maps does not meet the requirements of modern science. The Himālaya is the largest and most conspicuous feature of the Earth's surface; in its recesses we find summits higher than any other summits in the world, gorges deeper than any other gorges, and glaciers longer than any other glaciers outside sub-polar regions. Yet we have not deemed it necessary or advisable to spend the time or money to delineate their special features. Our Indian surveyors have paid no notice to the snow-line; and no individuality has been given to the glaciers themselves. In the 'fifties and 'sixties of last century the surveyors were expressly told " not to waste their time surveying barren regions above 15,000 feet", and though we find some of the officers concerned striving to explore and survey accurately the main features of the glaciers as far as was then possible, that same policy of *not wasting time* has remained almost unchanged until today.

The science of Glaciology has advanced since then; and this, no less than the fact that countless routes in the Himālaya—several of them being important trade-routes—traverse glaciers and passes above the snow-line, calls for something much better than in the past. But if this general change in policy is to be carried out, we must first train our surveyors to understand how glaciers are formed, their features and their movements, before we can expect those glaciers to be surveyed and drawn correctly.

This paper has therefore been divided into two parts. The first contains a brief account of how glaciers are formed, how they move, and what changes they undergo under various circumstances; the causes and results of their special characteristics, such as moraines, lateral, medial, and terminal, their ice-falls, crevasses and seracs. The second part shows and discusses the symbols that have been designed for these features, with special reference to Himālayan conditions and our Indian maps. A glossary of words, whose meaning may not be known to the surveyor, is included for convenience at the end.

I am indebted to Lt.-Colonel H. T. Morshead, D.S.O., R.E., and Major C. G. Lewis, O.B.E., R.E., of the Survey of India, for assistance in preparing this paper and to Sir Edwin Pascoe and Dr. A. M. Heron of the Geological Survey for helpful criticism.

THE FORMATION AND CHARACTER OF GLACIERS

Definition.—A glacier may be defined as a mass of compacted ice originating on any portion of the earth's surface that is permanently above the snow-line, and descending below that line. The snow-line is the lower limit of perpetual snow—the line above which the snow resists the heat of summer, and below which snow, as distinct from ice, disappears for a certain time of the year. This snow-line varies not only with latitude—it touches sea-level within Polar regions—but with various causes, climatic and otherwise, such as temperature and annual snow-fall, direction and moisture of prevailing winds, alignment of mountain ranges, presence of high plateaux, etc. It is not however within the scope of the present paper to discuss in detail these causes and their effects, nor to specify the height of the snow-line outside High Asia. The following table shows the *approximate* height of the snow-line in the various ranges of the Himālaya and Central Asia.

TABLE I.—*Approximate Height of the Snow-line.*

Range	Approximate Lat.	Approximate Long.	Approximate Snow-Line S.	Approximate Snow-Line N.	Authority
The Great Himālaya					
Assam-Himālaya ..	29°	94°	14,500	16,500	H. T. Morshead
Bhutān-Himālaya ...	28°	90°	16,500	18,500	do.
Nepal-Himālaya ...	28°	87°	16,000 *	19,500	do.
Kumaun-Himālaya ...	30½°	80°	15,500	18,500	Richard Strachey
Punjab-Himālaya ...	34°	76°	17,000	19,000	T.G. Montgomerie & A. Cunningham
The Zaskar-Himālaya ..	33°	78°	20,000	19,500	A. Cunningham
The Ladākh-Himālaya ...	32°	80°	...	20,000	Richard Strachey
	34°	78°	19,000	18,500	F. Drew
The Kailās-Himālaya ...	31°	81°	19,000	20,000 †	Richard Strachey & T.G. Longstaff
Western Tibet Ranges ...	33°	81°	20,000	20,000	R. Strachey, Drew, & H.H.P. Deasy
The Kailās-Karakoram ...	35°	77°	16,700 ‡	16,700 ‡	T.G. Longstaff
The Muztāgh-Karakoram	35°	78°	18,500	18,000	A. Cunningham
The Aghil-Karakoram ..	36°	77°	20,000	19,000	K. Mason
The Kun Lun	36°	80°	19,500	17,500	A. Stein
The Eastern Hindu Kush and Hindu Rāj ..	36½°	72°	18,000	15,500	C.G. Lewis
The Tāghdumbāsh Pāmīrs	37°	75°	18,500	16,500	K. Mason
The Nan Shan ...	39°	99°	18,500	17,000	A. Stein
The Trans-Alai Range .	39½°	73°	16,500	15,000	W. R. Rickmers §
The Alai Range ...	40°	74°	14,000	14,000	Morgan ‖
The Tien Shan .	42°	80°	11,000	11,000	Semenoff ‖

* Hooker gives the snow-line of the Nepal Himālaya (south aspect) as 14,700 feet. It may be so at occasional localities, though generally it is nearer 16,000 feet.

† Longstaff considers his estimate very rough.

‡ Longstaff's estimate was made in June. The snow-line would probably be 1200 feet higher by the middle of August at any rate on south slopes.

§ These heights are taken very approximately from Rickmers' photographs, and are subject to correction.

‖ Morgan's and Semenoff's figures do not give the aspect. Hence they must be considered as very approximate.

I have called this snow-line approximate. Various authorities disagree within narrow limits; in nature it does not follow a contour, for snow will lie longer and therefore the snow-line will be lower in sheltered ravines than on exposed hillsides. Local radiation, local variation of temperature, local snow-fall, direction and strength of the prevailing wind, directness of the sun's rays, all affect the line, and at best a mean can be estimated. But from the table, approximate as it is, some points are obvious. In the Kumaun-Himālaya of the Great Himālayan Range, the snow-line lies about 3,000 feet lower on those slopes with a southern aspect than on those facing north. In the Assam-Himālaya the difference is 2,000 feet, and the snow-line is low on both slopes. In the Bhutān-Himālaya the difference is also 2,000 feet, but the snow-line is higher on both slopes as this region lies in the "rain-shadow" of the Khāsi and Jaintia Hills. In the Punjab-Himālaya of the same range, the difference is again about 2,000 feet and the snow-line is higher still, thanks to the Pir Panjāl. This difference between the southern and northern aspects throughout the Great Himālaya is due to exposure to the damp winds from the Indian Ocean, which are arrested before crossing the range and deposit much of their moisture on the southern slopes as snow. We may therefore expect longer glaciers flowing south than north in the Great Himālaya.

After traversing the Great Himālaya in Ladākh, the effect of these damp winds is much lessened and there is little difference in the snow-fall on the southern and northern slopes of the Ladākh range. The snow-line is therefore higher on southward-facing slopes, owing to the directness of the sun's rays, than on northerly ones, where the sun has less power to melt the snow. On both slopes the snow-line has retreated to near the summits of the mountains, and glaciers are few. Beyond, in the Kailās-Karakoram, the snow-line is little different from that on the Ladākh-Himālaya but the mountains rise much higher and far above the snow-line. We therefore find great areas of snow and ice, and long glaciers. In the Muztāgh-Karakoram the snow-line is about the same, and we have groups of some of the highest mountains in the world, and some of the longest glaciers. This icy range shields the lower Aghil-Karakoram, which therefore receives far less snow. The snow-line is therefore higher here and the glaciers much smaller.

The Formation of Glaciers.—These effects are caused by the fact that glaciers are primarily formed by the fall of snow above the snow-line, where the temperature is below freezing-point. After a storm, the lower layers of snow are subjected to pressure and form what is known as *névé*. Subsequent falls cover and subject the previous fall to greater pressure, and gradually clear ice is formed in the lowest and oldest layers. The original layers of snow-fall can often be traced right down to the lowest limits of the glacier, showing as banded strata of ice, separated by layers of dust.

A glacier however does not go on piling up ice to an infinite height by successive snow-falls in its névé region. The weight of super-imposed ice and snow gradually causes *regelation* to occur in the lowest strata of the mass, and the body of the glacier slides forward and downward. If the snow-line lies near a summit—one covered with an *ice-cap*— the ice will slide down radially below that line. If the moving ice encounters a cliff, ice-blocks from the advancing mass will break off and tumble to lower ground, and there either melt or become compacted to form another glacier. Greenland is covered by one huge ice-cap of this kind, extending over 400,000 square miles. The Antarctic ice-cap is seven times as large as that of Greenland and has an area of three million square miles. Where the snow-line approximately coincides with the summits of mountains, as in tropical countries, the ice-caps are of comparatively small extent and rest on the summits of the ranges.

If however the limit of perpetual snow lies already in a hollow or in a valley, the névé is compacted here and converges towards the basin, and the glacier flows down that valley, far below the snow-line. The supply is greater than the wastage, and the "head" urges the mass downwards, till the melting caused by the increased temperature of lower altitudes balances the supply from above. Here is the end or *snout* of the glacier.

The névé portion of an ice-cap or of a "valley glacier" receives and converts the supply of snow to ice. Snow, and from it, ice, is constantly being added above the snow-line. But below that line there is always wastage, small perhaps at first, but ever increasing towards the snout. The thickest part of a glacier is normally just below the snow-line, and calculations have been made in certain of the longitudinal glaciers of the Karakoram, which lead us to believe that the thickness here may amount to as much as from 1,500 to 2,000 feet. The ice-cap of Greenland has been estimated to be 5,000 feet thick.

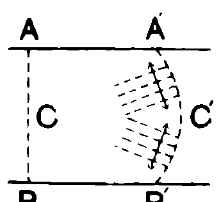
The Movement of Glaciers.—It has been said above that a glacier flows by regelation. It is not necessary to enter here into a scientific explanation of this movement. In popular language it may be said that the weight of the glacier causes the lower layers to melt by pressure, and the glacier slides on its partially melted ice. A continual process of melting and re-freezing is going on. If a glacier could lie on a perfectly even bed with a perfectly smooth floor and even fall, and flow in a perfectly constant temperature, conceivably it would slide perfectly regularly at a uniform rate, and its lower strata would melt uniformly. But friction affects it. In practice all points of a glacier do not flow at an even rate. It has been proved that the lower layers are retarded by friction; that the surface portions move more rapidly than the deeper layers; and that the motion is slowest at the sides and bottom where friction is greatest. Where a lateral valley—an *ablation valley*—exists between a glacier-trunk and one of its enclosing walls, the lateral friction is removed, and that side of the glacier will flow more rapidly than the side delayed by the other wall—possibly even quicker than the central ice-stream. Such lateral valleys are common in the Himālaya. They generally occur far below the snow-line, where wastage is great, and radiation from the rock walls is a powerful degenerating factor. In many of these ablation valleys of the Karakoram, Hindu Kush and elsewhere the ground has become fertile, and trees, bushes and flowers flourish in profusion.

The rate of motion of a glacier past the same spot is not uniform It will move quicker in summer than in winter, and, to a less extent, quicker in the afternoon than in the morning; for heat accelerates it, and cold arrests it. Nor is the rate of flow at any moment constant throughout its length; the steeper the fall, the thicker the ice, the higher the temperature, the smoother its rocky bed, the quicker its rate of motion.

Crevasses.—These variations in rate of motion set up stresses, and the brittle ice is split and torn. In certain areas where changes of fall occur, *crevasses, seracs*, or, if there is a definite drop in the bed, *ice-falls* and *ice-cliffs*, may always be expected. A continual creaking and rumbling will be heard in such areas, as individual crevasses advance, their upper central parts moving faster than their lower lateral ends. Temporarily they become curved and bent, convex towards the snout,—convex not only from side to side but from above downwards. These are the crevasses due to inequalities in the bed of the glacier. On reaching an even gradient they almost always close and *heal*. Here a new form of crevasse is usually met with; this is the crevasse due to the more rapid movement in the centre of the ice stream. The general direction of these crevasses is diagonally upstream from the sides towards the centre.*

A glacier in very many ways may be compared with a river. There appear to be ice-swirls and eddies as well as an upward creep on shelving curves. But this comparison must not be carried too far, for ice is a brittle solid, while regelation gives a glacier some properties of plasticity. It can shear and split into crevasses and seracs, and can flow uphill over an adverse slope, if there is sufficient pressure behind it. There are countless instances of this in the Himālaya and Karakoram. It is a common feature of many of the

* The diagram illustrates the cause of these crevasses.



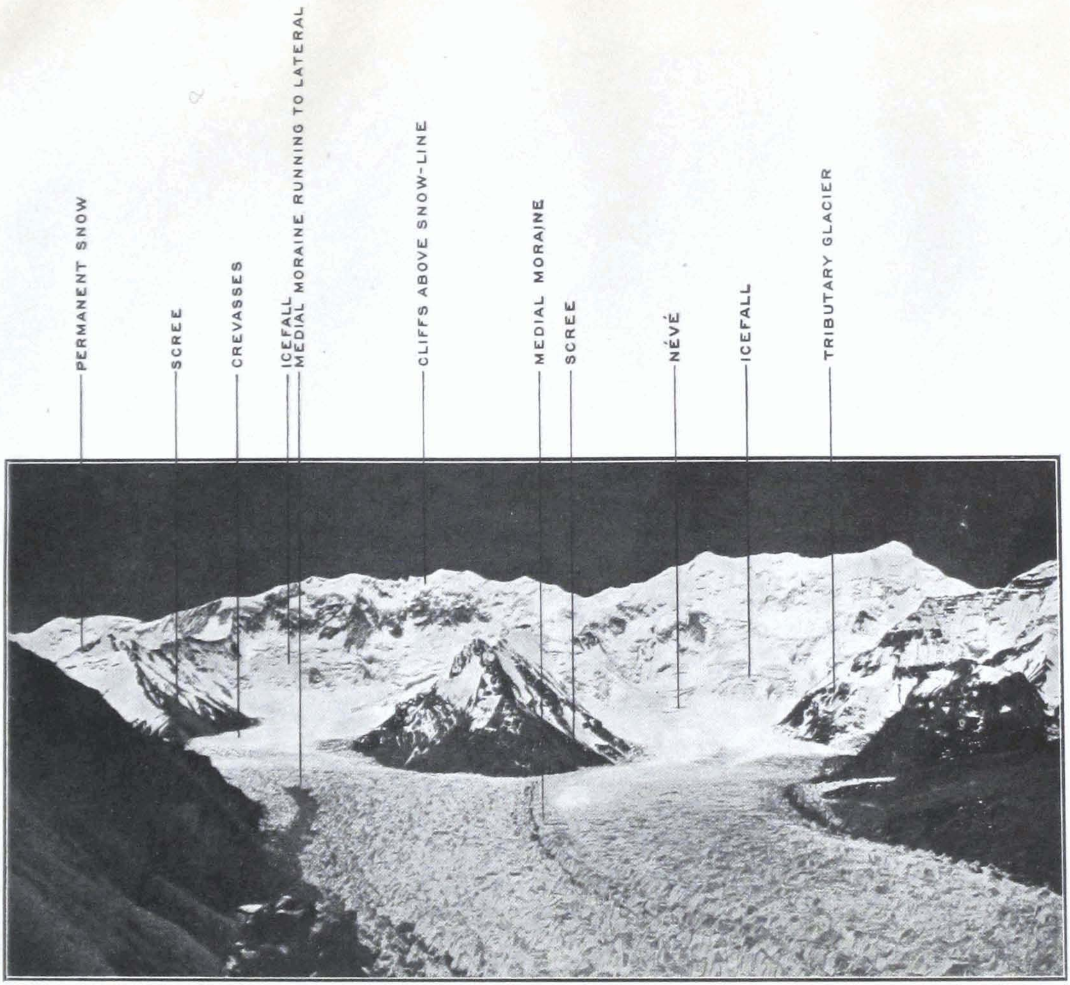
Consider a line ACB across a glacier. After a lapse of time the ice along ACB assumes the position A′C′B′. A′C′ and B′C′ are now longer than AC and BC, causing tension as shown by the double-headed arrows; crevasses form at right angles to A′C′ and B′C′. These crevasses are often very prominent near the snout of a glacier, as they widen by melting and "run out" at the edges owing to the sides of the glacier having melted away.

saddle glaciers of the Aghil; the great Rimo glacier, the source of the Shyok river, south of the Central Asian watershed, forces an arm of ice,—a branch distributary, as it were—over that watershed to form the source of the Yārkand river of Chinese Turkistān; and in the great "snow-lake" at the head of the Biafo glacier of the Muztāgh-Karakoram, a region "drowned in ice", the névé is forced upwards over the Hispar pass to feed the Hispar glacier, and over the Muztāgh range to feed the Khurdopin and Virjerāb glaciers of the Shingshāl basin.

We are here concerned with the effects rather than the causes of glacier movement; and in the main we are concerned with those effects which impede accessibility. In general the upper portion of a glacier is hidden under its mantle of freshly-fallen snow. If crevasses exist they are generally covered, and the surface appears smooth and unbroken. During the summer, as the glacier moves away from its snow-field or mountain-side, a crevasse of great depth, sometimes extending right down to the bed, and known as a *bergschrund*, is formed. The ice moves on, crevasses are formed and covered with fresh snow or fallen avalanches below the snow-line. This is the area of greatest danger from hidden crevasses, for the snow covering them,—the *snow-bridge*—is apt to break on the application of the least extra pressure.

The bergschrund is an easily recognizable and prominent feature in the upper reaches of a glacier. It always occurs at the change of slope between the névé proper of the mountain sides and the gentler slope of the nascent glacier in the valley floor; its position does not alter from year to year, though the ice along its upper edge will break away and join the moving mass below, leaving the crevasse itself in its permanent location. This is due to the different rates and different directions of movement of the névé and glacier proper. Lower down conditions are different, the main mass is moving more uniformly, it reaches the edge of a steeper slope, a crevasse is formed and moves on, and another takes its place. The crevasses themselves, and their attendant seracs, are on the move and thus an *ice-fall* may be formed.

Moraines.—On its journey, the glacier passes rock-promontories and cliffs, couloirs and tributary glaciers. All these load it with extra rock and snow and ice. The rock debris, shot from the heights, is first carried along with the moving mass in the form of *lateral moraines*. A branch glacier joining the main one, or two converging glaciers, will carry this moraine between them, and now it appears as a *medial moraine* below their junction. Frequently in compound glaciers, where several glaciers converge, we find a series of medial moraines carried along by the ice in parallel bands for long distances, each containing detached specimens of the rock specially characteristic of the mountain from which it originated. A beautiful example of this may be seen below "Concordia" on the great Baltoro glacier.



TYPICAL NORTHERN GLACIER OF MUZTAGH-KARAKORAM.

As these medial moraines approach the lower reaches of the glacier they may merge into one another, or if there is a lateral valley, the outer moraines may fall off and form stationary moraines. Rock debris is continually added from the barren lower walls, from *rock-avalanches, stone-shoots, scree slopes*, and *fans*; the surface of the glacier may then present a chaotic hummocky black mass, which completely covers and hides the ice.

Throughout the length of the glacier, the interplay of radiation, evaporation and temperature causes a variety of surface features and irregularities such as ice-pinnacles, towers, etc. Thin stones and dust transmit heat through their masses to melt the ice below them. This small debris sinks into the glacier and forms *en-glacial moraine.* It is lost to view and the surveyor need not consider it till it reappears near the snout. Thicker rocks with low conductivity may shade the ice below them, and as the neighbouring ice melts, these rocks remain supported in the form of *glacier-tables.* Eventually they collapse and may fall out of their true alignment.

Surface streams, lakes, seracs and pinnacles.—On glaciers of gentle even fall, comparatively free from strain, surface streams may be formed; these sometimes attain the size of unfordable rivers. Sometimes they carry along with them mud, dust and debris; they may flow for long distances before finally plunging into a crevasse, losing themselves among the seracs, or draining into a deep glacial lake.

North of the Muztāgh-Karakoram and elsewhere, though in a less marked degree, the glacier surfaces are broken up into a maze of giant ice-pinnacles and towers, among which the surface streams and lakes make progress almost impossible. Here the only lines of advance, except by laborious cutting of every step in the ice, are by the lateral or medial moraines, which form corridors, sometimes from the snout to some promontory above the snow-line. The correct delineation of these moraines on the map becomes a matter of great importance.

The supply area of a glacier bears a very variable relation to its area of melting, and is affected by many considerations. As a general rule the ratio of supply-area to melting-area is much smaller in Himālayan glaciers than in those of Europe. In extreme cases in the Himālaya, glaciers have been known to commence almost at the limit of perpetual snow. They seem to have almost no névé-basin. Such glaciers may be fed almost entirely below the snow-line by avalanches, fallen from the summits of the enclosing walls. Even glaciers with comparatively large névé areas may still receive a large supply from this accidental source far below the snow-line, and so prolong their snouts far below the altitude above sea-level, which they would otherwise attain. The Batūra, of which some figures are given below, is an instance of this.

Altitude of Glacier Snouts.—The altitude to which a glacier descends is also a function of its velocity. The steeper its bed, the faster it moves, the lower the altitude to which it is likely to persist. Burrard records that "in Sikkim, Kumaun and Spiti"—and we might add Kashmīr proper—"the glaciers of our time rarely descend to 11,000 feet. But in the Karakoram the glaciers frequently descend to 10,000 feet". At the far eastern end of the Great Himālaya the glaciers on the north face of Namcha Barwa in the Assam Himālaya descend to 9,000 feet, and, as a matter of fact some Karakoram glaciers descend much lower than Burrard's figure. The two transverse glaciers, of the Kailās-Karakoram, the Minapin and Hasanābād, of Hunza, descend to 7,050 and 7,290 feet respectively. These two glaciers probably receive an immense supply of ice from the peaks at their head and are subject to heavy ice and snow avalanches throughout their length. The snow-line here is about 18,000 feet, but the enclosing ranges exceed 23,000 feet and are literally encased in ice. The glaciers eventually emerge through narrow valleys.

The great longitudinal Batūra glacier, lying in the trough north of the Muztāgh-Karakoram, has a length of 36 miles, and descends to 8,030 feet, largely owing to the extra volume of ice that it receives from its almost continuous avalanches falling from the buttressed wall of the Muztāgh-Karakoram.

The following table gives the lengths and present altitudes of the snouts of the eight longest glaciers of High Asia :

TABLE 2.—*The Eight Longest Glaciers in Asia*

Glacier	Range	Latitude of snout	Length (miles)	Height of snout (feet)
Siachen ...	Muztāgh-Karakoram	35° 10′	45	12,150
Inylchek...	Tien Shan ...	42° 02′	·44	9,100 (approx.)
Fedchenko (Sel-dara)	Trans-Alai ...	39° 05′	44	9,880 (approx.)
Hispar ...	Muztāgh-Karakoram	36° 10′	38	10,500 (approx.)
Biafo ...	do. do.	35° 40′	37	10,360
Baltoro ...	do. do.	35° 40′	36	11,580
Batūra ...	do. do. (Hindu-Kush section)	36° 31′	36	8,030
Koi-Kaf ...	Tien Shan ...	41° 51′	31	11,320

NOTE:—Data of the Inylchek and Koi-Kaf glaciers are from Merzbacher's map of the Tien Shan, 1928. Those of the Fedchenko are from a brief paper by W. R. Rickmers in the *Alpine Journal* for May, 1929. Merzbacher's own height for the snout of the Inylchek was 9,650 feet. Reliable newer Russian surveys differ in important points from Merzbacher's height values. On the 1928 compilation of Merzbacher's map, modified by these later surveys, the lower end of the Inyichek is given as 2,770 metre (approx. 9,100 feet). The height of the Koi-Kaf snout is from 100-metre form-lines on the 1928 map, and these form-lines do not appear to have been corrected by the later surveys. This height 11,320 feet, may therefore be about 550 feet too high.

The approximate height of the snow-line is 18,500 feet in the Muztāgh-Karakoram, 16,000 in the Trans-Alai, and 11,000 feet in the Tien Shan. No other glaciers than the above are known to exceed 30 miles outside sub-Polar regions.

"*Advance*" *and* "*Retreat*" *of Glaciers*.—It will be readily understood that the position of a glacier's snout may vary from year to year. As has been stated above, it lies at that point where the rate of melting balances the rate of supply of ice. The position therefore depends on both these factors.

If the supply of ice is uniform, and a general increase in temperature occurs, the melting will increase, and the snout apparently recedes. If the temperature falls, the snout advances. If a change in climate occurs, there may be an increase or decrease of snowfall in the feeding area. This will ultimately mean an advance or retreat of the snout. Such secular changes in temperature or climate lead to what are known as *secular* movements of the snout. They will be distributed over long periods of time.

But apart from secular variation of climate and temperature, there are periodic and seasonal changes. The effects of these are generally much more noticeable, and with steep transverse glaciers—those flowing at right angles to a main range—the periodic and seasonal snout movements are liable to cloak the secular change entirely.

Of those transverse glaciers that I have myself studied the two with the greatest periodic movements are curiously those two, the Minapin and the Hasanābād, whose snouts today descend lower than any others in the Himālaya or Karakoram. Their ice may be likened to the mercury of a clinical thermometer. As the volume of the mercury increases in the bulb, it is forced through the narrow tube. Though the tube is graduated to read degrees, it really records the change in volume of the mercury due to change in temperature. So with these two glaciers. Their volume of ice within the névé area is subject to great changes, and the ice is forced down through the narrow exit valleys, to record those changes of volume by the position of the snout.

All valley glaciers may indeed to some extent be likened to thermometers laid on the bosom of the earth, whose periodic and seasonal fevers are recorded by the "reading" at the end.*

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* In 1906 various members of the Geological Survey of India marked the rocks adjacent to the snouts of certain glaciers of the Himālaya, in order that future observers should be able to record accurately the movements of the snouts. Some of these have since been visited by travellers, and interesting data have been collected. The glaciers marked were the following: the Hinarche and Barche (Bagrot); the Minapin, Hispar and Yengutsa (Nagar); the Hasanābād (Hunza); Sōnapāni, the Bara Shigri, and the Perad (Lahul); the Pindari, the Milam, the Shankalpa, and the Poting (Kumaun). Full details will be found in *Records of the Geological Survey of India*, Vol. 35.

If surveyors and travellers have time, it would be of the greatest interest if they would record carefully the position of the snouts of these glaciers relative to the marks of the Geological Survey, and cut new marks to show the position of other glacier snouts not yet marked. A large-scale plan would also be of value. The marks should be chiselled in rock *in situ*, for cairns are liable to destruction and loose boulders may move; the date of the observations should of course be recorded.

An advancing snout deposits little or no terminal moraine; and what little moraine is thrown off is usually carried away by the stream issuing from the glacier. A stationary snout will form a terminal moraine-bank, through which or round which the glacier stream must maintain a channel. A retreating snout will form a lower terminal moraine, but covering a larger area, unless the stream has the power to carry it away. As it retreats its volume near the snout will diminish, its end becomes flattened, en-glacial moraine comes again to the surface, and debris is cast off at the sides, forming lateral moraine banks. Sometimes if retreat is rapid, isolated blocks of *dead* ice are left in advance of the *living* ice of the glacier. Moraines on the surface of living ice are called *live* moraines; those deposited from this ice to the valley slopes or floor are *dead*. Live moraines may be *lateral* or *medial;* dead moraines are *lateral* or *terminal* *.

The existence of ancient moraines, long since dead, of glacier-borne erratic boulders, and the striations of rock, graved by moving ice far below the levels to which glaciers descend today, show that the glaciers of our time are mere relics of the huge glaciers that once extended throughout the Himālaya. High up the walls of valleys now deeply carved out by water are found evidences of these great glaciers. On the southern slopes of the Dhauladhar range, old moraines have been recognized as low as 4,700 feet above sea-level. Sonamarg in the Sind valley of Kashmīr is a mass of deposited moraine now buried with soil and covered with grass and flowers. The great Siachen glacier was once a thousand feet deep at a point 45 miles lower down the Nubra valley than its present snout. And such instances might be multiplied indefinitely.

Enough has been said perhaps to give a general account of the formation and movement of glaciers, and of their characteristics. Unless some knowledge is obtained of these facts, it is difficult to realize the importance of representing the glaciers accurately on our maps, and impossible to show them with any approximation to the truth.

THE DELINEATION OF GLACIERS

General.—Up to the present glaciers have been represented on Survey of India Maps conventionally. In the old hachured maps they were conveniently and most economically shown as a complete blank. Their enclosing walls were hachured in black irrespective of whether they were arid slopes below the snow-line, afforested slopes still lower, or precipices, ice or snow above that line. Ice-caps were not distinguished from rocky summits; they too were hachured. The mountain-side was hachured down to a point where the surveyor

* Some people consider that some lateral moraines *off* the glacier and terminal moraines in the vicinity of the snout are or may be 'live', where they are subject to disturbance by the living glacier. This I believe is technically wrong: for you cannot kick a corpse to life.

considered it was time to stop hachuring, and the valley glacier was left white. Sometimes the words "Glacier" or "Snow-bed" were written across the blank space; occasionally it was tinted green by hand.

With the introduction of contoured and coloured maps, this practice was not convenient; and as the re-survey of the Himālaya was taken up, a conventional sign was gradually introduced. Generally speaking, the summits under permanent snow (ice-caps) have still been left indistinguishable from barren summits, the brown contours being retained for both. Again, at a point where the surveyor thought fit, the brown contours have been stopped and a broken blue line has been shown to indicate the edge of the glacier. Well below the snow-line this glacier edge has been easy to survey; above it the edge has been purely arbitrary. And at this arbitrary edge contours have ceased to be surveyed; they have not been surveyed across the ice of the glacier; though they have been surveyed across the ice of the névé, and shown in brown. An attempt has been made to show ice-falls and seracs, but the conventional sign showing these features was unexplained, with the result that surveyors and draftsmen have considered this as part of the conventional sign for a glacier, and drawn it irrespective of whether ice-falls and seracs exist. A few brown dots here and there have been conventionally put in, to indicate that if there is no moraine there ought to be.

Glaciers will in future be surveyed and the limits of the permanent ice and snow shown. Contours will be shown across the ice, and, as far as the scale permits, glacier features and moraines will be surveyed correctly.

The Limits of ice.—In large glaciers which extend several thousand feet below the snow-line, the only difficulty may be to distinguish between "dead moraine" and the glacier covered with living moraine. With such glaciers the snout can almost always be found by its issuing stream and ice-cave, but it is often necessary to visit the actual snout. Further up clearer ice is visible, and main glaciers are still in valleys. Below the snow-line their edges will be clearly marked and can be easily surveyed. Higher still the regions of glacier-ice merge imperceptibly into névé, both on the glacier itself and on the enclosing slopes. In late summer when most of the surplus snow has melted, there will be crevasses below the snow-line where the bed changes slope, and frequently an open bergschrund along the edge of the enclosing wall. Hanging glaciers on steep side-walls are inextricably mixed up with areas of névé; the limits of the whole mass however are easily distinguishable. While it is not simple for an inexperienced surveyor to distinguish between glacier,—though as a rule it ends abruptly—and a fresh fall of snow near the snow-line *, it should always be possible for him to survey

* Fresh snow is whiter than old snow, névé, or ice It covers rocky and exposed arêtes which cannot retain névé or ice, and from which it generally descends in the form of avalanches.

accurately the limits of a glacier well below that line. They should be shown on his planetable by a line of yellow-green dots.

It will often not be possible for a surveyor to visit the areas above the snow-line, or to survey correctly the limits of ice-caps. Frequently however they end as hanging glaciers, with a "clotted-cream" appearance, and terminate abruptly with an ice-cliff which is easy to survey.

In all cases contours across ice will be shown on planetables in yellow-green. It must be realized that it is physically impossible for a barren ice-free gentle slope to exist above the snow-line; and therefore brown contours should never be shown above that line. If there is no snow or névé or ice, it can only be because the slope is too steep for these to remain, and the cliff symbol is appropriate.

Contours across glaciers.—It cannot be too strongly urged on surveyors that contours *must* be surveyed across glaciated areas and glaciers. With ice-cap and hanging glaciers this is not difficult, for they conform roughly to the contours of their bed.

With valley glaciers, however, there are certain principles which will help a surveyor to show the form of his ice correctly.

A valley filled with a glacier is typically U-shaped; a valley cut by water action is generally V-shaped. If these facts are borne in mind, it will be realized that since, throughout the Himālaya, glaciers are of less extent than formerly, the enclosing walls of a glacier are generally concave, that is, the lower slopes are less steep than the higher.

Figure I represents a normal glacier in plan. If we consider a section across the valley at AB, assumed to be above the snow-line, we shall have something like figure II. The actual fall and slope of the valley-sides are at right angles to the glacier's direction and therefore the contours run almost parallel to the valley, as shown at *a a a* in figure I. At the head of the glacier *k k k* there will be an almost imperceptible junction between the glacier and the hillside, except for a change of slope. The ice and névé at AB may be covered by fresh or avalanche snow.

We will now consider a section CD below the snow-line. We will assume that on one side there is a rock-fall split from the cliffs above by the action of frost; while on the other an avalanche has been shot from above the snow-line and deposited on the glacier. The track of the avalanche is accidental; it is not permanent.* On the glacier it will cover crevasses, so that these cannot be surveyed,

* It is no part of this paper to describe the causes of avalanches, or the different kinds of avalanches, in detail. But since surveyors may have had little or no experience of them, and since perhaps more accidents among the mountains are caused by them than by any other agency, it may not be out of place to state that *avalanches are not acts of God*; their science is an exact science based on definite physical laws.

Snow from winter or spring storms, deposited on ice or névé on a slope greater than 23° is liable to avalanche during the spring, either when under the influence of the sun during the day, or during a warm cloudy night. On crisp starlit cold nights, such snow is safe after it has been deposited 48 hours, provided no fresh fall of snow and if it is a large avalanche its lower layers will be converted into ice and feed the glacier. The rock-fall is often a more permanent feature, and a more permanent danger. The rocks fall continually to the surface of the glacier, and are carried by its motion in the form of a continuous lateral moraine along the edge of the main trunk. A section at CD is shown in Figure III.

T_1 and T_2 are two tributary glaciers. T_1 has a large area of névé, and falls steeply to join the main glacier; T_2 is less significant. At the two rock promontories, P_1 and P_2, more rock debris is thrown upon the surface of the glacier. The pressure of T_1 and its ample ice convert the lateral moraine and the rocks from P_1 into a medial moraine; the rocks from P_2 are barely affected by T_2, whose wastage from melting is great, and the rocks tumble off the main glacier to form dead moraine.

We will now consider a section at EF, some distance below the junction of these two tributaries. The hillsides are no longer covered by permanent snow; the slopes receive their winter snowfall, which either melts and trickles to the valley bottom, or descends more violently in the form of spring avalanches. By midsummer this "new snow" has cleared away, and we find the beginnings of lateral ablation valleys. The surface of the glacier is now definitely convex. In the northern hemisphere the valley on its north bank will usually be more pronounced than on its southern bank owing to radiation from the barren valley walls with a southerly aspect. The section will be something like Figure IV*, and the contours will take the form as shown at EF in Figure I.

Figure V shows a section across the snout of a strongly advancing glacier; Figure VI shows a section near the snout of a retreating diminishing glacier. In the first the ice tends to maintain its height but encroaches on the lateral valley, pushing aside its dead lateral moraine. In the second figure, the degenerate glacier is flattening. The contours will be somewhat similar to those shown in Figure VII. Under no circumstances can the contours near a glacier snout be correctly shown as in Figure VIII. *Such a possibility is inconceivable.*

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has occurred. The location of these spring avalanches in the Himālaya is extraordinarily constant. In summer no fresh snow lying at an angle greater than 23° is safe for 72 hours after a heavy fall, by which time it should either have avalanched or become compacted with the under-mass; the steeper the slope, the greater the danger.

Snow lying at a greater angle than 23° on the lee-side of a snow mountain should be treated with suspicion. This may cause a dangerous slab-avalanche, but I do not believe this type occurs in the Himālaya in the summer or below the snow-line, except perhaps in midwinter

No snow whatever can avalanche on a slope of less than 23 degrees; all snow lying at a greater angle than 30° degrees, and all country lying close under such a snow-slope, should be treated with respect. Officers, before taking the field to survey glaciated areas, should study some standard work on snow-craft and explain the general principles of avalanches to their men. A very good account of them is given in Arnold Lunn's *Alpine Ski-ing*, Chapter IV.

* In the section EF the ablation valley on the north side is not emphasized owing to the crushing of the tongue of glacier T_1. It will however be more marked in section GH.

Moraine material has been shown on the above figures entering below the snow-line. A rock cliff above the snow-line may commence a moraine; that moraine is then covered by snow and may never appear again until the snout is reached. It may become consolidated in the névé, and work its way as en-glacial or sub-glacial moraine throughout the length of the glacier. *A confused mass of moraine debris does not and cannot exist above or near the snow-line on a broad glacier.* Here moraines, if they exist, follow definite lines, and it is important to survey them.

Barren moraines, living or dead, will be shown on the plane-table and on the published map in black. Dead moraines covered with vegetation should be in burnt sienna. Contours across clear ice or living moraines will be shown on the planetable in yellow-green, and on the finished map in blue. Contours across dead moraine, both on the planetable and on the map will be in burnt sienna. The margins of the glacier will be shown on the plane-table by yellow-green dots, and not by a continuous line, which should be reserved for contours, bergschrunds and other ice-features. The dots showing the snout should be strengthened. No coloured wash to show the glacier will appear on the plane-table or on the published map.

Additional Observations.—The following additional observations will also help surveyors to indicate glacier features and other features in the neighbourhood of glaciers correctly :—

(a) Crevassed and serac'ed areas are permanent over a long period of time, as are also the positions of ice-falls and bergschrunds, though individual crevasses and seracs below the snow-line move forward. and individual crevasses may heal by counter-pressure.

The fact that the central ice of a glacier moves faster than that at the sides produces crevasses across the lines of stress. The general direction of such crevasses is thus diagonally upstream from the sides towards the centre of the ice-flow.

(b) Bergschrunds may be expected at the base of steep ice-slopes above the snow-line, and at the snow-line, when clear of snow. They should be surveyed if the scale permits.

(c) Surface streams, rivers and lakes may be expected to occur on flat uncrevassed straight reaches of glaciers of even gradient.

(d) Couloirs are steep gullies on precipitous mountain-sides, either with or without ice. They are frequently funnels for falling rocks and are therefore often dangerous. If the scale permits they should be shown.

(e) Cornices form on most snow-ridges above the snow-line, and consist of compacted wind-driven snow on the crest opposite to the prevailing wind. Their outer edge, being generally formed of less compacted snow, is always dangerous whether near the snow-line or far above it. Cornices cannot however be shown on ordinary topographical scales.

(f) Screes and rock-falls are very prevalent above the tree-line, where the binding effect of vegetation is wanting. They are prominent features of the landscape on the arid hillsides of the higher ranges and often form a succession of cones or fans along the lower slopes of the valleys. The larger ones can usually be shown on topographical maps.

The accompanying specimen, Figure IX, has been drawn by Major C.G. Lewis, and approved by the Surveyor General. It gives the symbols that should henceforth be used on maps of the Survey of India. Few glaciers will contain all the features shown on this specimen and *no glacier in nature will be exactly represented by this specimen.*

The colours of these symbols will be as shown in the annexed table.

TABLE 3.

Features	Plane-table	Map	Remarks
1. Limits of all areas of permanent glaciation, whether glacier or névé, and all ice features.	Yellow-green	Blue	No tint. The limits of the glacier will be shown by a fine line of dots.
2. Water features whether on or off ice.	Violet-blue	Blue	...
3. Live or barren dead moraines, lateral, medial, or terminal; scree, rock-falls and fans.	Black	Black	Care should be taken to avoid the appearance of sand. The rocks comprising moraine are of all sizes; so also should be the dots.
4. Dead moraines if under vegetation (grass, scrub or trees).	Burnt Sienna	Brown	...
5. Contours across glaciers and névé, including those across live moraine.	Yellow-green	Blue	...
6. Contour-values pertaining to the above (a) across ice & snow (b) across moraine.	 Yell-grn. Black	 Blue Black	The contour values may be either alongside or breaking the contour line, whichever is most suitable.

TABLE 3.—(*Contd.*)

Features	Plane-table	Map	Remarks
7. Contours across hill-slopes below the snow-line, across dead moraines, scree, fans, etc.	Burnt Sienna	Brown	*Brown contours should never be shown above the snow-line.* Bare ground above this line must be cliff, and should be shown by the cliff-symbol
8. Cliffs above or below the snow-line.	Burnt Sienna	Brown	...
9. Paths, tracks, routes, huts.	Red	Red	...
10. Passes and names.	Black	Black	...

In fair drawing, items (1), (4), (5), (6_a), (7) & (8) will normally be drawn on the "Hill-sheet"; items (2), (3), (6_b), (9) and (10) on the "Outline-sheet." In exceptional cases, all may be drawn on one sheet.

Surveyors before taking the field for the survey of glaciated areas should have this paper explained to them, and practice drawing the symbols. They should try and recognize the various features and become expert in surveying them. Skill will only be attained by experience.

GLOSSARY.

Ablation valley.—A subsidiary valley between a glacier and its valley wall, generally due to wastage of the glacier-ice, caused mainly by radiation from the hill-side (pp. 4, 5, 13).

Arête.—The crest of a ridge or buttress leading to a summit.

Avalanche.—A mass of snow detached and sliding from a mountain-side (pp. 7, 8, 12, 13).

Bergschrund.—The crevasse, often of great depth, formed by a glacier moving from its névé. It always occurs at the change of slope between the névé on a mountain-side and the gentler slope of the nascent glacier in the valley (pp. 6, 14).

Cornice.—Overhanging compacted wind-driven snow formed on that side of a crest or arête opposite to the prevailing wind (p. 14).

Couloir.—A steep gully on a precipitous mountain-side, either with or without ice (*ice-couloir, rock-couloir*) (pp. 7, 14).

Crevasse.—A rent or crack in the surface of a glacier, caused by the uneven bed or motion of the glacier (pp. 5, 14).

Fan.—Erosion debris emerging fan-wise into the gentler slopes of the valley-bottom. The debris may be mud, sand, gravel, scree, boulders, etc. (p. 7).

Glacier.—A mass of compacted ice originating above the snow-line and descending below that line.

A Hanging glacier is one formed by an ice-cap, and clinging to a steep mountain-side. It frequently terminates in an ice-wall on a precipitous edge (p. 12).

A Valley glacier is one flowing in a valley (pp. 4, 11).

A Longitudinal glacier is one flowing in a main valley-trough parallel to a main range. Its *fall* is generally small (p. 8).

A Transverse glacier is one flowing transversely to the axis of a main range. Its *fall* may be great (pp. 8, 9).

A Saddle glacier is one descending to and lying astride a ridge, sometimes throwing branches into the valleys on each side of the divide (p. 6).

A Glacier table is formed by a moraine slab supported on an ice stem (p. 7).

Ice-Cap.—Compacted snow and ice on summits above the snow-line (pp. 4, 10, 11).

Moraines are formed by debris detached from exposed rocks and deposited on glaciers (pp. 6, 7, 9, 10).

En-glacial Moraine.—Rock debris carried along within the body of a glacier (pp. 7, 14).

Lateral Moraine.—Rock debris carried along at the sides of glaciers (*live*), or deposited on the valley floor from the sides of glaciers (*dead*) (pp. 6, 7, 10, 13).

Medial Moraine.—Rock debris carried along on the surface of a glacier below the junction of two or more glaciers (pp. 6, 7, 10, 13).

Sub-glacial Moraine.—Rock debris dragged along beneath a glacier (p. 14).

Terminal Moraine.—Rock debris deposited from the snout of a glacier (pp. 9,10,13).

Live Moraines.—Live moraines are carried on the surface or in the body of a glacier. Moraines deposited on the valley slopes or floor are *dead* (p. 10).

Névé.—Snow above the snow-line which has not reached the consistency of ice.

Regelation.—The process continually taking place in the lowest strata of a glacier, causing the glacier to move (p. 4).

Scree.—Loose small rock debris standing at or near its limiting angle of slope (pp. 7,14).

Seracs.—Detached broken columns of ice in the crevassed areas of glaciers, often formed by crevasses intersecting one another. The term is sometimes loosely but incorrectly applied to all ice-pinnacles on a glacier, however they may be formed (pp. 5,14)

Snout.—The lower end of a glacier where melting by the increased temperature of lower altitudes balances the supply of ice from above (pp. 4,7-10).

Snow-bridge.—Snow covering crevasses and bergschrunds, and formed by snow-fall or avalanche (p. 6).

Snow-line.—The lower limit of permanent snow (pp. 2-4).

Geod. Br. P.O.—111—500—1929.

NOTE.—Since the above paper was sent to press Mr. Rickmers has informed me that 17,000 feet and 15,000 feet are the approximate average heights of the snow-line on southern and northern aspects of the Trans-Alai range, while in extreme cases the limits may be 17,500 feet and 14,500 feet (*see* Table 1, page 2).

Mr. Rickmers also informs me "that exact measurements from photogrammetric material result in 77 kilometres (roughly 48 miles) as the length of the Fedchenko glacier, measured along the stream-line." The Fedchenko thus becomes the longest glacier outside sub-polar regions (*see* Table 2, page 8, and note below).

K.M.

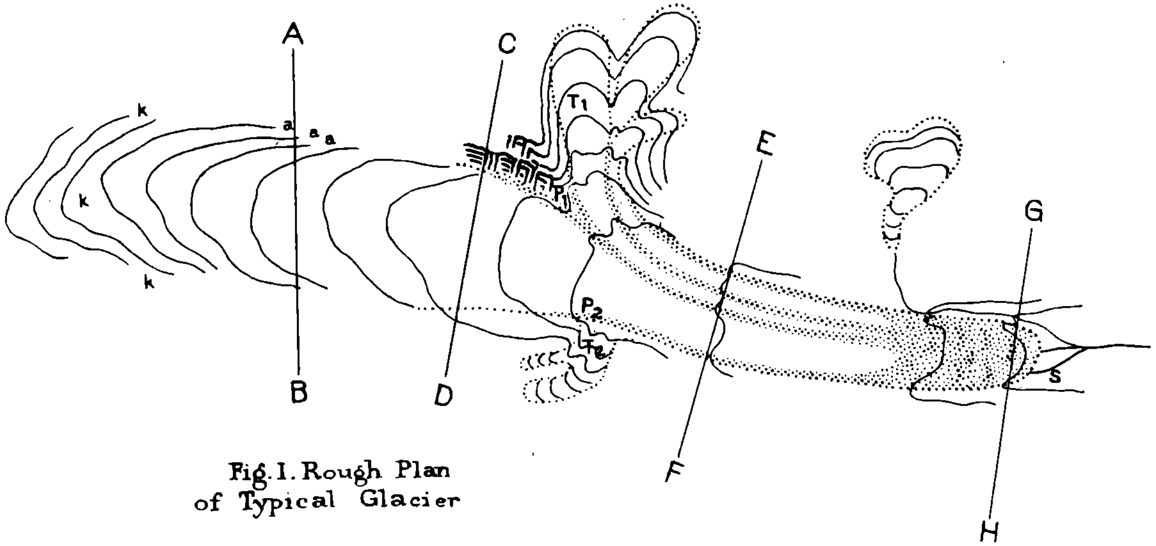


Fig. I. Rough Plan of Typical Glacier

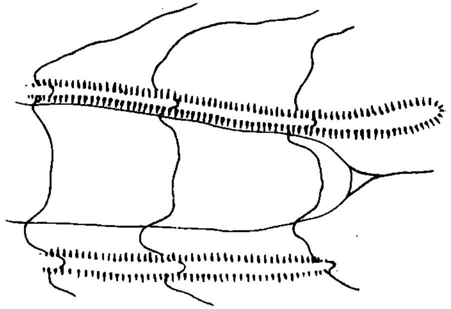


Fig. VII.

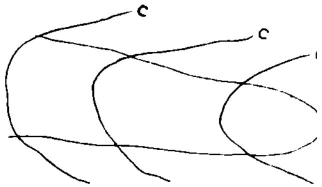


Fig. VIII.

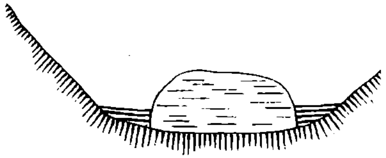


Fig. V.

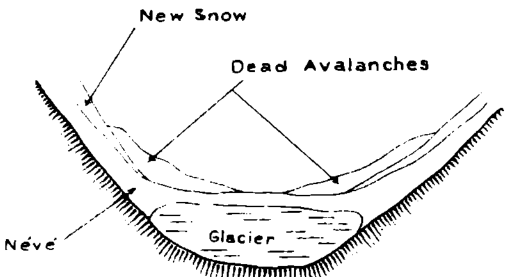


Fig. II. Section on AB

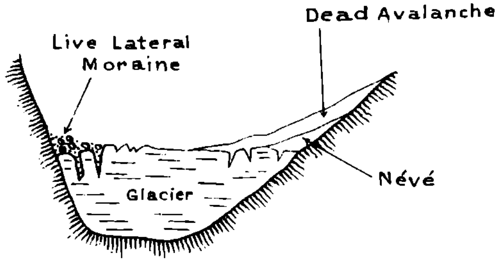


Fig. III. Section on CD looking down-stream

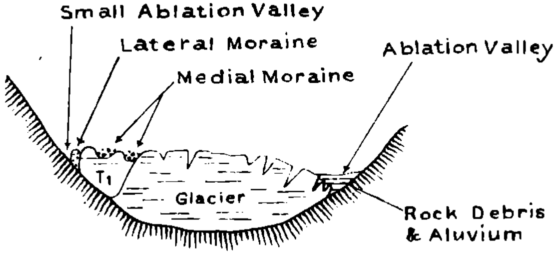


Fig. IV. Section on EF looking down-stream

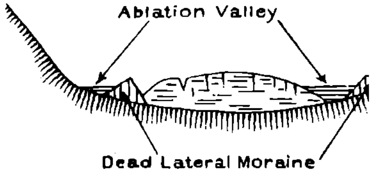


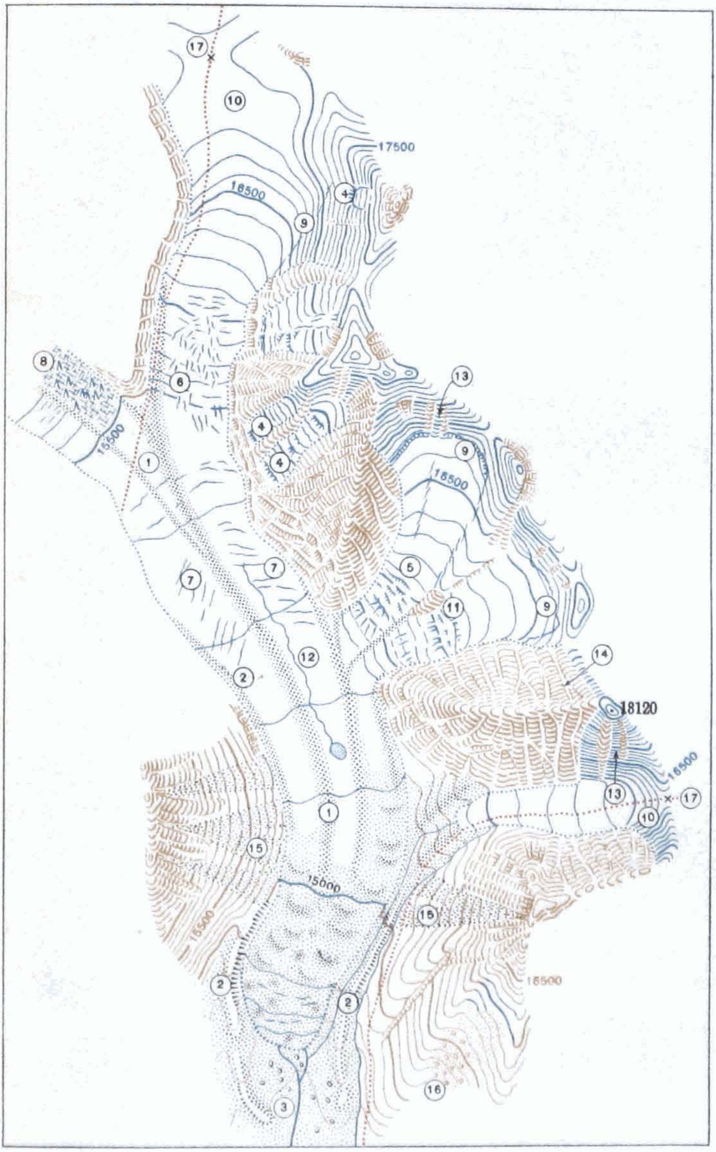
Fig. VI.

Reg. No. 1360 D. 29. 520.

Helio. S. I.

Specimen of Snow, Ice & Rock Forms.

Fig. IX.



Reg. No. 1045 D. 29. 700.

Helio S. I. O., Calcutta.

References

1. Medial Moraine
2. Lateral Moraine
3. Terminal Moraine
4. Hanging Glaciers
5. Ice fall
6. Crevasses due to uneven bed
7. Crevasses due to movement of ice stream
8. Seracs
9. Bergschrunds
10. Nevé
11. Rock outcrop
12. Glacier stream & lake
13. Ice Couloir
14. Rock Couloir
15. Scree
16. Rockfall (Large rocks)
17. Route over glacier, with pass

Corrections to "Professional Paper No. 25: The Representation of Glaciated Regions on maps of the Survey of India", 1929

Page 12—

In the 2nd and 9th lines, *correct* "yellow-green" to "blue-green (viridian)".

No. 1, dated 1-2-31.

Page 14, 2nd para. of the page—

In the 4th and 5th, and the 8th lines, *correct* "yellow-green" to "blue-green (viridian)".

Insert the following as penultimate sentence of the para.:

These dots will, however, be omitted below rocks having a definite edge.

No. 2, dated 1-2-31.

Pages 15 and 16.

Delete existing table 3, and *substitute*:

	Features.	Colours on plane-table sections.	Colours on published maps.	REMARKS.
i	Limits of all areas of permanent glaciation, whether glacier or névé, and all ice features.	Blue-green (Viridian).	Blue	Limits of all areas of ice & snow, whether glacier or névé, will be shown by a *dotted* line, which is omitted below rocks having a definite edge; no limit between a glacier and its névé will be shown. The rock cliff symbol will never be drawn in blue to represent ice-falls or ice walls. These features have special symbols.

	Features.	Colours on plane-table sections.	Colours on published maps.	Remarks.
ii	Water features whether on or off ice.	Violet Blue.	Blue	......
iii	Live or barren dead moraines, lateral, medial, or terminal; scree, rock-falls, and fans.	Black	Black	Care should be taken to avoid the appearance of sand. The rocks comprising moraine are of all sizes; so also should be the dots. Screes, on the other hand, are usually uniform and regular and should be represented by uniform dots, generally in fanwise lines.
iv	Dead moraines if under vegetation (grass, scurb, or trees).	Burnt Sienna.	Brown	......
v	Contours across glaciers and névé including those across live moraine.	Blue-green (Viridian).	Blue	......
vi	Contour values pertaining to the above, across ice, snow, and live moraine.	Blue-green (Viridian).	Blue	The contour values should break the contours as in brown contours.
vii	Contours across hill slopes below the snow-line, across dead moraines, scree, fans, etc.	Burnt Sienna.	Brown	*Brown contours should seldom be shown above the snow-line.* Bare ground above this line is usually cliff, which should be shown in the appropriate style. Brown contours will always have brown contour value.
viii	Cliff above or below the snow-line.	Burnt Sienna.	Brown	......
ix	Tracks and routes, over glaciers and permanent snow; club huts.	Red	Red	......
x	Passes and names ...	Black	Black	......

NOTE.—In fair drawing, items 1, 4, 5, 6, 7 and 8 will normally be drawn on the contour sheet; items 2, 3, 9, and 10 on the outline sheet. In exceptional cases all may be drawn on one sheet.

No. 3, dated 1-2-31.

Page 16—

In the 2nd line of the last para. above "Glossary" *correct* "practice" to "practise".

No. 4, dated 1-2-31.

Glossary—

Under "*Fan*"—

In the last line, after "etc.", *insert* a comma, and *add* the following after it:

and may be overgrown by grass or scrub

Under "*Glacier*"—

In the 2nd line, *insert* "usually" after "and".

Under "*A Glacier table*"—

In the last line, after "ice stem", *insert* a full stop, and *add* the following after it:

Its formation is due to the protection of the underlying ice from the heat of the sun

Under "*Ice-Cap*"—

In the first line, after "summits", *insert* "and ridges".

Insert the following as new item in its proper place:

Ice fall.—This occurs on a glacier at a change of slope to a steeper gradient, where crevasses are formed. When such crevasses intersect one another at right angles, they often degenerate in seracs and tumbled blocks of ice resembling a rock fall (pp. 5, 6, 11).

Under "*Terminal Moraine*"—

In the last line, after "glacier", *insert* a comma, and *add* the following after it:

from the medial, lateral, and sub-glacial moraines

Insert the following as new item in its proper place:

Rock fall.—A mass of tumbled rocks in a gully or on a mountain side (pp. 12, 13).

Under "*Scree*"—

In the first line, after "small rock", *insert* "or shale".

Under "*Snow-line*"—

Delete the existing descriptions, and *substitute* the following:

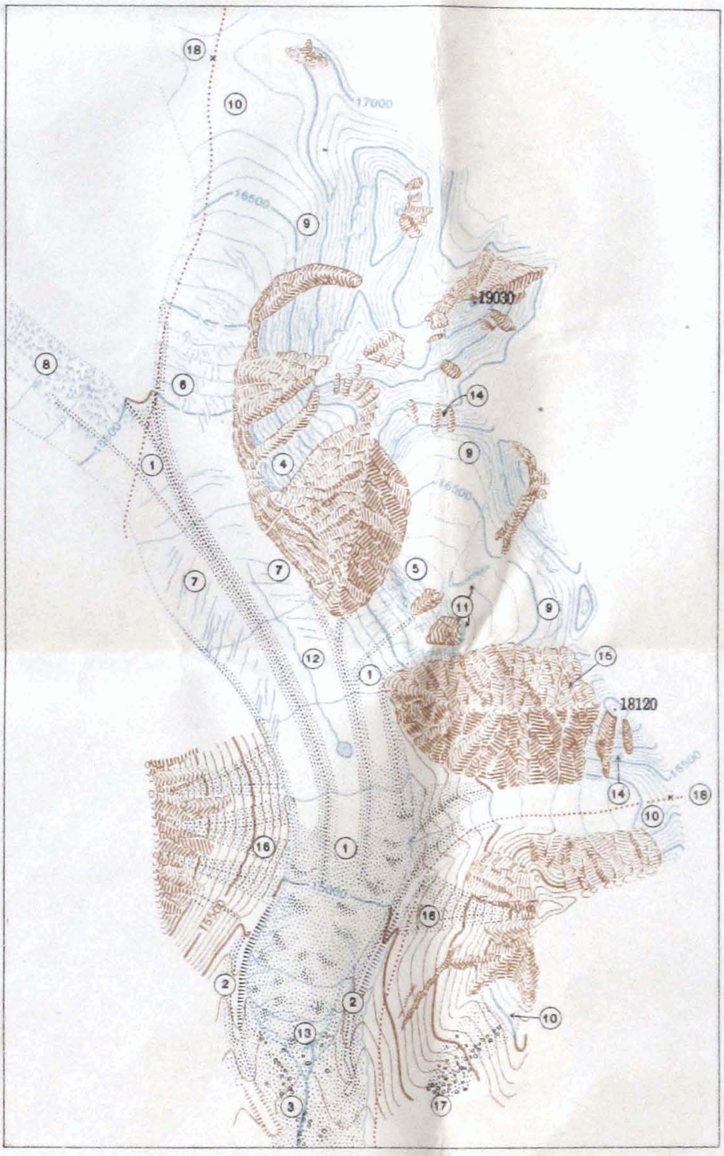
The average lower limit of permanent snow.

No. 5, dated 1-2-31.

Delete the existing "Specimen of Snow, Ice, and Rock Forms", and *substitute* the following:

Specimen of Snow, Ice, & Rock Forms.

Fig. IX.



References

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9. Bergschrunds
10. Neve
11. Ice cliff
12. Glacier stream & lake
13. Ice cave
14. Ice Couloir
15. Rock Couloir
16. Scree
17. Rockfall (Large rocks)
18. Route over glacier, with pass

No. 6, dated 1-2-31.