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NIEVES PENITENTES ON SHAFAT GLACIER. AT ALTITUDE OF ABOUT 18,000 FEET.

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Nieves Penitentes in Himalaya.

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

THE curious and interesting formations known as 'nieves penitentes' have been mostly described by Andean explorers. For a long time they were regarded as peculiar to that chain, where they have been met with from the equator to 35° 40′ lat. S. Later Hans Meyer and C. Uhlig report having found them on Kilimandjaro, in Africa. They have been seen chiefly on glaciers, though sometimes on an earth or rock-basis, at elevations above where freezing occurs at night.

While Mrs. Bullock Workman and myself were exploring the Nun Kun mountain group in Suru, Kashmir, during the summer of 1906, we found large portions of the névé-covered surface of the Shafat glacier, from 33° 57′ to 33° 59′ lat. N., at altitudes of from 16,000 to 18,500 ft., here also above the line of freezing at night, thickly covered with these formations. This was the first time in five seasons of Himalayan exploration that we had met with them or anything resembling them, and I am not aware that their existence in Himalaya has been mentioned by any other observer.

They varied in height from 8 in. to 3 ft., and had the shape of wedges or pyramids flattened at the sides, with curling, fluted crests, all turned in the same direction. They were arranged in parallel lines running diagonally to the axis of the glacier, the long diameter of each nieve being parallel to the long diameters of others in the system, and coincident with the direction of the lines. They were composed of granular snow, hard frozen in the morning, but softening more or less under the heat of the sun. No ice was found in them. The central portion of each, even when softened by the sun, was much denser than the outer surface or the surrounding névé, offering, even in the case of the smallest, decided resistance to the thrust of an ice axe, while the two latter could often be scraped away with the fingers. The névé on which they stood sloped at angles of 30° to 40°. Between them it was undulating, but without deep depressions around their bases.

As this was the only one of many Himalayan glaciers we have explored presenting this phenomenon, attention was directed to the conditions obtaining on it as furnishing a clue to the mode of formation of the nieves. This glacier differs

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from most glaciers in that it is acephalous, having no proper head or basin of origin backed by mountains. It is fed by masses of snow and ice poured down from the Nun Kun peaks on the N. and from the slopes of Z1 on the S. side, which meet near the central line, forming a great longitudinal depression, on the slants of which the nieves were met with. The upper or W. end of the glacier is entirely open and exposed to the prevailing winds, which sweep down its course with considerable force even in fine weather, and during storms must attain a high velocity.

Another important condition not seen by us on other glaciers was the long-continued fine weather. During our Baltistan expeditions fine weather was the exception, almost daily snow-storms being the rule; but here from early in June till our departure on August 9 the weather was continuously pleasant, only one slight squall being noted. In ascending the glacier, and on the mountains above, even to over 21,000 ft., no new snow was met with, and the névé was well consolidated by the continued action of sun and frost. To these two conditions the formation of the nieves penitentes here seen may be referred.

It is a matter of common observation that, when any object lies upon a glacier which protects the snow and ice beneath it from the sun's heat, or a condition exists that offers resistance to the same, the surrounding surface melts away, leaving an elevation of snow or ice in such place. When a rock rests on a glacier a glacial table supported on an ice-pedestal may result. Ice-pyramids are sometimes seen capped with mud, or stone, or fine detritus. When a portion of a glacial surface becomes more dense than that around it, the softer portions melt away, leaving the denser one standing as an upward projection.

This premised, the development of these nieves may be read as follows: During and after the winter and spring storms the wind, sweeping down the glacier, drifted the loose snow into waves and ridges. These, particularly the latter, were formed parallel to one another with a direction more or less transverse to the axis of the glacier. The force of the wind packed the snow composing the ridges, so that it became much denser than that in the hollows between them. Wind is the only natural force conceivable that could have caused ridges and wavy condensations of snow in the positions occupied by the nieves upon fairly smooth slopes not exposed to avalanches and above the line of rain. This action of the wind being granted, it follows that the formation of waves

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NIEVES PENITENTES ON SHAFAT GLACIER. PARALLELISM SOMEWHAT DISTURBED BY MOVEMENT OF GLACIER.

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and ridges of condensed snow was the first step in the process of development.

Then came the prolonged period of fine weather, when no new snow fell to cover the roughened glacial surface, when the latter was exposed during the long days of June and July to the full action of the sun, burning with a heat of 170° to 206° Fahr., and, as I once observed, even of 219° Fahr. As melting proceeded the softer snow of the hollows yielded to a greater degree than the harder snow of the ridges, thus accentuating the difference of level between the two; and the ridges themselves were sculptured out, the densest and most resistant parts remaining as apices till finally the pyramids, known as *nieves penitentes*, were fully formed.

The fact that the discrete pyramids, many of them with the ends of their elongated bases touching the similar ends of the bases of adjacent ones, stood in lines parallel to other lines indicates (1) that they were formed out of pre-existing ridges or linear wavelets, and (2) that the condensation of the snow of the ridges was not equally great at all points, but occurred *in foci*, the crests of which were a little distant apart, each crest, as melting proceeded, forming the apex of a nieve.

The glacier falls from W. to E., almost due E. (E. 10° N.), and the line of union of its N. and S. lateral slopes corresponds with its axis. The direction of the longer diameters of the nieves and of the lines of which they formed a part was, on the N. slopes, E. 20° S., whilst that of those on the S. slopes was N. 45° E. The former cut the glacial axis and line of union at an angle of 30°, and the latter at one of 35°. The linear rows of nieves on the two slopes were therefore inclined to one another at an angle of 65°. From this arrangement it would appear that the directions of the primary ridges were determined not only by the wind, common to both, but also by the slant of the slopes on which they were developed, practically corresponding with the direction of the latter. Hence with a constant wind the direction of the primary ridges varied with the slope. The same was found to be the case with the nieves high above the central line of the glacier. The accompanying diagram shows the relation of the lines of nieves on the two slopes to the glacial axis and to each other. This arrangement does not conform to the statement of Professor R. Hauthal in his article on nieves penitentes in the 'Zeitschrift des Deutschen und Österreichischen Alpenvereins' for 1903, that the rows of nieves all run in the same direction independently of the slope.

The apices of the nieves on both slopes curved over more

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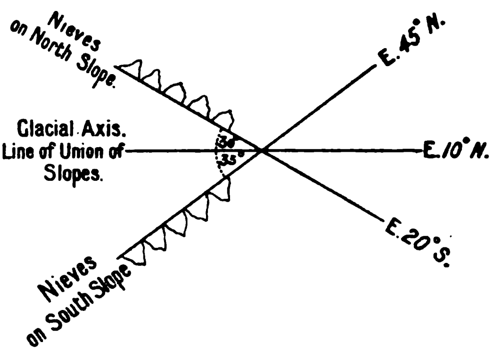
or less, giving the pyramids a convex contour on one face and a concave one on the opposite. These as well as the overhanging hoods, with which many of them were crowned, all pointed in the same direction, *i.e.* toward the E. down the glacier, away from the prevailing wind. This would indicate the constancy of the west wind that produced the primary elevations. During the three weeks we passed on this glacier the wind never varied from its westerly course. Both the curving apices and the hoods were probably due to the cornices formed by the wind along the crests of the primary ridges, which, being denser, offered greater resistance to the sun's heat than the snow immediately beneath them and persisted as overhanging parts of the nieve. It is not unlikely that the freezing at night plays a *rôle* in the development or modelling of nieves. It certainly would solidify not only the crests but



every part of the nieves by congealing the water they might contain resulting from the melting caused by the sun's heat.

Not the least noticeable features of the nieves were the parallelism of the flattened opposite sides to each other and to the similar sides of all the rest in a system, and the coincidence of the long diameters of them all with the parallel lines of which they formed a part. In trying to account for this arrangement I was naturally led to consider the effect which the sun's position in its passage across the sky might have on the development of the nieves. I began my observations with the nieves on the south slope of the glacier, the lines of which oriented from S.W. to N.E., over which the sun passed from end to end, *i.e.* in a direction essentially parallel to the flattened sides, as during the time of their development it rose a number of degrees N. of E.

Here was a constant relation of the sun to the flattened sides, and to the direction of the rows in which the nieves

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stood, from which I tried to evolve a hypothesis of cause and effect, which was assuming considerable shape, coinciding very nearly with a similar one advocated by Meyer in his book 'In den Hoch-Anden von Ecuador, 1907,' to be referred to later, when it was overthrown by the discovery of the nieves on the north slopes of the glacier, which pointed in a direction E. 20° S., over which the sun passed transversely to the flattened sides.

Further speculation in this direction was evidently useless, and I was thrown back on the only other apparent explanation, viz. on the original forms of the foci of condensed snow, which would naturally correspond to those of the wavelets, being broad below and narrow at the top, with their long diameters coinciding with the direction of the lines and their short diameters or thickness approximately with the direction of the wind, more or less at right angles with the former. In the process of melting these shapes would be preserved irrespective of the position of the sun and determine those of the nieves. Therefore not only the existence of the nieves themselves, but their shape and relation to their neighbours may be referred to the existence of foci of condensed snow caused by an antecedent action of wind or other agent.

From the foregoing the conclusion may be drawn that the formation of nieves penitentes, such as were here seen, depends on two conditions—(1) the existence of a strong wind blowing constantly from the same direction, driving the snow into wavelets and ridges usually parallel to one another, and condensing it into compact masses at foci a little removed from one another; and (2) a prolonged period of fine weather following, during which the softer portions are melted away by the sun's heat, both direct and reflected, leaving the denser parts standing in the well-known shapes. In stormy seasons the ridges after being formed would be protected from the sun's action by new snow, under which they would be buried, and no nieves would be developed.

In the three weeks which elapsed between the time when we first saw the nieves and our departure, the great heat of the sun caused the disappearance of large areas of névé covering the ice, and of the nieves which stood upon them. It also caused nieves to disappear where névé still remained, this residual névé being probably more dense than the nieves which covered it. The life, therefore, of nieves of the variety here seen may be short, they being formed, reaching their greatest development, and disappearing within a few weeks.

I have stated the argument thus far as it developed itself

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in my mind from the observation of the material which presented itself. This was an entirely original study, inasmuch as it was wholly unbiassed by any suggestions from the literature of the subject, with which at that time I was not familiar, and to which I had no access, until months after a preliminary study, written in India in 1906, had been accepted for publication by the editor of the 'Zeitschrift für Gletscherkunde.' *

Six miles further W., beyond the Nun Kun massif, rise two snow-peaks two miles apart, D41 of the Indian Survey, 20,571 feet, and an unnamed peak, 19,080 feet, christened by us Mount Nieves Penitentes. From their flanks and a high arête connecting them another glacier springs, which stretches away westward between precipitous mountain walls. On this glacier, thus protected, although its reservoir was abundantly covered with névé, no nieves were seen, neither did any exist in the Nun Kun basin, three miles to the E., lying at an altitude of 20,300 to 21,600 feet, and protected by seven enclosing peaks, though it was deeply covered with névé.

We made first ascents of the two peaks above mentioned. The summit of Mount Nieves Penitentes breaks abruptly into precipices on the E. and S., but on the W. falls gently away for about 300 feet of altitude in a symmetrical curve, open to the west wind. The whole surface of this was covered with nieves, consisting, like those already described, of granular snow. They were largest at the extreme summit, differing from those lower down and those on the Shafat glacier in being separated from one another by deep depressions enclosed by snow buttresses running between the bases of the pyramids, giving the surface a honeycombed appearance.

At 10 o'clock A.M., after the sun had been shining upon the summit for 4 hrs., on stepping into the depressions one sank in soft snow nearly to the knees, while the buttresses, which had been exposed to the sun to a much greater degree than the depressions, remained hard enough to sustain the weight of a man without yielding, and the nieves rising above them were still harder.

The upper part of D41, above 19,000 ft., rises very abruptly at angles of 60° to 70°, terminating in a nearly perpendicular rock-apex. The slants here, facing S. but fully exposed to the W. wind, bristled in every part, quite to the summit, with nieves rising above one another in unbroken succession like a vast series of steps with deep pockets between them. The pockets and the interior of the nieves were composed

* See Band ii. Heft i. July 1907.

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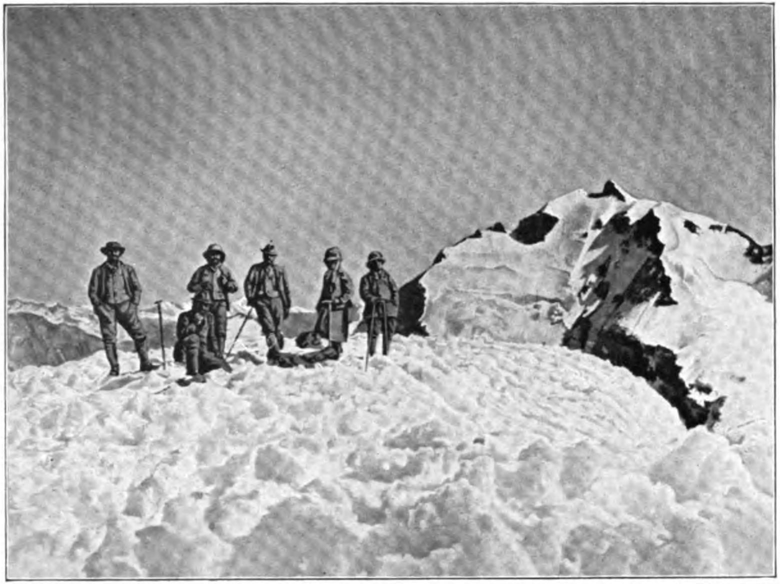

From photograph by Dr. and Mrs. Bullock Workman *Swan Electric Engraving Co, Ltd.*

NIEVES ON SUMMIT OF Mt. NIEVES PENITENTES. PEAK IN BACKGROUND IS D41. TWO MILES DISTANT.

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of ice, thus supplying a firm foothold, which enabled us to climb the exceedingly steep ice-slope in safety, though in the absence of nieves it could only have been ascended with great difficulty and danger.

The pyramids averaged considerably higher and larger than those on the Shafat glacier, and might be regarded as more perfectly developed in that their internal structure consisted of ice. The ice was undoubtedly formed by the water, which resulted from the sun's heat, settling into the pockets and pyramids and being congealed by the freezing temperature which at that altitude supervenes as soon as the sun leaves a slope.

A conversion of their snow into ice would make the nieves more resistant to the action of the sun and give them a longer life; and, as it was the middle of August when these were discovered, it seems probable that they might in considerable part survive the summer, and again serve as bases upon which the wind might raise new waves and ridges and new foci of condensation during the succeeding winter.

Here again the conditions do not support the assertion of Professor Hauthal that nieves penitentes occur exclusively in sheltered places, in connection with which it is interesting to note that those observed by us at three different points occurred on surfaces fully exposed to wind, that the higher and more exposed the surface the larger were the nieves; and that the largest, most perfectly developed, and apparently the most durable of all were found at the highest altitude, where the wind would naturally be strongest.

Sir Martin Conway, who met with nieves on Aconcagua, concludes they are carved by solar radiation out of old avalanche beds and nothing else, wind having nothing to do with their origin. Nieves formed in this manner would be found only on circumscribed areas, in positions which avalanche beds might occupy, and not widely distributed over glacial surfaces and mountain sides and tops, as in the case of those seen by us, where there could be no question of avalanche beds. The conditions under which nieves have been observed have evidently differed somewhat in different places.

Professor Hauthal also regards the sun as the sole agent in the formation of nieves. This hypothesis fails to explain satisfactorily the parallelism of the lines in which the nieves stand; and to account for the modelling action of the sun he assumes that its rays exercise a selective power in melting away some portions of a glacial surface and leaving others

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intact, a supposition difficult to prove. Both the parallelism of the rows and the modelling are, on the contrary, readily accounted for, as has been stated, by the known action of wind in causing parallel wavelets and ridges and condensing the snow in them.

While most observers are agreed that the sun is the chief and, in most cases, the only agent concerned in modelling the névé covering a glacial or other surface into nieves, many fail to recognise or do not sufficiently insist on the fact, which should be apparent to those having an opportunity of studying these formations, that antecedent differences in density or physical condition of different portions of the névé must exist, which determine whether the sun's action shall result in the development of nieves. The névé must be transformed into alternate hard and soft layers, the softer of which melt more rapidly under the sun's heat than the harder. This process probably occurs in more than one way, which accounts for the diverse opinions expressed by observers who have seen them under different conditions.

Conway considers that layers of varying density more or less perpendicular to the direction of fall of an avalanche are formed by pressure when it comes to rest, but mentions no other causes.

Güssfeldt, one of the early observers, speaks of the agency of wind in the first stage of development of nieves, but does not state that it forms strata or foci of condensation.

Uhlig thinks that waves or furrows caused by wind in loose snow may form a basis for the development of nieves and determine their direction when the former have been fixed by freezing and thawing.

W. Deecke suggests that the wind causes a difference in the inner structure of snow, that conditions the direction of the parallel ridges, the tops being hardened and thickened by frost and melting.*

Meyer in 'In den Hoch-Anden von Ecuador, 1907,' pp. 436–7, endorses the two last views, but he also considers 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 the pressure, which the heat of the sun differentiates into ridges and hollows.

In this I agree with him, but the arrangement of nieves,

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* *Globus*, 1905, Bd. lxxxvii. pp. 261–2.

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I have described above, on contiguous slopes standing at angles of 65° to one another controverts the further opinion expressed by him that the sun's course must correspond to the direction of the strata of hardened névé in order to produce large nieves in rows, and that when the sun's course is transverse to the strata it will melt the surface fairly evenly. The nieves seen by me, over which the sun passed transversely, were just as large and of the same shape as those with whose long axis the sun's course coincided, which fact caused me to discard a hypothesis I had formed essentially similar to this of Meyer.

None of these observers nor any other whose writings I have seen expresses the view I have stated above, that the wind packs the snow in the wavelets and ridges into hardened foci, which, though undoubtedly made still denser by thawing and freezing, are fundamentally hard enough to determine the formation of nieves under the action of the sun. I have often in Himalaya walked over névé surfaces, where the meteorological conditions were not favourable to the formation of nieves, where this hardening in foci was very apparent, though the surface was not frozen.

Finally I would suggest one more possible cause of this stratification of névé, viz. rhythmic seismic vibration, which occurs in Himalaya and probably in other high mountain regions, which in certain cases may exercise an influence in converting névé into strata of unequal density. This and the cause mentioned by Meyer, as well as that assigned by Conway, may account for the formation of nieves in places sheltered from wind.

Meyer mentions a variety of nieves seen by him on high, exposed tropical summits protected from the direct heat of the sun by the constant presence of clouds, the formation of which he attributes to the melting power of strong, moist, warm winds. Under these circumstances it would appear that the heat contained in the air currents acts upon the glacial surface in the same manner and with the same effect as that carried by the sun's rays, *i.e.* melts away the softer portions more rapidly than the denser ones. The strength of the warm winds concerned in the process does not necessarily imply any direct erosion of the névé, but it may well serve to apply more effectually the heat borne by them.

The fact that nieves may be sculptured out by warm winds in the absence of direct action of the sun affords another argument against the supposition that the sun's rays exercise any special action, other than as conveyers of heat, in virtue

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of their character or course. Hence the inference may fairly be drawn that the development of nieves of every kind yet observed occurs under the same ultimate conditions which, expressed in their simplest form, are (1) an antecedent differentiation of névé into areas or layers of unequal density, and (2) a consequent unequal melting under applied heat.

'Another Way of (Mountain) Love.' *

By F. W. BOURDILLON.

THE love of mountains is, no doubt, in many persons an acquired habit—like smoking, or eating olives; in some it is even a simulated pleasure—again like smoking, or eating olives. But in the latter case it is liable to break down under strain; as in the well-known story of the Frenchman in *glacé* boots and best kid gloves, toiling up the steep side of Ben Lomond, and at last exclaiming to his companion, 'Aimez-vous les beautés de la Nature? Moi je les déteste!' But besides these persons we may distinguish at least four classes of mountain-lovers. First, there are those who like to gaze upon mountains at a safe distance, as from a comfortable hotel at Berne or Lucerne; or to play lawn tennis somewhere within forty miles of them, as at Villars or other places of that kind. Secondly, there is the numerous class of persons who have courage enough to go right up to them, and so to speak stroke and make friends with them, without ever trusting themselves on their backs. This class composes the bulk of the holiday-makers who crowd the hotels of Grindelwald or Pontresina in the month of August; for them is the 20-centime-in-the-slot telescope focused on the peak of the Wetterhorn or the Cervin; for them is provided the cinematograph in the evening. The third class is of those who go in lifts and funiculars and rack-and-pinion railways to the top of anything which can be ascended in this way. They enjoy the excellent *table-d'hôte* at the top of Pilatus—and indeed it is, or was, worth going for—and stand muffled round with cloaks at the Eismeer station of the Jungfrau Bahn. The members of this class

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* A paper read before the Alpine Club, May 1, 1906. Owing to a misapprehension, this paper was not printed in the the *Alpine Journal*, but appeared in the *Monthly Review* for June 1906, from which it is now reprinted by the kind permission of the publisher, Mr. John Murray.