Harrington Putnam Esq.
with regards of
William Hunter Workman

6. # A STUDY OF

NIEVE PENITENTE IN HIMALAYA

PAPER No. 2

BY

WILLIAM HUNTER WORKMAN, M.A., M.D., F.R.G.S.

Reprinted from the
'ZEITSCHRIFT FÜR GLETSCHERKUNDE,' May 1909
with some additions

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1909

Himalaya
Nieve Penite

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 1.—Wind-conditioned nieve penitente, variety III., on ice-wall above Haigatum glacier at altitude of 5500 metres. Pinnacles arranged in lines following the inclines of surface.

[*Frontispiece.*

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Plate 2.—Patches of névé, the remains of preceding winter's snow, lying on moraine-slants, Hispar glacier. They are covered with straight-edged parallel ridges, subsidence ridges, coinciding in direction with slant of patches. On converging slant of patch in centre they converge.

[To face p. 2

Dr. W. Hunter Workman, *Photog*., 1908.

Plate 3.—Surface of upper part of Hispar glacier covered with névé-ridges following the direction of slopes, and curving with them. Surface descends to right and left from point where several members of our party are seen. Névé-ridges take same directions. Ridges crowned at many points with penitente-pinnacles, obscured in this view by distance.

[*To face p.* 2.

A STUDY OF NIEVE PENITENTE IN HIMALAYA

(Paper No. 2)

By William Hunter Workman, M.A., M.D., F.R.G.S.

In a paper under the above title that appeared in the 'Zeitschrift für Gletscherkunde,' Band II., Heft 1, 1907, and in a more detailed paper in the May 1908 'Alpine Journal,' I took the ground that the ice and névé-shafts, pinnacles, and pyramids, constituting what is known as nieve penitente, result from the action of heat, whether applied by the sun's direct rays, or by reflection, or by warm air-currents as observed by Dr. Hans Meyer, upon névé and glacial surfaces in which condensed foci have been formed antecedently by different causes, melting away the softer portions and leaving the denser ones standing as upward projections.

Since the above-mentioned papers were written, it has fallen to my lot during an exploring expedition to the Hispar glacier and its branches on the Hunza Nagar frontier of Northern India, and to the neighbouring Biafo and Skoro glaciers in Baltistan, in the summer of 1908, to be able to make an extended series of observations on nieve penitente found in great abundance under a variety of conditions, the correctness of which I had opportunity to verify many times over. These observations have strengthened my conviction of the general truth of the above proposition, and may, I hope, tend to dispel some of the clouds which have hitherto enshrouded the question of the development of nieve penitente.

The melting action of heat as a secondary and final factor common to the development of every kind of nieve is so self-evident and so generally conceded that it is not necessary to dwell upon it here. The more complicated and less understood question of the antecedent transformation of a glacial surface into conditions that enable heat to sculpture out nieve from it is one of special interest and importance. These conditions are so intimately connected with the resulting pinnacles that by them a differentiation of nieve into classes, each having peculiarities of its own, can be made. Such classification I shall attempt to make in the following pages, describing the different varieties as they presented themselves to my notice on the three above-named glaciers.

These glaciers are situated in a rectangle comprised between 35° 33′ and 36° 14′ lat. N. and 75° and 76° long. E. The length of the Hispar and Biafo glaciers is about 60 km. each. They rise from an altitude of, approximately, 3350 m. each at their tongues to that of 5327 m. at their culmination in the Hispar pass, where they join each other. The Hispar has a number of large branches, especially on its north side, which reach lengths of 10 to 15 km. The Skoro glacier, lying several miles south of Askole, is smaller, being only about 8 km. long, and rising from 4500 to 5400 m.

We passed the months of July and August, in all eight weeks, on these glaciers. During the greater part of June and to July 20 the weather was clear and warm, many days in succession being absolutely cloudless, so that, as was the case in the Nun Kun region in 1906, the season was favourable to the development of nieve penitente. We met with no new snow even up to an altitude of 6000 m. until the first week in August.

My attention was early attracted to a very marked feature of the sloping névé-surfaces of the region of the Hispar and its branches, whether the névé lay in isolated beds, or covered large areas of glacier or mountain slopes, viz. that they were almost invariably striated

Dr. W. HUNTER WORKMAN, *Photog.*, 1908.

PLATE 4.—Flat-topped penitente-pinnacle, variety I. a, developed somewhat in form of glacier-table. Composed of three parts, two upper forming, primarily, an avalanche-block, resting on third, a hardened agglomeration, or centre, of small avalanche-débris packed together by pressure, as photo well shows. Upper stratum of avalanche-block being of denser material than lower has resisted effect of heat to greater degree, and has larger periphery. Height 1·7 metre.

[*To face p.* 4.

with parallel ridges separated by furrows (*vide* plates 2, 3, 8). These ridges were undoubtedly caused in many cases by wind, in others by avalanches, and in others by the settling down and condensation of the névé on rather sharp slopes. The snow composing the ridges, even on higher glacial surfaces where the névé was of recent formation, was, as a rule, denser than that in the hollows, bearing the weight of a man where the latter would not, though this was not always the case when the névé was softened by the sun. Where the névé was old and well consolidated the difference in density was not so apparent, though it still existed.

These ridges, however formed, ran, almost without exception, in the same direction as the incline of the slopes, and, as different slopes inclined in different directions, they oriented in different cases to all points of the compass. When a given slope changed its course its ridges changed theirs to correspond. If a slope diverged at its base like an open fan, its peripheral ridges likewise diverged, and, on converging slopes, they converged toward its central line.

The wide distribution of such ridges on sloping névé (exclusive of the avalanche-channelled, precipitous névé and ice-slopes so common on Himalayan peaks) leads me to the conclusion that moving snow, whether it moves rapidly as when driven by the wind or in an avalanche shooting over a sloping surface, or by the slower process of settling downward, tends to accumulate in columns vertical to the surface with a direction coincident with the line of motion, which latter is determined by the shape and inclination of the slope. The same tendency was observed on the Shafat glacier in the Nun Kun in 1906, *vide* 'Zeitschrift für Gletscherkunde,' Band II., Heft 1, 1907, diagram on p. 24. These ridges having become converted into ice were found to persist as longitudinal surface-ice-ridges for two to three km. below the lower limit of névé, their direction coinciding with that of the descent of the portion of the glacier where they were seen.

Now these ridges are of importance to the subject in hand from the fact that, while on many surfaces they existed simply as ridges without further distinguishing features, on a vast number of others mammillation occurred in them, which developed into characteristic nieve penitente, proving that not all parts of the ridges were equally hard, but that foci of special density existed in them. Abundant opportunity was afforded to study the stages of transition from simple ridges to the perfected nieve-pyramid. No more need be said of these ridges here, as their relation to nieve penitente will appear further in what follows.

The nieve-pinnacles observed differed considerably in form. Some stood in square or rounded columns with flat tops. Others were conical, many of these being slender with sharp apices resembling curving horns. Others still were wedge-shaped. But by far the greater number were more or less regularly pyramidal in form, most of them being flattened on two opposite sides so as to present a long and a short axis. These last, being greatly in excess of all others, may, perhaps, be regarded as the typical form.

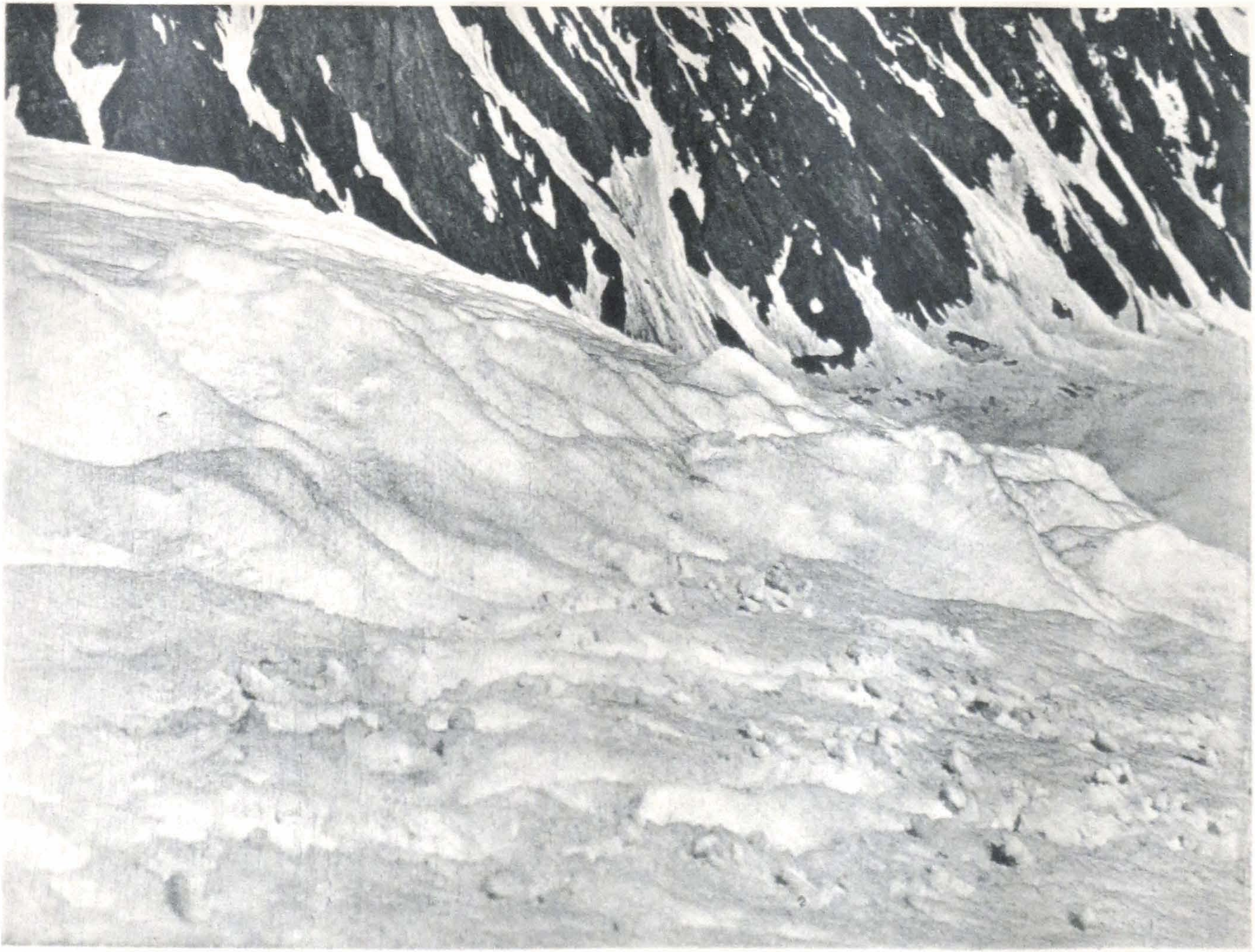
Nieve penitente, as has been stated, was met with under a number of different conditions, in accordance with which eight distinct varieties, the first including three sub-varieties, could be recognised. These were :

(I.) The avalanche variety.—(*a*) That occurring on slopes upon which avalanches had fallen and over which they had passed (*vide* plates 4, 5). This variety is mentioned by Sir Martin Conway, who, apparently, recognises no others. Numerous instances of this variety were seen at various points. On the south bank of the Hispar glacier, just west of the entrance of the Haigatum branch, at an altitude of 4200 m., two large névé-beds lying at the base of the mountain-wall were crossed, the first sloping directly north and the second north-east. Avalanches had fallen upon and passed over both of these, probably during the preceding winter. Their surfaces were scored into parallel ridges with ragged sides running in the direction of the inclines of the slopes and of the courses of the avalanches, in the first case due north and in the second north-east. The ridges were crowned with shafts and projections of various shapes undergoing modelling by the sun, a large number of which had been converted into typical nieve peni-

Dr. W. HUNTER WORKMAN, *Photog.*, 1908.

PLATE 5.—Avalanche-bed on Hispar glacier. Nieve penitente-pinnacles, variety I. a, in different stages of development some of them stratified.

[*To face p. 6.*



Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 6.—Nieve penitente on bed of sliding snow-avalanche, variety I. b, on névé-slant above Haigatum branch of Hispar. Pinnacles arranged in lines and of pyramidal type. Lines and long diameters of pyramids orient with direction of motion of avalanche. Height, 40 centimetres to 1 metre.

[*To face p. 6.*

tente-pyramids with their long axes parallel to the ridges. Some of them were stratified horizontally, dark dust-stained layers alternating with white ones of pure névé. Their height varied from 50 ctm. to 2 m. Some were evidently developed from blocks brought down by the avalanches, but many, perhaps the majority, were formed from snow-foci condensed between the pressure of the moving snow behind and the resistance of that in front.

A still more pronounced example was found at an altitude of 4850 m. on the south side of the Hispar glacier near its upper end at the base of a mountain, the face of which is encased in huge masses of ice clinging with precarious hold to the steep crags on which they rest, and whose lofty brow is fluted with equally large overhanging cornices, which frequently break away and fall thousands of feet in avalanches of tremendous proportions. The nieve here encountered had been developed on the bed of one or more avalanches that had fallen some time previously.

At a first glance the glacial névé appeared to be ploughed up and great blocks of ice to be scattered about in chaotic confusion; but on closer inspection of the crater-like area a certain order was seen to prevail, though the surface had been torn up to a far greater extent than in the instances first mentioned. The ice and névé-blocks, although scattered over all parts of the avalanche-bed, were arranged, largely, in lines following the path of the avalanche and parallel to one another. The more finely divided and pulverised portions of the avalanche-débris had formed ridges, ragged but distinct, also parallel to one another, running in the same direction. The tremendous power that had hurled the masses of ice and snow thousands of feet down the mountain-face, had condensed the snow of these ridges into foci, which the sun's heat was in some cases fast moulding, and in other cases had already moulded, into nieve penitente-pyramids.

Many of the smaller blocks had also been fashioned into pointed columns and pyramids, some with their long diameters parallel with the ridges and some with the same transverse to them, according to the original shape of the blocks. It is worthy of note that the ridges in all parts of the area were parallel to one another and oriented from south to north, coinciding with the direction of the slope of the glacial surface at this point and with the avalanche-path. Not one transverse ridge was seen. Many of the ridges and some of the blocks showed marked stratification. The height of the pinnacles here ranged from 1 to 2 m.

In these three instances the avalanches that conditioned the nieve were originally composed largely of solid material, which, first falling perpendicularly, was much broken up in the descent. On reaching the névé-slopes at the base the mixed débris tore its way for some distance down them till stopped by friction and gravity. In such cases the factor of forward motion is, without question, the cause of the arrangement of the débris in lines and ridges.

I saw several avalanche-beds on or at the bases of ice-falls, on which nieve-pinnacles were scattered about without any apparent arrangement in lines. In all these cases the pinnacles were modelled from ice or névé-blocks, which had not moved any great distance forward after striking the glacier.

(*b*) We now come to another order of avalanche-conditioned nieve, viz. where avalanches of snow slide down over sloping névé-surfaces (*vide* plate 6). Here parallel longitudinal ridges are formed, crowned largely, if not exclusively, by nieve of the pyramidal type. In the ascent of the exceedingly steep snow- and ice-covered east wall of the Haigatum branch of the Hispar glacier adjoining the Nushik La several avalanche-beds were encountered, where snow-avalanches had slid down over the névé. One of these beds, about half a kilometre in length, the whole course of which I followed up, afforded a most interesting study. Its width varied from 15 to 20 m., and it formed a stripe from 1.5 to 2.5 m. in thickness superimposed on the surface of the névé. It was divided into several longitudinal ridges varying in number in different portions, all orienting from east to west in the line of descent of the slope and of the avalanche, which were crowned throughout their whole length with perfectly developed nieve-pyramids,

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 7.—Avalanche-penitente, variety I. c, greatly serrated, formed from soft, new snow, which had slid down steep mountain-wall at altitude of 5800 metres and lodged at base. Pyramid-lines irregular, some being transverse to direction of fall and others coincident with it.

[*To face p. 8.*

flattened on two sides and tapering from base to summit, their long diameters being parallel to the ridges.

In a few places on the edges of the avalanche-bed groups of several pyramids had their long diameters turned at an acute angle with the ridges, as if the snow of the foci from which they were developed had encountered some resistance, which had turned it from the direct line of advance. Near the central part of the bed the long diameters of several pyramids ran transversely to the axis of the bed. With these few exceptions the long diameters of the pyramids oriented with the direction of the ridges they surmounted. The pyramids were composed of dense névé, and averaged from 40 ctm. to 1 m. in height.

In another instance a snow-avalanche issuing from a narrow gorge above the Kanibasar branch of the Hispar glacier descended upon a névé-surface, at first due west, but at the lower part it turned nearly south. Its bed was, like the last, covered with longitudinal ridges bearing well-formed nieve pyramids, their long diameters coinciding with the direction of the ridges, only one transverse pyramid being noted. Both ridges and pyramids, at first orienting west, turned with the course of the avalanche and finally oriented south, showing, perhaps, even better than in the preceding instance, that the condensed foci forming the pyramids were developed by pressure in the direction of the line of descent of the avalanche and not transversely to it. None of the pinnacles of the forms above described were crowned with hoods, but some had strongly curved apices.

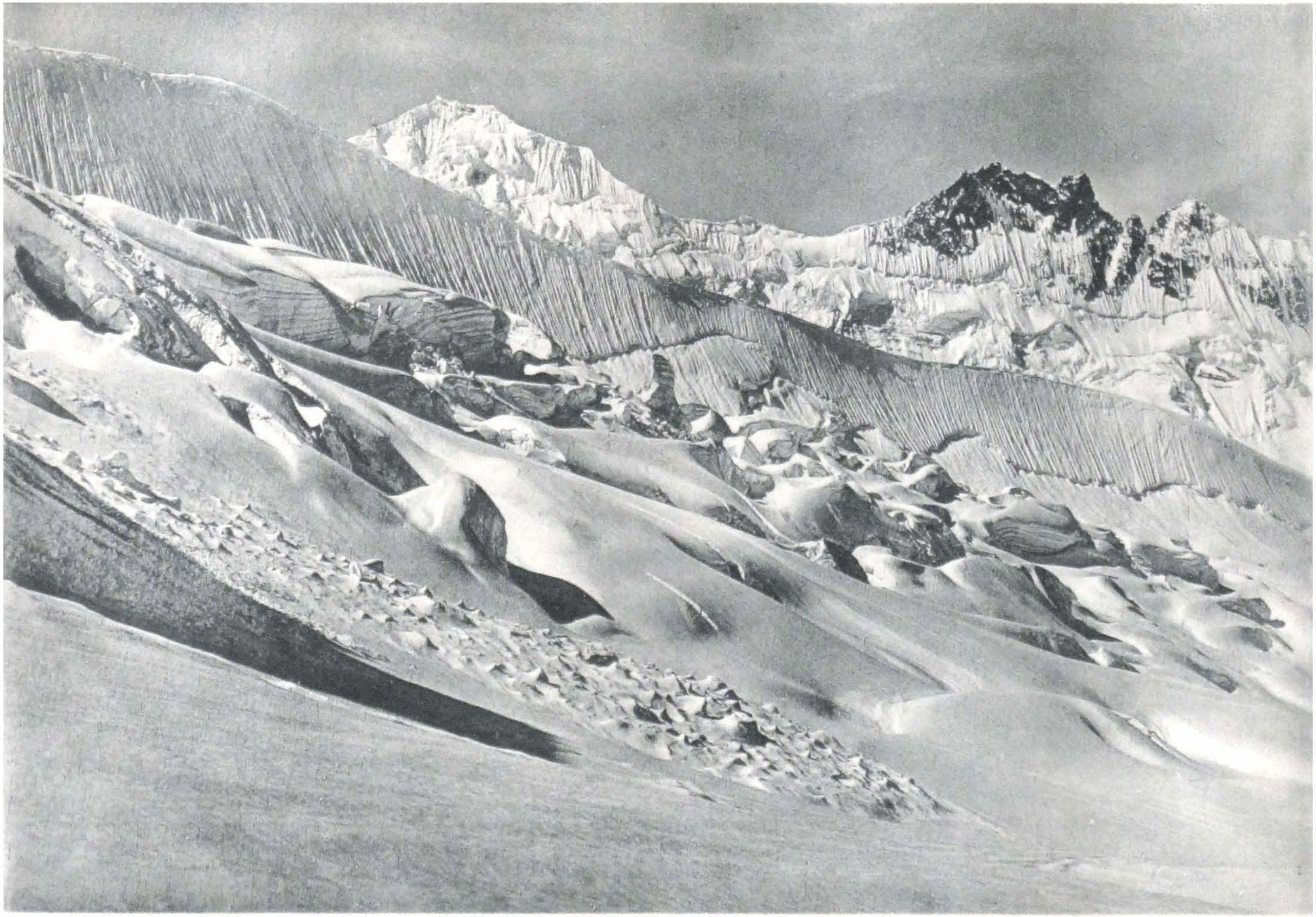
(*c*) Still another kind of avalanche-nieve was seen at several points high up on the mountain sides at an altitude of 5800 m. on the water-shed between the Hispar and Biafo glaciers (*vide* plate 7). The avalanches here were composed of new, soft snow, which slid down steep inclines and lodged where it struck without travelling forward to any extent. The pinnacles were of rather indefinite shape, and were arranged in rows mostly transverse or inclined at different angles to the line of fall, though in some places coincident with it. Their crests were greatly serrated. Their substance was porous, lacking the density of pinnacles modelled from more consolidated material.

Still, in their form and arrangement, the denser centres from which they were formed could be traced.

We camped for two weeks opposite the great snow-covered and corniced mountain-wall that bounds the upper part of the Hispar glacier on the south, and had an opportunity to watch the descent of more than a dozen large avalanches daily, and to study the arrangement of their material as it swept over and settled itself on the surfaces beneath. As these avalanches, which were mostly composed of rather finely divided material, thundered down the ice-covered slants, they were resolved by the channelled and ribbed surfaces, and even by the smooth ones, into columns which descended in spray-like streams accompanied by rolling clouds of snow-dust upon the névé-slopes and fans formed by the débris of former avalanches. When the snow-clouds cleared away the avalanche-tracks were seen to be covered with longitudinal ridges with more or less serrated tops, the peripheral ones being usually most sharply defined, and, in case of fans, diverging with their diverging contours. The only factor necessary to convert these into nieve penitente, as had already been done in other similar cases, would be the action of the sun's heat for a sufficient length of time.

From my observation I should judge that, the more finely divided the avalanche-material and the greater the horizontal or forward distance travelled after striking, the greater would be the chance of development of typical nieve penitente in lines on an avalanche-bed.

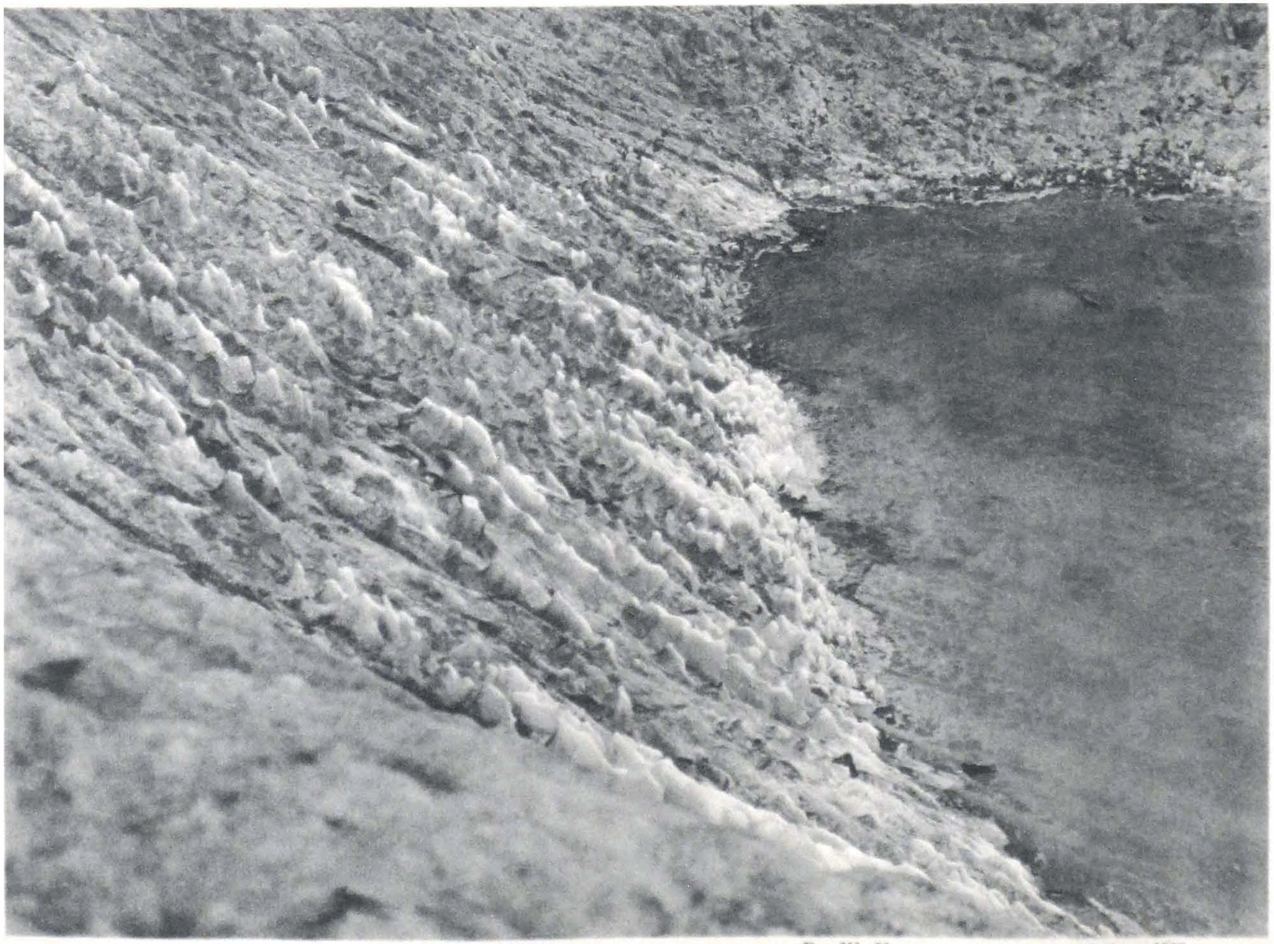
(II.) Subsidence variety, *vide* plate 9. Dr. Meyer in 'In den Hoch-Anden von Ecuador,' p. 437, suggests that, on slopes not sufficiently steep to give rise to avalanches, the settling and downward movement of snow, though it may not be great in distance, causes strata of different density to form through pressure, with their surfaces perpendicular to the direction of pressure, which the heat of the sun differentiates into ridges and hollows. The following observations testify to the truth of this suggestion, except in one particular, where they show that the strata have their surfaces coincident with the direction of pressure or downward movement, and not perpendicular to it.



Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 8.—View at source of Hispar glacier, 5183 metres. In foreground bed of nieve penitente, variety I. a, pinnacles mostly developed from avalanche-blocks. Centre-ground broken into ice-fall with horizontally stratified ice-masses. Behind this, ice-wall striated with parallel subsidence-névé-ridges orienting with slope of wall. In background south Hispar ice-wall also extensively striated.

[To face p. 10.



Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 9.—Portion of surface of lake in a deep depression in centre of Kanibasar glacier. Parallel lines of nieve penitente, of subsidence, or variety II., on steep slope leading down to lake. Lines and penitentes orient from north to south, coinciding with direction of descent of slope. Pinnacles point up the slope.

[*To face p. 10.*

They show further that foci of special density are formed in the denser strata (or ridges) which condition the development of nieve-pinnacles.

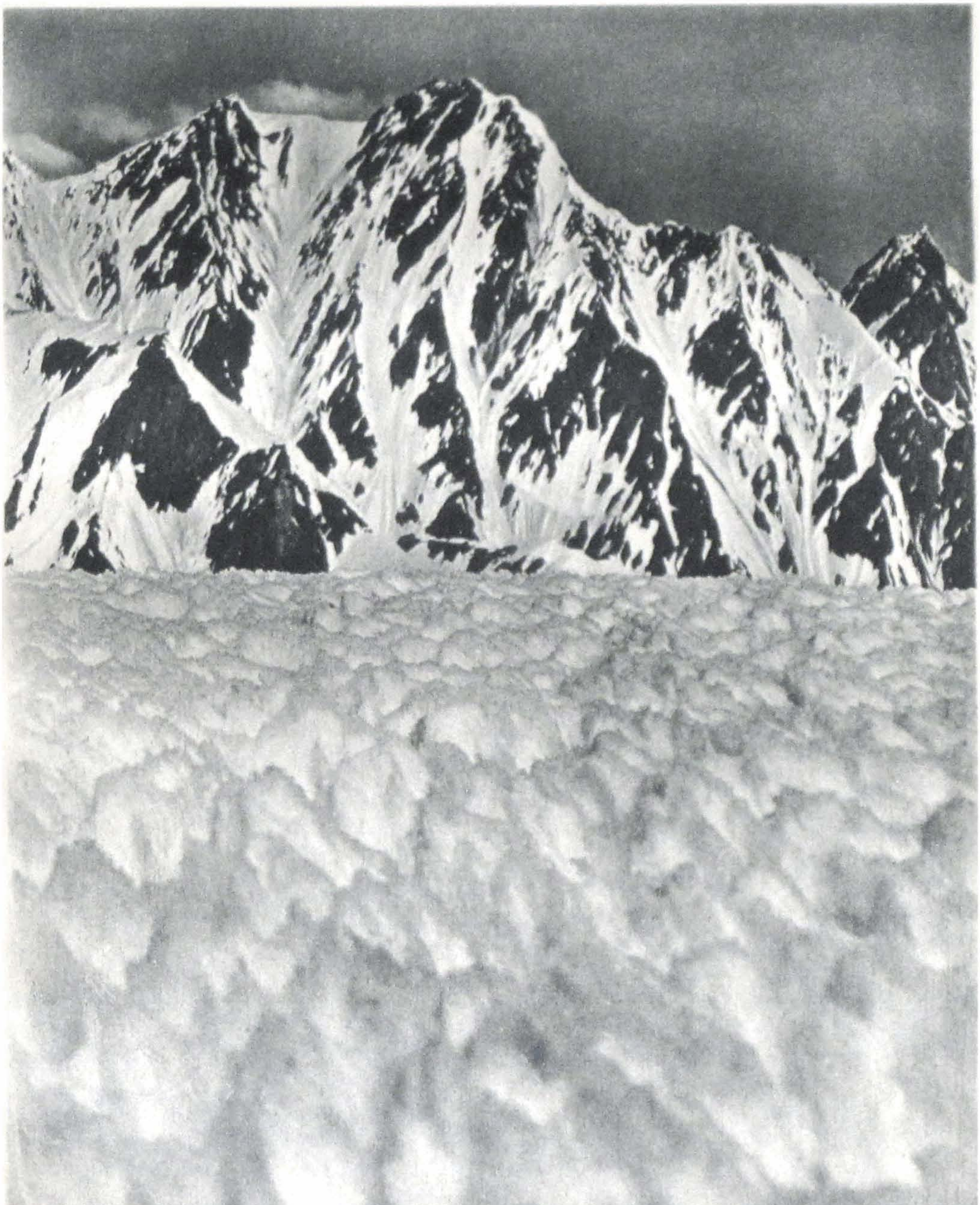
On the Haigatum glacier a névé-bed was seen, which illustrated the formation of this variety of nieve so well, and was so typical of similar examples elsewhere observed, that I will describe it. The bed, which was composed of old, consolidated névé, filled an angle at the base of two adjoining mountain-sides, had the form of a fan, sloped down at an angle of about 45° to the edge of the Haigatum glacier, and its central line faced directly south-east. Its surface from the upper edge downward was scored with longitudinal, not transverse, ridges, of which four central ones ran parallel to the central line. The others diverged as the fan broadened, following the lines of descent of the névé-columns of which they formed the upper parts. On the east side the fan descended considerably lower than on the west, corresponding to the fall of the glacier, and this lower corner turned to the east before joining the glacier. The two peripheral ridges on this side turned with the slope, their upper parts orienting south-east, and the lower directly east.

The summits of these ridges were sculptured out into small but perfectly formed nieve-pyramids with rounded tops, their long axes coinciding with the direction of the ridges. This was not an avalanche-bed, no snow lay above it, and its surface was free from detritus. Its inclination was sufficient to cause it to settle as suggested by Meyer, and the results were evident in the production of longitudinal strata containing denser foci, which formed the basis of nieve-pyramids.

At the head of the Jutum or Jutmaru branch of the Hispar glacier, at an altitude of 4700 m., several much larger névé-beds were seen showing similar characteristics. There were also fans of old névé sloping at 35° to 45°, facing south, and banded with strata bearing nieve-pyramids, which oriented south-east, south, or south-west, according to the spread of the fans. This variety of nieve was found widely distributed on mountain-sides and glacial slants, always on well-consolidated névé. The pyramids were of moderate size averaging 50 ctm. in height, of regular shape, and destitute of hoods.

(III.) Wind-conditioned variety, existing where the névé-covered surface of a glacier or mountain is transformed by wind into centres or foci of increased density, which form a basis for the development of nieve. This variety, which was discussed at length in my two former papers above referred to, was found covering large areas of the higher névé-surfaces of the Hispar and its branches removed from avalanche action and not sufficiently inclined for the formation of foci in the névé by sliding or subsidence, *vide* plates 1, 10. The pinnacles, which were almost invariably pyramidal, ran in wavy parallel lines coincident with the slopes. Where the latter curved so as to change their direction, the nieve-lines did the same. The pyramids were of medium size averaging from 30 ctm. to 70 ctm. in height, with evenly rounded summits, on which but few hoods were seen. They were generally separated from one another by oval fossæ enclosed between their bases. In some places where two opposite slopes ended in narrow surfaces falling away in a direction different from either, and also at the bases of slopes, where the névé ran nearly level or inclined in a direction different from that of the slopes, the lines of névé on the latter cut across those of the slopes often at right angles. The banks of glacial streams were also covered with nieve of this description, orienting in all directions, according to the windings of the streams formed from the remains of the preceding winter's snow.

After the ascent of the avalanche-swept, very steep, eastern wall of the Haigatum glacier, our party came at an altitude of 5500 m. to a series of rolling névé-covered slants ascending, one above another, to a corniced ice-peak above. These slants were clothed with a remarkable nieve-formation, consisting of closely approximated lines of pyramids running in the same direction as the inclines of the slants and curving around with them, resembling in arrangement a typical, ripple-marked, sandy sea-beach (*vide* plate 10). The pyramids were symmetrical in shape, and, though not large, averaging only 20 to 30 ctm. in height, though in some places they reached 50 ctm., were perfectly formed and were crowned with fringed hoods of ice, that glistened in the sunlight like myriads of diamonds, as in every case



Dr. W. HUNTER WORKMAN, *Photog.*, 1908.

PLATE 10.—Nieve penitente, variety III., at altitude of 5500 metres on névé-slants above Haigatum glacier. Extensive surfaces covered in this manner. Height 20 to 50 centimetres.

[To face p. 12.

they nodded toward the tops of the slants. There can be no question that these were developed from snow-wavelets traced by the wind on that mountain-top with all the delicacy of frostwork.

On p. 28 of 'Zeitschrift für Gletscherkunde,' Band II., Heft 1, and on p. 7 of the May 1908 "Alpine Journal," I suggested that the nieve-pyramids of one season, if not melted entirely away, might serve as bases on which the wind might build new foci for future pyramids. This was found to be verified on the higher portions of the Jutmaru glacier, where nieve-covered beds of white névé deposited the preceding winter alternated with areas of older, denser, dust-stained névé, which bore the ridges and truncated, though still well-marked, pyramids of an older nieve-formation. The ridges of the latter were continuous with those of the former, and, when the pyramids of the more recent névé were removed with the ice-axe, those of the older, on which they were resting, were laid bare.

Transition stages of névé into nieve were not wanting, occurring at first as a differentiation of the surface into mammillations with depressions between them arranged in more or less regular order, which became more pronounced until they developed into fully formed pyramids. It may sometimes be difficult to distinguish ridges and penitentes due to the antecedent action of wind from those due to subsidence. In such case consideration should be given to the slopes on which they are situated and to the character of the ridges and névé.

Where the ridges or lines of penitentes are due to wind, although parallel to one another, they run in a wavy or somewhat serpentine course, occur on level or gently sloping surfaces, and are usually composed of recently deposited, clean and white névé ; while in the subsidence variety the ridges have smooth sides and run in straight lines, unless the slope they stand on curves, when they curve with it as do those of the wind-variety, and the penitentes crown the ridges instead of, as in the wind-variety, often standing in lines the ridges between which have mostly disappeared. They also occur on old, well-consolidated névé, often much discoloured, and on slopes of decided inclination.

It has been suggested by some observers that the differentiation of névé into ridges, and of these again into nieve-pinnacles, is due to the melting and erosive action of running water, but no satisfactory evidence of the manner in which such a process may occur has been presented. In no instance where ridges and penitentes of the avalanche, subsidence, or wind-varieties have been observed by me, has any free or running water been noticed or any evidence that their formation has been influenced by it, such water as may have resulted from melting of the névé having either evaporated or settled into the névé so as not to be perceptible to the eye. The evidence of my observations has all been in favour of differentiation occurring in consequence of the greater resistance to the effect of heat of denser centres formed as stated.

(IV.) Thin débris variety. A fourth variety of nieve, which I do not remember to have seen mentioned, was found in abundance on the Hispar and its northern branches, particularly the Jutmaru, on those portions where the névé had melted away or become converted into granular and even denser glacial ice. Between the pinnacles the surface of the glacier was honeycombed with pockets or pools of various sizes with perpendicular walls, at the bottom of each of which was a thin layer of finely divided earthy material, gravel, or one or more thin fragments of shale. The shape of the vast majority of these pools was oblong, the long diameters orienting nearly or exactly east and west, so that, on the Jutmaru glacier descending from north to south, the lines of pinnacles projecting above them cut perpendicularly across the longitudinal glacial ridges, while on the Hispar, descending approximately from east to west, they ran in the same direction as the ridges which they crowned. In some places the long diameters of the pools oriented north and south, but this was exceptional.

As the melting due to the absorption of the sun's heat by the dark-coloured earthy deposit and shale-fragments proceeded, the dividing walls between many of the pools disappeared, and the latter coalesced into larger pools. Where these were situated on sloping surfaces many discharged their water and remained as furrows, always

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 11.—Thin débris, variety IV., penitente on Jutmaru glacier. Débris scattered about between pinnacles. Behind is pinnacle of glacier-table-penitente, variety V., caused by large granite-boulder, which has slid off from it to lower pedestal still supporting one end of boulder. Pinnacle stands directly north of boulder, which slid off from north to south.

[*To face p. 14.*

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 12.—Glacier-table on lower third of Biafo glacier. Height of ice-pedestal 4 metres. Note difference in circumference between base and upper end of pedestal. Glacier-table with much lower pedestal seen behind at left.

[*To face p.* 14.

deepening by the melting caused by the material lying at their bottoms. The melting of the glacial surface beneath these deposits, which was very rapid and in some places of marvellous extent, left prominences of ice between the pools, which were shaped by sun and heat into nieve-pinnacles of various sizes (*vide* plate 11). These, notwithstanding the great amount of earthy and petrous débris scattered over the surface, were composed of clean ice. They varied in height from 20 ctm. to 2 m., the smaller, in many instances, tapering on all sides to sharp points, while the larger had softer outlines. One peculiarity was common to all sizes, viz. that the long sides were, mostly, perpendicular instead of sloping, as would be natural from the method of formation, the detritus cutting its way into the ice in a perpendicular direction. In many one side only was perpendicular, the others being sloping, in which cases the perpendicular one extended considerably lower into the ice than the others owing to the more rapid melting caused by the earthy material or shale-fragments always to be found at its base.

The regularity in arrangement of the earthy patches as well as their oblong shape suggest that they were originally deposited as little wavelets upon the névé-surface by the wind. The same might be true of the sand and gravel-patches, but it is not so easy to account for the shale-splinters largely intermingled with the finer débris at a distance of 8 to 10 km. from the mountains from which they appeared to be derived. In this form of nieve the primary sculpturing out of the glacial surface into prominences and hollows may not be due so much to the pre-existence of denser centres as to the rapid local application of heat by the superimposed débris, unless the latter were, perchance, originally deposited in hollows consisting of softer material; but after differentiation of the surface has occurred, the softer of the remaining unmelted parts must melt away first in the modelling that ensues.

(V.) Glacier-table variety. A fifth variety is that connected with glacier-tables. This was found only on ice from which the névé had disappeared, or on ice covered with rock-débris, often so thickly that the nieve-pyramids were the only ice to be seen, appearing to stand on débris, though really their bases were continuous with the ice beneath. These were met with on the Hispar and its Kanibasar and Jutmaru branches, the latter of which was covered throughout its whole length, below the névé-line, with myriads of glacier-tables, the tops of which consisted almost invariably of granite boulders. They were also seen in great numbers on the Biafo glacier, over large portions of which, below the névé-line, boulders and glacier-tables were scattered so thickly that one could not advance three metres in any direction without encountering one, and on the Skoro glacier.

The process of development appears to be as follows. Boulders of granite or other rock fall on a glacial surface. Their weight, often amounting to hundreds of tons, compresses the névé beneath them into columns much denser than the surrounding névé. Owing to this density and to the protection from the sun's direct rays afforded by the rock-covering, which is too thick to permit the sun's heat to be transmitted through it, these columns persist as shafts somewhat diminished in diameter by reflected heat, supporting the rock-tops, after the surrounding softer névé has disappeared. At this stage we have the glacier-table, often with a shaft 2 to 3 m. or even more in height, the névé of which the shaft was originally composed having become converted into ice through pressure, thawing, and freezing. (*Vide* plate 12.)

At first the rock top sits level on its shaft or pedestal. After a while, the sun passing over it somewhat to the south and warming its southern face more than the northern, and the reflected heat likewise warming its southern under edge, the heat thus conducted to the shaft on that side causes its upper surface to melt faster than on the northern side, with the result that the top begins to tilt to the south; which process continues in an increasing degree, till finally the top slides off on the glacier, leaving the shaft standing behind it. (*Vide* plate 13.)

As the top tilts, the shaft, melting on one side and remaining

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Plate 13.—Glacier-table penitente-pyramid, variety V., on Kanibasar glacier. Its former rock-top lies against its southern side. Height on upper or northern side 1·7 metre, on southern side greater. Slant at left of apex indicates bevelling which shaft underwent before rock slid off.

[*To face p. 16.*

intact on the other, assumes more and more the shape of a wedge or pyramid, the angles of which are rounded off by direct and reflected heat, so that often when the top slides off, and sometimes before, a nieve-pyramid has been fully formed, and in some cases more than one. In most cases, however, the shaft is left with a bevelled upper surface, which soon sharpens off to a point.

On the Jutmaru and Kanibasar glaciers and on the Biafo, which descend towards the south, the glacier-table-tops slid off without exception in the quadrant from south-east to south-west, mostly south. (*Vide* plates 13, 14.) The same was in general true on the Hispar, which descends towards the west, many here sliding off south-east—i.e. up hill or against the slope. A few exceptions were noted on this glacier, where on rather sharp slopes facing north-west they slid off north-west or with the slope. On the Skoro glacier falling towards the north, they slid off on the south side or against the slope.

The pyramids of this variety were higher and more massive than those of any other except of the one next to be described and the sérac-variety, their size, as a rule, being proportioned to that of the boulder covering the shaft from which they were developed. Many exceeded 2 m. in height. They were typically and beautifully moulded with apices pointed or rounded, but without hoods. They were composed of granular and crystalline ice. They stood both single and in groups, the latter arrangement being due to the pre-existence of several tables close together, or to the development of several pyramids from a single shaft, owing, undoubtedly, to the formation in it of different columns of unequal density under the unequal pressure of the uneven lower surface of the superimposed boulder.

I saw a number of cases where well-formed pyramids existed under boulders still in position; the modelling having been effected by reflected heat, which had melted away from side to side the softer parts of the shafts corresponding to the inequalities of the under surface of the boulders. (*Vide* plate 15.) In one case a boulder rested on two massive but perfectly formed pyramids entirely distinct from each other except at their bases, which together constituted the large base of the original shaft. In many instances boulders had slid off from their pedestals to surfaces somewhat lower, the original pedestals having been transformed into nieve-pyramids behind the boulders, beneath which in their new position new pedestals were in process of formation. In such instances the pyramids stood on the north side of the boulders. (*Vide* plate 11.)

These glacial table-pyramids oriented in every direction, the trend of their long axis being, doubtless, determined by the shape of the original columns condensed under the pressure of the boulders.

Reflected heat plays a prominent *rôle* in the development of this variety. Much of the modelling is due to it, especially of the upper portions of the shafts, which are protected by the rock-tops from the sun's direct rays, except for a brief period at sunrise and sunset. The melting of these protected portions to a greater degree than that of the bases of the shafts, which are exposed to the sun's direct rays, thus producing a pyramidal form, shows how effective as a modelling agent reflected heat may be. The action of reflected heat must be reinforced to a considerable degree by that of the heat contained in the surrounding air and the vapour borne by it, and to a certain, though much smaller, extent by the evaporation which takes place from exposed ice and snow surfaces.

In connection with this form, as indicating how rapidly an unprotected glacial surface may melt away under a July sun, may be noted the following facts.

(*a*) The upper surface of a large, flat boulder near one of our glacier-camps at an altitude of 5017 m. was just emerging from the névé, when the camp was made. Ten days later, on a second visit, the same surface was found to be 70 ctm. above the névé. This represents the actual amount of melting of the névé during that time, 7 ctm. per diem, as the lower surface of the boulder was still deeply embedded in the névé and the sun's heat could not affect the latter beneath it.

(*b*) A stake was inserted in a consolidated névé-bed near our base-camp on the Hispar at an altitude of 4815 m. at 12 noon on July 31.

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 14.—Glacier-table penitente-pyramid, variety V., on Jutmaru glacier at part heavily covered with rock-detritus. Height about 2 metres. Large boulder at left formed top of former glacier-table, of which ice-pyramid represents the shaft. Boulder slid off on south-east side.

[To face p. 18.

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 15.—Group of glacier-table penitente-pyramids on Biafo glacier, variety V., formed around and under granite-boulder, which rests on several of them. Note sculpturing from reflected heat, which has taken place beneath boulder.

[To face p. 18.

On August 4 at the same hour the névé had melted 26 ctm., or 6.5 ctm. per diem, the last thirty-two hours the sky having been obscured by clouds and mist.

(*c*) On August 5 at 2.30 P.M. the stake was again inserted in the névé near the same place. On August 10 at the same hour measurement showed the névé to have disappeared to an extent of 41 ctm., or 8.2 ctm. per diem.

From these results it can be seen that, with an average melting of about 7 ctm. per diem, only two to three weeks of fine weather would be required for the development of nieve-pinnacles of good size. I would say here, that the smaller varieties of nieve in this region, as well as that seen on the Shafat glacier in the Nun Kun in 1906, were at their best during the third week in July, after which they began to disappear.

(VI.) Thick débris variety (*vide* plates 16, 17, 18, 19). Another form of nieve analogous to the last, in which the projections were capped with earthy material (alluvium, sand, or gravel), was found in great numbers on the lower three quarters of the Biafo glacier, to a much less extent on the Hispar and its branches, and upon the Skoro glacier at altitudes between 3400 and 4600 m. This was seen in a few instances on névé, but mostly along the courses of medial moraines and boulder-strewn stretches where névé had disappeared, dotting plain ice-surfaces, ice-slants, the sides of séracs, and forming serrated skylines on sharp ridges (*vide* plate 17). The projections, which had the form of cones, pyramids flattened or fluted on sides, wedges, and ridges, occurred single, in groups, and in lines, and oriented in every direction irrespective of inclines.

They varied in height from 10 ctm. to 3 m. Many were symmetrical in shape, others had one or more buttresses running out from the apex in sharp ridges. In all cases the apices and ridges were covered with detritus, as well as more or less of the slanting sides, and in some the whole pyramid was concealed from view under a thick deposit. Where the covering was thickest, the ice projected highest, and large pyramids were often studded with smaller ones as well as with ridges, covered more deeply than the ice around them (*vide* plate 18).

A considerable portion of the Biafo glacier where these existed was banded with perpendicular longitudinal strata. These passed through the nieve-pyramids, often cutting through their apices, thus affording proof that this form of nieve was developed out of glacial ice. All pinnacles, even the smallest, were composed of very hard compact ice, destitute of air bubbles, and breaking with a vitreous fracture, quite different from the soft, aerated ice around them.

The development of this variety may be thus regarded. Patches of mud or sand are deposited on a glacial surface, just how is not apparent.[1] These with a thickness of several or many centimetres protect the ice beneath them from the effect of heat, while the exposed surface around melts away, leaving the protected portions as raised projections. As melting proceeds, the mud or sand at the periphery of the projections falls away and lodges at the bases, thus protecting the latter but leaving the upper edges exposed, which then melt, giving the projection a slanting form. This process continues, melting occurring wherever the covering falls away, and diminishing or ceasing where it lodges, until the characteristic formations are fully developed, often, as stated above, dotted with smaller projections and ridges, where the sand or mud has found resting places, the apices and projecting parts being invariably protected by a coating of the same.

This variety being, as a rule, modelled out of glacial ice, may be employed as an approximate measure of the amount of melting which has occurred in the ice-surface around it. Estimated by this standard the glacial ice had disappeared, at several points noted, to a depth of 2.5 to 3 m. A still more remarkable instance was observed on the Hispar glacier (*vide* plate 19). A typical, symmetrical, quadrilateral pyramid of this variety with fluted sides, composed of dense greenish

[1] There was no indication from the condition of the glacier around that these deposits were of aeolian origin. That some of them were alluvial is very likely, though none were found where water was then present. Many were situated on the summits of high ridges where water could not reach them. Some of the gravel deposits might have resulted from disintegration of rocks, of which many instances were seen in different parts of this region.

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 16.—Mud-covered nieve penitente, thick débris, variety VI., in centre of Biafo glacier; coating thickest at apices. Pyramids arranged in two lines Largest 70 centimetres high. Large median moraine short distance behind them.

[*To face p. 20.*

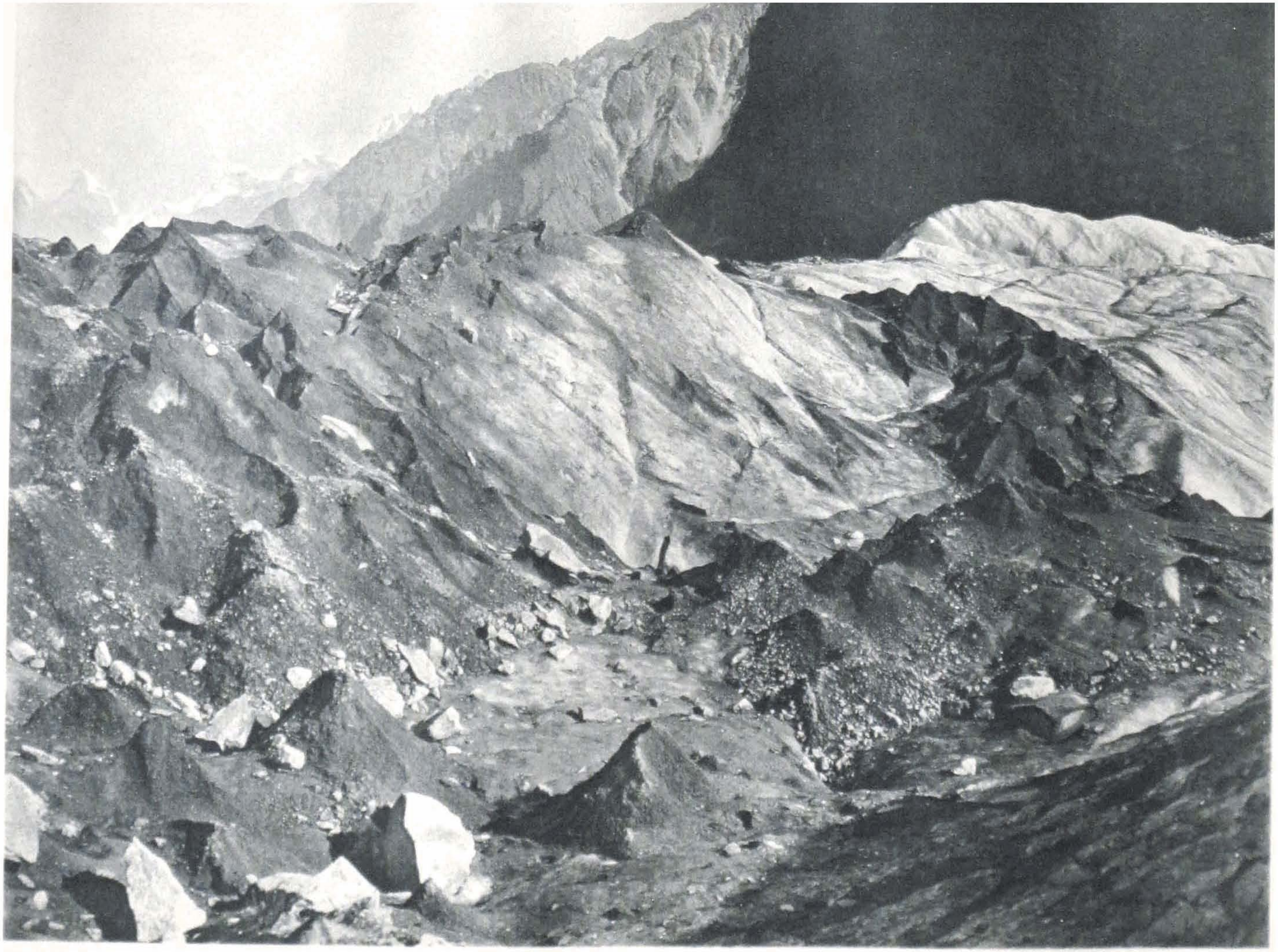
ice, its surface covered thinly and its apex and ridges more thickly with sand, stood entirely alone upon a large, slanting ice-field with an even surface, no other nieve-pyramid being in sight. After careful inspection and comparison its height was estimated at between 9 and 10 m., which would indicate a disappearance of glacial ice at that point to that extent. Conversely, the degree of protection from the sun's heat afforded by these deposits of mud and sand to the ice beneath them may be judged of by the same standard. This protection preserves large pyramids of densest ice intact under a burning sun, whose heat has melted away the solid ice around them to a depth of from 2.5 to over 9 m.

(VII.) Lacustrine or composite variety. A seventh and apparently rare variety of nieve was met with on beds of hardened névé lying at the bottom of depressions and clefts in the Hispar glacier opening on a glacial lake (*vide* plate 20). The surfaces of these beds were divided into triangular and quadrilateral pyramids from 30 to 40 ctm. high, arranged with great regularity, each pyramid connected with those around it by sharp ridges, the marginal pyramids being most perfectly shaped. These pyramids were covered with a layer of fine black mud, thicker over the apices and connecting ridges than in the hollows, that on the apices being thickest. The beds bent around in various directions with the windings of the clefts in which they lay. One surface near the lake had evidently been under water only a few hours before I saw it. It was covered with thin plates of ice bounded by the apices and ridges of the pyramids, from beneath which the water had escaped. These ice-plates glistening in the sunlight gave the surface the appearance of the faceted mirror-rooms seen in old palaces. The faces of the ice-cliffs enclosing the lake were also extensively eroded above the nieve-beds in scollop-forms.

At first I was puzzled to understand how these nieve-beds were formed, but, on camping for ten days on a moraine above the lake, a clue was found in the fact that the water-level of the lake fell about 40 ctm. per day, and had been considerably higher before our arrival. This fact accounted for the existence of the ice-plates and for the deposition of alluvium upon the nieve from the mud-laden water of the lake, and showed that the peculiar form assumed by the névé might have been partly produced by water action in melting, or washing out, or consolidating into hollows the softer portions of the névé, the sun completing the process later. How the much denser apices and ridges of the pyramids became more thickly coated with mud than the lower softer portions I will not venture to say, though perhaps wave-motion may have been responsible for this; but this mud-covering, acting in the same manner as that of the preceding variety, would protect the raised parts from melting in the sun as fast as the hollows between them, where the coating was thinner.

A few days later an event occurred which threw further light upon the formation of this variety. The barriers of a glacial lake in the mountains above gave way, and a large, mud-laden torrent was discharged over a bed of consolidated névé below our camp. The discharge continued for twenty hours till the lake was emptied. After the flow subsided, the part of the névé covered by it was found to be excavated into ridges, apices, and hollows, which were coated with mud, similar to those above described but not quite so regularly arranged. The apices and ridges, which proved to be of ice and therefore much denser than the névé of the depressions, were, as in the former case, coated more heavily with mud than the latter. They oriented with the slopes of the névé and not with the course of the torrent, except where this coincided with the former, thus showing that they had existed as denser strata and foci in the névé previous to the flood, and had resisted the erosive action of the water, which had washed out the softer portions between them. A week's action of the sun upon this surface converted many parts of it into well-marked nieve penitente with medium-sized pyramids.

Now there is no doubt that strata and centres of greater density, evidently due to subsidence, existed in this last sloping névé-bed previous to the flood, for they were found and tested in the portions which had not been submerged. There is, as well, every reason to believe that such centres, caused either by subsidence or by wind,



Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 17.—Mud-covered nieve penitente, thick débris, variety VI., on Biafo glacier, filling furrow on glacial surface and running up side and along sky-line of ice-hillock. Pyramids from 50 centimetres to 1 metre in height.

[*To face p.* 22.

existed in the névé-beds first mentioned antecedently to their immersion in the water of the lake.

It is also very likely that a differentiation of the surface into elevations and hollows had taken place before such immersion, which the water, in virtue of its higher temperature or erosive action or weight, might have accentuated. If not, then the water in virtue of these properties must have excavated the softer parts of the névé, as it did in the case of the flood, antecedently to or coincidently with the deposition of the mud; otherwise the mud would probably have settled on the névé-beds in an even layer, as it did on other parts of the bed of the lake. This antecedent differentiation was indicated by the fact that the névé-surfaces when uncovered by the falling of the water of the lake had the nieve formation described, which became more pronounced the longer they were exposed to the sun.

This variety may therefore be regarded as a composite one in which development that ordinarily would occur under the conditions obtaining in varieties II and III is complicated by water-action and the deposition of mud, thus introducing a factor which is essential to the development of variety VI.

This variety differs from the last (VI) in several particulars (*a*) in occurring on névé instead of on ice, (*b*) in an alluvial deposition on a previously differentiated surface, while in VI the process of differentiation evidently begins only after the occurrence of deposition, and (*c*) in the arrangement and nature of the resulting pyramids, which in this form are rather small and arranged in beds with almost geometrical precision, while in form VI they are often discrete and reach sizes larger than those of any other variety except the sérac.

It is evident from the foregoing that débris on a glacial surface may, according to its nature and the conditions of its deposition, induce the development of four distinct varieties of nieve penitente having quite different characteristics, though they may occur in association with one another. In one case the débris being deposited on the ice in very thin layers exerts its effect by absorbing and transmitting the sun's heat so as to cause the ice beneath it to melt, while the intervening ice remains intact. In the other three cases the deposit is of considerable thickness and protects the ice beneath from the action of heat, by which the glacial surface around it is melted away.

(VIII.) Sérac variety. An eighth variety was that developed from séracs. This was well seen among the séracs on the eastern edge of the Jutmaru glacier, among those of a steep ice-fall on the Kanibasar glacier, among those of the lowest ice-fall of the Biafo, and of a precipitous, much shattered one forming the junction of one of its largest western branches with it. Nieve of this form can be divided into two classes: (*a*) where the projections upon séracs are sculptured by heat into nieve-forms of average size, 50 ctm. to 2 m., and (*b*) where entire séracs from 10 to 20 m. high are thus transformed, constituting a giant form of nieve. The former assumed conical and pyramidal shapes as in the case of other varieties. Most of the pinnacles of the latter consisted of huge, slender spires, many having pointed curving apices, and in two instances streamers of ice projected from their points. True pyramids also were not wanting. Although of giant size, the contours of all were evidently shaped by the same laws that govern the development of smaller varieties, and they exhibited the same prominences, curves and other features that characterise nieve penitente in general. They were séracs. They were equally nieve penitentes. Their final form was merely a question of the sculpturing and moulding by sun and heat of the splintered ice-fragments of the glacier (*vide* plate 21).

Many crevasses on these glaciers were fringed with nieve-pyramids on one or both sides. Some of these were formed from the remains of the preceding winter's snow, which had bridged the crevasses, and of such many had hoods. Others owed their origin to glacier-tables, or to the melting caused by shale and alluvial débris between the pyramids, or to hardened ice-foci on the edges of the crevasses. The sides of all these, except of some formed from snow, toward the crevasses fell away into the latter perpendicularly, while the opposite parallel sides slanted down to the ice in the regular manner. In

Dr. W. HUNTER WORKMAN, *Photog.* 1908.

PLATE 18.—Mud-covered penitente-pyramid, thick débris, or variety VI., with fluted sides, on Skoro glacier. Height, three metres. Apex and ridges thickly coated with mud. Smaller pyramids entirely coated with black mud at left.

[To face p. 24.

Dr. W. Hunter Workman *Photog.*, 1908.

Plate 19.—Sand-covered penitente-pyramid, variety VI., of dense green ice with fluted sides, bearing smaller pyramids, met with in centre of Hispar glacier. Height nearly or quite 10 metres. Similar small pyramid beyond left angle of base.

[*To face p.* 24.

several instances twin pyramids stood, one on either side of a crevasse, which was spanned by a boulder resting on their apices.

It by no means follows that nieve penitente-pinnacles must be of large size, or that the foci from which they are developed must be represented by séracs, avalanche-blocks, or large waves in névé several metres distant from one another. The foci may be mere ripples on the surface only 5 to 10 ctm. high, in rows separated from similar ones by only a few centimetres, and yet the resulting nieve-forms may be as perfect as any of larger dimensions. A miniature bed of such nieve was seen on a névé-shelf at an altitude of 5500 m. Its length was 7 m., its width 4 m. This space was completely covered with diminutive pyramids, beautifully shaped, in longitudinal rows orienting from south to north. Those at the upper end were about 10 ctm. high, but they diminished in height with the slant of the bed, until at the lower (north) end they were only 2 ctm. high.

The German adjective 'zierlich' most appropriately expresses, perhaps, the beauty of this little nieve-bed. It was 'zierlich,' and appeared as if made for a model. One could not help feeling that it ought to be taken up entire, like a valuable ancient fresco, handsomely framed, and preserved in one of the great museums, as an example of what a typical bed of nieve penitente should be.

The foregoing observations, while sustaining the conclusions as to the development of nieve penitente stated at the beginning of this paper, also enable me to extend them somewhat and to define them with greater exactness. In the light of these observations I feel justified in considering nieve penitente to be developed by the action of heat, from whatever source derived, upon névé in which ridges containing centres or foci of hardened snow, and sometimes such centres independent of ridges, have been formed by avalanches, subsidence, or wind, the size and shape of the centres determining the size and shape of the resulting pinnacles ; and also upon névé but more notably upon ice, on which detritus has been deposited under circumstances described, or which has been disrupted into comparatively slender fragments or séracs.

In all cases heat melts away the softer and less protected portions more rapidly than the harder and better protected ones, leaving the latter standing as nieve penitente. The sculpturing process may be assisted in rare cases by the action of water, as in variety VII, which melts, erodes, or compresses the softer parts so as to accentuate the difference in height between them and the harder, and also to a limited extent by evaporation from exposed surfaces ; but I have seen no evidence of erosion by wind, ice-crystals, or sand. During the period when the pinnacles were in process of development the wind was light or wanting, no loose snow was flying, all snow being fixed by thawing and freezing, and I nowhere observed any general deposition of sand on surrounding surfaces to indicate that sand was moving in the air.

This paper, as its title implies, is a study based wholly on my own observations. After it was written, and after my return to India from the Hispar and Baltistan, I received the April 1908 'Zeitschrift für Gletscherkunde' containing the interesting communications of Herr Hans Spethmann and Professor Ed. Brückner relative to Schmelzkegel. Although neither author calls the Schmelzkegel in question nieve penitente, it may be asked why they should not be considered as such.

They have the shape and arrangement characteristic of nieve pinnacles. Their size presents no obstacle to this view, for many perfectly formed wind-conditioned penitentes are smaller ; neither does the fact that they were covered with earthy material, as this only represents a factor in their development, which as described corresponds closely to that of the penitente variety I have classified under variety VI, which includes both névé, or firn, and ice-formations of this character, though in my experience the pinnacles formed from névé have been few and have been seen only one or two in a place. Conversely it may be asked whether all nieve pinnacles are not Schmelzkegel developed by heat from firn and ice under different predisposing conditions ; and what nieve penitente is, if not a greater or less collection of such Schmelzkegel. An apple does not cease to

Dr. W. Hunter Workman, *Photog.*, 1908.

Plate 20.—Nieve penitente due partly to action of water and mud found in clefts on Hispar glacier near glacier-lake. Lacustrine or Composite variety VII. Pyramids appear flattened, as photograph was taken from a higher level on opposite side of cleft. Height 30 to 40 centimetres. Face of ice-cliff above eroded in scollop-forms.

[*To face p. 26.*

be an apple because it may happen to be the only one found on an apple tree, neither is the nature of a Schmelzkegel or a nieve pinnacle altered by the circumstance that it stands alone, provided it be developed under the same or similar conditions as when associated with others.

The varieties of nieve penitente observed in the Nun Kun, Hispar, Biafo, and Skoro, regions may therefore be classified according to their antecedent causes as follows :

Variety.
I. Avalanche. Sub-varieties, *a*, *b*, *c*.
II. Subsidence.
III. Wind-conditioned.
IV. Thin débris.
V. Glacier-table.
VI. Thick débris, or mud, sand, or gravel covered.
VII. Lacustrine, or composite.
VIII. Sérac.

As this classification is based only on what was actually observed, I do not claim that it is exhaustive. Further observation may add other varieties to those here given.

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Plate 21.—Sérac penitente, variety VIII., both large and small, on Jutmaru glacier. Smaller scattered about on surface of larger. Two glacier-tables near apex of large pinnacle in centre of upper line indicate bevelling of surface by heat, which has occurred at that spot.

[*To face p. 28.*