Glacier Mechanics

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IT is interesting to note how many of the pioneers of mountaineering in the Alps were men of notable achievement in other lines of endeavor. For centuries mountains and glaciers had been feared and avoided, but when this supposedly forbidden field was found to be singularly enticing and full of interest by those sufficiently venturesome to explore it, the lure of the mountains seems to have been felt most by those who were unusually vigorous, mentally as well as physically. In many of them, the stimulating hours of exercise on rocks, snow, and ice aroused a strong curiosity to understand better the natural phenomena with which they came in contact. New observations, novel and often surprising ideas featured the published accounts of their explorations, and speculative interpretations were advanced with the enthusiasm of a small boy with a new toy. Not a little of the charm of the mountaineering literature of these pioneer days lies in the observational and mental by-products of the early mountain conquests.

From De Saussure to Tyndall and even much later, climber after climber sought to explain how solid, crystalline ice could wend its way from a broad névé down a narrow, winding valley to the glacier snout. It was obviously rigid and brittle enough to crack easily into innumerable crevasses and yet, like a river, the moving ice molded itself readily to the valley configuration, swept around sharp bends, recovered its continuity after steep icefalls, and continued on still as brittle as ever to its terminus. It manifested other contradictions. Though appearing to flow like a river, or move downslope like a mass of soft tar, a glacier was found to scratch and groove the rock surfaces over which it passed, as if the rock fragments embedded in its basal portion had been held with the firmness of engraver's tools. This Jekyll-Hyde combination was an intriguing puzzle to many early explorers of glaciers. How was it that glaciers did these things? Various hypotheses were proposed, most of which contained some element of truth, yet none altogether satisfied the requirements. Controversies waxed and waned among adherents of different views, but the nature of glacier motion remained an unsatisfactorily answered question. As specialization became

increasingly the spirit of the times, mountaineers gradually retired from the field of glacier mechanics and left further efforts more and more to the geologist and physicist.

Later progress has been slow. Most geologists have devoted their summers in the field to other problems, while the physicists remained in their laboratories; too few of either have breathed the fresh air of the snowfields. Nevertheless, not a little has been learned in later years about the mechanical behavior of snow and ice in the large masses in which they occur in the mountains. Much, however, still remains to be done.

It has long been known that snow passes into glacier ice by a transformation of the snow flakes into granules through transfer of molecules by melting and freezing, together with settling of the individual granules and compaction of the mass. In 1938 this transition was given a careful investigation by Mr. G. Seligman's Jungfraujoch Research Party during five months of field work on the Aletsch Glacier, but as yet only very brief preliminary statements of their results are available.[1] They found that the winter cold wave had penetrated to a depth of about 15 meters by simple conduction, below which point the whole glacier was presumably at the melting point for the existing pressure. With the first spell of really warm weather early in June melt-water from the surface percolated downward in the névé until, on encountering the negative temperatures, it froze and gave up its latent heat thus causing the temperatures to rise rapidly towards O° C. The rate of temperature rise was found to depend on the névé structure and its permeability to water. By late mid-summer the whole of the glacier apparently was at the freezing point and remained so till the next winter cold wave started downward.

On the other hand, in very cold parts of polar regions where there is little melting, the glaciers are probably frozen throughout their mass even in summer, and Odell is of the opinion that the glaciers of Mt. Everest likewise have below-freezing temperatures down to the underlying rock.[2] Whether the mass of the glacier

[1] Jungfraujoch Research Expedition: Preliminary Report, *G. J.*, xciii (1939), 346. Results of the Jungfraujoch Research Expedition, *Association for the Study of Snow and Ice*, i, 2 (1939).

[2] N. E. Odell, "The Glaciers and Morphology of the Franz Josef Fjord Region of Northeast Greenland"; *G. J.*, xc (1937), 111. "Some Scientific Researches in the Region of Mount Everest"; *Nature*, 143 (1939), 545.

is at the melting point or considerably below will naturally make a difference in its mode of movement.

In an accumulation area where there is important summer melting, as near the Jungfraujoch, the surface melt-water seeps down through the névé until on reaching some thin crust or difference in the capillarity between two layers its progress is stopped and, when the temperature is below freezing, it congeals as a band of ice. In this way the névé acquires one variety of stratification. The other variety is due to dirt bands arising from wind-borne dust which accumulates on the surface of the snow field and is later buried beneath fresh snow. Both types travel far down the glacier tongue in the area of ice wastage.

The most striking surface features of the moving glacier are the crevasses, together with their offspring the jagged ice-blocks and seracs of the icefalls. They result from tension which cracks the brittle ice and, with further pulling apart of its walls, the crack opens into a gaping fissure. As the tensile stresses develop in different ways in different parts of a valley glacier, the crevasses are accordingly grouped in three categories. These are, as probably most mountaineers who have traveled much on Alpine glaciers have already observed: (1) transverse crevasses in the medial and larger portion of the ice stream, (2) diagonal crevasses along each side, and (3) longitudinal crevasses approaching the terminus.

No glacier in the mountains is flowing over a perfectly plane surface; instead it is passing over an irregular bed, some portions of which have a steeper slope, others a gentler gradient. Those who have walked up a mountain valley down which a glacier rode during the Ice Age, but from which it has since either disappeared entirely or else shrunk far back toward its source of supply among the high peaks, will probably recall that they rose by several fairly steep steps between which lay longer, leveller strips of valley floor like as not beautified by one or more small lakes. The old glacier had a rough journey. A river, given time, would smooth out its cascading course by cutting it down to a more uniform gradient. But the improvident glacier only digs deeper at the foot of a steep pitch increasing its height, though leaving us later the legacy of a charming tarn or mountain lake. In the living glacier the icefalls, terribly riven by crevassing, mark the steeper pitches of its uneven bed.

In passing over even a slight convexity of the underlying rock surface the sheet of ice must bend accordingly because of the cooperation of gravity. To give the necessary curvature its upper surface must be stretched. Ice will bend readily enough under slowly applied compression, but under tension its strength is much less and it cracks apart instead of stretching notably. As the direction of greatest tensile stress is here essentially that of the ice movement, the ice cracks most easily, according to a well-known principle of mechanics, in lines approximately at right angles to the glacier flow. Thus arise the *transverse crevasses* which trend across the valley. Tension, developed as outlined and possibly produced also by the upper portion of the glacier moving faster than that beneath, pulls the walls of some of the cracks apart opening crevasses.

The troublesome *diagonal crevasses* which one encounters along each side of the ice stream are to be blamed upon the differential movement of the ice down the valley. They run diagonally upstream inward from the glacier margin toward the middle portion. At moderate distances in from the margin the trend changes to approach that of the transverse crevasses which run more nearly straight across the glacier. These marginal crevasses running obliquely upstream from each side, combined with the transverse crevasses in the middle portion of the glacier between, give a general arcuate pattern of crevassing, convex upstream. This seems very strange indeed, for as everybody knows that the middle of a glacier moves down the valley faster than the ice on the two sides, one would certainly expect the crevasses to cross the glacier in curving lines convex downstream. The dirt bands on the surface do curve just that way. So also the lines of secondary shearing. Intelligent observers are often perplexed by this seemingly strange behavior of the crevasses. An engineer at the Kennecott copper mine in Alaska once asked: "What is the matter with this crazy glacier?" as we looked down upon the big Kennecott Glacier close by. Nothing was the matter; it was behaving quite normally. It crevassed as it did for the very reason that the middle was moving faster than the sides!

Suppose one were to select a relatively flattish portion of the surface of the glacier close to one side and measure upon it a line 100 yards long from a point near the ice margin straight in toward

the middle of the ice stream. Suppose at intervals of ten yards he drove in stakes (to be reset when necessary) or placed flat slabs of rock which would maintain their position on the ice for a few weeks in spite of the daily melting. Because the ice moves more and more rapidly with increasing distance from the side, he would find, after a while, that the line of stakes, originally running straight in from the glacier margin, now extended diagonally downstream. Whether the line remained straight or not, stakes 1 and 11 at the two ends would be more than 100 yards apart instead of the 100 yards that formerly separated them. Although the lengthening of the line involves shearing as well as stretching, there is, at times, sufficient tension developed in the direction of the line to cause the brittle ice to split in a crevasse at right angles to it. As the direction of tension is diagonally downstream from the margin of the glacier, whatever crevasses form will extend diagonally upstream from the margin.

Where the snout of a glacier does not cover the full width of the valley floor, the ice tends to spread out as it moves toward its terminus. The resulting tension, concentric with the curving end of the glacier tongue, splits the ice into crevasses at right angles to the edge of the ice, or parallel to the direction of ice movement (Fig. 1). Forming in the direction of ice flow, these are *longitudinal crevasses.*

In the lower tongue of a valley glacier, where the thrust from behind is great, there is nearly everywhere developed the familiar *banded, parallel,* or *ribbon* structure described by many authors, though with much difference of opinion as to its origin and significance (Fig. 2). One may observe readily that this structure is of a twofold nature, consisting in part of planes of slippage and even distinct fractures, and in part of thin bands of relatively transparent, bluish ice essentially free from air bubbles, alternating with thicker bands of more opaque, whitish ice filled with air bubbles. The lines of this banding on the surface of a glacier tongue invariably parallel approximately, or are concentric with, the curving glacier margin (Fig. 3). Near the sides of a long tongue the banded structure stands nearly vertically though in general dipping in toward the middle of the glacier; near the terminus it dips upstream at lower angles. Thus, wherever examined, the dips are prevailingly inward toward the direction from which the thrusting comes,

and in fact, together with the curving trend of the banding, are a very convenient means of determining one's approximate location on a large glacier in time of fog.[3]

The changing trends and dips are precisely what are required by the mechanics of shearing in solid material. In the central, axial portion of the ice tongue the major thrust is down the valley, and the ice from behind shears up and over that in front, along planes dipping upstream and trending across the valley. Well back from the terminus, particularly where the lower ice tongue has a gentle gradient and hence there is much flat-lying glacier in front to offer resistance, and where an icefall behind develops strong thrusting, relief is obtained by some upward movement of the ice as well as forward movement. Because of the strong upward component of the ice movement, the inclination of whatever shearing planes develop becomes steeper, and may even reach verticality in such portions of the glacier. On the other hand, as the lower end of the glacier is approached and the frontal slope steepens, resistance to the forward thrust of the top portion of the glacier is greatly reduced, both actually and relative to the resistance offered to the basal portion. Hence the upper ice shears over that beneath, along planes which become progressively lower in angle toward the end of the glacier. They may even reach horizontality or, if the terminus is located on a considerable slope, may even dip slightly down the slope (Fig. 4).

Along the side of a glacier tongue the movement is somewhat different. At the surface of the faster-moving valley glaciers the velocity in the middle may be more than ten times that at the sides, though in the slower ones the proportion may be only three to one. Much of this differential motion is of the nature of shear, as ice moves past ice. We may in fact picture a forward movement of longitudinal strips of ice at different velocities. Where distinct planes of shear are visible, they naturally stand nearly vertically, or inclined steeply toward the middle of the glacier, and trend (strike) in the direction of the movement which is approximately parallel to the glacier sides (Fig. 3). A component of thrust from the

[3] One needs to remember, however, that in case several separate glaciers have coalesced into a large trunk glacier, each contributing unit retains its own individual banded structure far down the valley and very commonly even to the terminus of the composite glacier.

middle of the glacier outward modifies dip and strike to a varying extent depending on the location.

The slip along most of the planes is probably slight, but along some it is very considerable, rock débris in some cases being dragged up from the base of the glacier. In fact an accumulation of dirt in these zones of shearing is a very familiar observation. The writer once noted along the west side of the powerful Valdez Glacier in Alaska a strip of water-worn pebbles dotting the surface of the ice where it was intersected by a prominent inclined shearing plane. The line of pebbles was nearly parallel to the side of the glacier, about 100 yards in length, and a few score of feet in from the edge. The pebbles obviously could have been rounded only by a stream flowing beneath the glacier; they were quite unlike the angular fragments of rock which fell from the neighboring cliffs. From beneath the terminus of the glacier, about a mile and a half away, many small sub-glacial streams emerged, branching into such a network of channels that it had required some ingenuity to get from Valdez village onto the glacier without wading above boot tops. It was perfectly clear that the ice on one side of the observed shear plane had moved up the incline and had dragged with it an abundance of water-rounded pebbles from one of these sub-glacial stream courses. Melting, however, had practically obliterated other evidence of the very considerable displacement of ice which must have taken place. The thickness of the glacier beneath the line of pebbles may be inferred from the fact that they were some fifty feet above its nearby edge.

As the variation in movement from place to place is but the appropriate local manifestation of the movement of the glacier as a whole, so the banded structure has definitely related trends and dips throughout the ice tongue. Viewed from an adjacent mountain summit, its surface trend lines are seen to curve like a parabola concave upstream.

The so-called *blue bands* are another feature of the banded structure and serve to make it more conspicuous by the color difference. They are bands of clear, bluish ice from a fraction of an inch up to several feet in thickness, nearly free from the air bubbles which give the ordinary glacier ice on either side its whitish appearance. While some stratification does develop in the névé by the formation of bands of bluish ice from the freezing of melt-water in zones,

the characteristic blue bands of the lower glacier tongue are oriented like the shear planes and, like them, are developed by the internal deformation of the glacier. Not uncommonly one set of parallel blue bands is found crossing another set at an acute angle. In places, particularly in a long glacier which has undergone changing stress orientation, the bands of one set have been dissevered and offset by displacement (faulting) along some of the bands of the other set which have not been broken or offset. This relationship tells us two things: the faulted blue bands are an older set, and newer blue bands have formed along the planes of faulting. One may note also that the later blue bands are sharply defined whereas the older structures are less and less distinct in proportion to their age.

There seem to be several possible ways in which these blue bands may originate. Where shearing has developed a distinct fracture, heat from the friction of ice being shoved along the fracture surface may cause local melting followed by freezing of the friction water. This shoving takes place intermittently. If at times the fracture is not entirely tight, melt-water from the glacier surface may penetrate and freeze along it. In either case the fault fracture becomes healed and there are few bubbles of air in the band of new ice which is clear and gives a bluish color. Under certain temperature conditions, the ice crystals in a zone of compressive shearing may be sliced or fragmented (development of cataclastic structure). The friction water refreezing rebuilds the crystals, healing the fractures, but without including the air liberated in the earlier part of the process. Another factor probably also operates to produce banding during the deformation. Unbalanced pressure (differential stress) lowers the melting point of solid substances. The shearing planes are planes of maximum tangential strain along which much energy is expended in the deformation. One might well expect strain melting along these planes during times of deformation, alternating with regelation upon relaxation. By an exceptional amount of alternate melting and refreezing in the zones where greatest yielding takes place the air bubbles are eliminated from them, developing bands of bluish, transparent ice, while at the same time there is more growth of granules in these bands than elsewhere, which checks with observations.

These bits of glacier behavior all tell us something about how a glacier moves. But in spite of all the studies which have been made, we do not yet know precisely how this movement takes place. The real difficulty is that the movement is accomplished, not by a single simple process, but by several processes acting together. The problem is complex. Although the various processes and factors are already fairly well understood individually, just what contribution each makes to the whole phenomenon of glacier motion has not been satisfactorily determined. Indeed the relative importance of the contributing processes probably varies under different conditions of temperature, pressure, stress, and other variables. The controversies over glacier motion have arisen, just as most scientific controversies arise, because one man, or one group, finds that a certain process is in operation and, enthusing over that and ignoring or minimizing everything else, concludes that this gives the whole explanation, whereas another investigator equally impressed by some other process which is known to operate, believes that this process is the whole story. Nature, however, is not so simple in many things, of which glacier motion is one.

In the névé the individual granule, or ice crystal, is the fundamental unit of movement. In general the larger granules grow at the expense of the smaller ones of sharper curvature, or of those less favorably placed. Thus the granules change their positions with respect to one another. They settle in compaction of the mass and creep downhill. As the névé is only partially consolidated and the ice crystals are not tightly locked together, the latter have considerable freedom of movement by slow rotation or moving past one another in an adjustment to space requirements under ever-acting gravity. By innumerable small adjustments between the granules, or small aggregates of granules, the whole mass moves slowly in the direction of least resistance, which is downhill.

As the névé passes into true glacier ice the granules become more firmly interlocked and their individual movements restricted and more difficult. Nevertheless, in a substance as easily deformed as glacier ice near its melting point, the granules should continue to move to some extent with respect to their neighbors even in the lower glacier.

Particularly should this behavior be expected when we call to mind the fact that special mechanical properties are exhibited at

intergranular boundaries. In metals near the melting point, the boundaries between grains are surfaces of weakness compared with any planes within the grains.[4] The same has been found true of pond ice under shearing stress. Deeley has suggested that the molecules at the intercrystal boundaries are in an abnormal state of strain, the crystal lattice being distorted, and that these molecules, therefore, are more easily brought into the liquid relationship than those in the interior of the crystal.

Closely related is the process of molecular transfer by which molecules move from positions of greater stress to positions of less stress. Differential stress, which lowers the melting point and favors melting, is greatest at these points of contact between granules which offer most resistance to shifting of the granules. Molecules therefore tend to migrate from these points of special resistance to places where they offer less resistance, thereby facilitating adjustments between the granules.

Other investigators have appealed to a very thin film of brine between the crystals to explain the observation that glacier ice in the sun melts more readily at intergranular boundaries than within the granules. A certain amount of ocean salt is brought to the glaciers by winds and rainfall. The quantity is very small, but such salt would be excluded from growing ice crystals and would tend to concentrate between them. If, in reality, there should be enough salt along the contacts of the glacier granules it would, by its solution effect, obviously aid movement between the individual grains. That there is sufficient salt to have an important effect, however, has not been proven. But in any case there is the familiar fact that the surface of a glacier after considerable melting under a hot sun crumbles readily into its constituent granules (Fig. 5).

So it is believed by many that small adjustments between the innumerable granules play an important part in the downhill passage of the lower glacier, as they unquestionably do in the névé. It has been computed that the mean motion of the average granule relative to its neighbor need be very slow indeed to account for the glacier velocities which are observed. A glacier moving in such fashion obviously can mold itself to fit the irregularities of its valley, undergo

[4] L. Hawkes, "Some Notes on the Structure and Flow of Ice"; *Geol. Mag.*, lxvii (1930), 111.

bending, and yet maintain the integrity of its granules and the observed crystalline properties at all times.

Another mechanism which is coming to be better understood from researches on the deformation of various crystals and metals (aggregates of small crystals) is minute slip along certain planes within the crystals. A crystal may be bent because a slight amount of slip can occur relatively easily along certain internal crystallographic planes without rupture. This is a process of slicing on a very minute scale and it gives the crystal some degree of plasticity. A crystal of ice is made up of thin laminæ at right angles to the optic axis. Between these are the well-known gliding planes along which the laminæ can slide easily over one another without distortion of the lattice structure of the crystal or loss of cohesion. Yielding along the gliding planes of favorably oriented ice crystals may thus be a factor in the mass movement of glaciers.

F. D. Adams, using high differential pressures, compressed cylinders of marble and other crystalline rocks into quite a different shape by "rock flowage." Some recrystallization occurred, but there was also much shattering of the individual crystals whereby the strength of the rock was considerably reduced although it held firmly together. The slower the deformation, the less the reduction in strength. Allowed to "rest" for a few days the marble partially recovered its strength. From Tarr and von Engeln's experiments we know that when a block of ice is made to change its shape notably by strong compression, individual ice crystals are fragmented into many angular pieces with different orientations and yet the mass remains coherent throughout. The deformed ice is coherent because the process of regelation, emphasized by Tyndall, promptly heals the fractures.

There is, therefore, abundant evidence that ice, if subjected to sufficient differential stress, will change its shape, "flowing" in the direction of least stress by either sliding along gliding planes in its crystals, or by fragmentation of the crystals with differential displacement of the fragments and regelation, or partly by one process and partly by the other. A glacier moving by the summation of small slips *within* its granules, like the glacier moving by the summation of small adjustments *between* the granules already discussed, would change in shape to fit its valley and yet be a

coherent crystalline mass. It cannot, however, be emphasized too strongly that these two processes are not mutually exclusive. There may well be slip within some of the granules as well as slip between some of them. The real question is the relative importance of the two methods of yielding. In this the temperature must be a factor; intergranular melting will facilitate adjustments between granules; in very cold glaciers fracturing must increase in importance relatively, whether this be between granules, within granules, or in major fault planes extending for long distances across the glacier. There is presumably also some difference between the behavior of ice near the surface of a glacier and that deep down beneath a heavy overburden.

In addition to the general pervasive movement of the types already considered, there is also local concentration of movement along many prominent shear planes (Fig. 6). On some the displacement is slight, but others are striking thrust faults on whose surfaces the overriding ice has been shoved forward for considerable distances. Where there is a succession of these well-developed faults, one above another, the ice has fractured into a succession of slices which have been driven forward by the thrust from behind, each slice sliding over the one below. This slice thrusting involves large masses of ice; it is slip on a large scale. Some of the slices show also much internal distortion. Lines of older structures, made conspicuous by dirt accumulated along them, have been bent sharply into overturned folds not unlike the folded rock strata commonly seen in mountain peaks (Figs. 7 and 8). In fact, there is no great difference in kind between faulting and folding in a glacier and the folding and faulting of the deforming earth crust which has produced many of the great mountain ranges of the globe, though mountain masses are pushed up and glaciers move downhill. Glacier ice is in every respect a crystalline rock and it deforms as such. Its notable peculiarity is in being at, or not far below, the melting point.

Probably enough has been said to give some idea of the different processes involved in glacier motion. Much more investigation will be needed to evaluate them properly. More measurements to show just how glacier velocity varies with air temperature, amount of sunlight, heavy rains and time of day, like those of Washburn

and Goldthwaite[5] on the South Crillon Glacier in Alaska, may establish facts bearing significantly on the methods of motion. Not only was the movement of the surface of the Crillon Glacier found to be jerky, but especially rapid motion was recorded at three and usually four periods each day. These were shortly after midnight, about 7 A.M., 2 P.M., and again in the early evening. No explanation was offered, but possibly it means a rough six-hour rhythm, irrespective of day and night. Three of the four periods (which we may note were when the glacier surface was cold) occurred consistently; the early afternoon advance (when the sun's effect was most felt) was more irregular and sometimes entirely absent. Measurements should be made on other glaciers for confirmation and comparison. Another promising line of attack is the systematic crystallographic study of the glacier crystals recently started by the Jungfraujoch Research Expedition to discover, among other things, to what extent and under what conditions the crystals show a preferred orientation. Their results are awaited with interest. Odell urges that no opportunity be missed by climbing parties in the higher Himalaya to note the characteristic features and any peculiar behavior of the glaciers in this environment where melt-water plays a minimum rôle in the glacier mechanism. Mountaineers who are interested might try their hand at a study of bergschrunds. So far these have escaped much of the critical scrutiny given to the lower ice tongues, readily reached without the expenditure of much muscular effort, although they have been commonly regarded as a feature of much significance. Glaciers thus still present plenty of problems only partly solved. As the possibilities of working out new climbing routes become increasingly limited among the better-known mountains, the mountaineer may still find opportunities to use his powers of observation to good advantage on the glaciers.

Note.—Through the courtesy of Mr. H. Bradford Washburn, Jr., we are presenting a unique group of the National Geographic Alaska photographs of glaciers, as follows:

1. Mt. Logan and King Peak seen across the Logan Glacier. This glacier has some of the finest medial moraines in Alaska.

[5] Bradford Washburn and Richard Goldthwaite, "Movement of South Crillon Glacier, Alaska"; *Bull. Geol. Soc. Amer.*, 48 (1937), 1653.

2. A beautiful series of recessional moraines marking the retreat of the snout of Iliamna Glacier.
3. Fascinating crevasse patterns in the snout of Miles Glacier where it plunges into Miles Lake, near Cordova.
4. The heavy crevassed surface of Sheridan Glacier showing the fanning out of the crevasse system as this glacier spreads out over the coastal plane near Cordova.
5. The Nunatak Glacier in Yakutat Bay. This glacier has receded more than eight miles since 1909, and its present ice front occupies a point which was buried beneath 2000 ft. of ice thirty years ago. The retreat of this glacier is one of the most remarkable records in the annals of glaciation.
6. The Barnard Glacier with Mt. Natazhat in the left background, and Mt. Bear in the upper right corner. The medial moraine system of this glacier is one of the most beautiful that has ever been recorded.
7. Vertical photograph of contorted medial moraines on the Bering Glacier. This curious morainic deformation takes place as a result of variations in the speed and volume of flow of the tributary glaciers from a main trunk glacier.
8. Magnificent contorted medial moraines between Steller Glacier (left) and the main mass of the Bering Glacier (right) seen from 15,000 ft.
9. The stagnant pitted snout of the Woodworth Glacier in the Tasnuna Valley, illustrating the way in which a completely dead mass of ice may slowly melt itself away from the terminus of a receding glacier and then slowly disintegrate. The scale in this photograph is enormous—about 500 ft. to an inch.
10. A beautiful example of an esker and striations beyond the snout of Woodworth Glacier. The dormant portion of the glacier shown vertically in No. 9 is in the upper left-hand corner, whereas in the upper right-hand corner, although the glacier has receded, it still seems to be quite active. Note the alluvial fan at the end of the esker which marks the terminus of the glacier at the time the esker was formed. I am certain from discussions with geologists that this is the only photograph in existence of an esker connected to an active glacier. Most eskers that have been found are features of the Pleistocene glaciation.