APPENDIX I

GLACIOLOGY: SNOW CONDITIONS AND AVALANCHES

The most striking property possessed by Himalayan glacier ice as found in the Kangchenjunga district is its plasticity. This results in several striking differences in the general characteristics of glaciers as compared to Alpine glaciers, which at first sight strike the Alpine mountaineer as curious.

Why should Himalayan ice be more plastic than Alpine ice? The answer is temperature range. Unfortunately, we did not measure the direct heat of the sun at mid-day on the snow-fields of Kangchenjunga, but it is considerably greater than that of an Alpine sun, for it shines almost directly overhead and to the climbers at least its rays seemed often to beat down with paralysing intensity. The air temperature is, however, at or below freezing-point as a rule even at mid-day. At night the temperature may drop to -30° F. or more below zero. Thus the temperature range between mid-day and midnight is enormous, probably over 200° F. It will be seen from this that *ordinary* climatic conditions in the High Himalayas resemble a combination of winter and summer Alpine conditions, the night temperatures being comparable to Alpine winter night temperatures, and the sun temperatures during the day being far in excess of sun temperatures in the Alps at midsummer.

The exact physical process that occurs in snow and ice as a result of continual temperature fluctuations is a matter for physicists. Of its effects, I can only quote from my own observations. Let us consider exactly what happens to snow that is changed by pressure and temperature range into ice. First of all the snow is compacted and consolidated by the pressure of more snow falling on top of it; it becomes at first brittle flaky ice, and then is changed by increasing pressure into harder and tougher ice. In the Alps pure ice is formed by pressure considerably below the surface of a snow-field. As the temperature of the ice once it has been covered by newly fallen snow, is more or less constant, it is only affected by pressure, and the effect of pressure is not the same as that of temperature range. Alpine ice is formed almost entirely by pressure and temperature range does not enter into its formation to nearly the same extent as it does in the Himalayas.

In the Himalayas, owing to a far greater temperature range, snow is changed into pure ice nearer the surface than it is in the Alps. Pressure, of course, enters into it, but it is not principally pressure that forms Himalayan ice, but pressure assisted considerably by temperature range. Thus, instead of a flaky intermediate stage, snow is converted almost straight away into ice, and ice tougher and more glue-like than that found in most Alpine districts. Mountaineers who have climbed on the Brenva face of Mont Blanc declare the ice there to be exceptionally tough. I can vouch for this, for during the three ascents I have made of that face, I encountered ice so tough that many more strokes than usual were required to cut steps in it. Dr. Claude Wilson described it in the *Alpine Journal* as " Steep slippery ice, of a hardness unknown to us before, and with a curious quality unique in our experience, born probably of great cold and enormous pressure—a quality of viscosity which gave the impression of cutting into something which would not chip, but whose particles clung together like stiff tar . . . almost as hard as marble and tough as rubber."

Now, there is probably no mountain face in the Alps that experiences a fiercer sun, and lower night temperatures, and the temperature range is probably greater than on any other peak in the Alps.

There is one more factor which enters into the question, evaporation. It is difficult to see how this can affect the formation of ice, but it probably results in the disappearance of the brittle surface ice, leaving only the tougher ice.

The toughness of Himalayan ice leads to conditions of interest and vital importance to the mountaineer. The main ice streams of Himalayan glaciers have usually a convenient corridor on either side, between the ice and the mountainside, which offers a convenient line of least resistance. Such corridors are seldom found in the Alps, owing to the fact that the ice being more brittle, breaks away at the side, filling any intermediate space that may be formed between the glacier and the mountainside.

Still more interesting is the scarcity of crevasses. Even in a steep ice-fall where the ice is hummocked and pinnacled, there are few actual crevasses. This again is due to the plasticity and bending capacity of the ice. Like glue, it prefers to bend over an inequality in the ground rather than split into crevasses. Pressure may raise its surface into mounds, knobs and even pinnacles, but it cannot break the ice as it does in the Alps. We frequently observed ice pinnacles bent over like candles in a heat wave, and it is not until the bending becomes so great and an enormous stress is exerted on the base of the pinnacle that the ice is fractured and the pinnacles collapsed.

This quality of bending is no doubt partly responsible for the enormous avalanches that fall from the hanging glaciers of Kangchenjunga. As we learnt to our cost, these hanging glaciers are very much " alive " and the speed of their downward movement is, owing to the huge annual snowfall, considerably greater than that of similar hanging glaciers in the Alps. Also, these hanging glaciers are frequently of enormous thickness, and walls of ice 600 to 1,000 feet high decorate the sides of Kangchenjunga. Were hanging glaciers of this size in the Alps, there would be great avalanches, but they would not be nearly so great as those that occur on Kangchenjunga. The reason is this : were these hanging glaciers in the Alps, the ice, owing to its brittleness, would break away more often, and there would be many avalanches, but none of a magnitude comparable to those that fall from Kangchenjunga. On Kangchenjunga the ice walls bend farther over the edge of precipices before breaking off, and when at last the ice is no longer able to withstand the internal stresses set up by unstable equilibrium, it cracks, and a huge avalanche occurs.

Thus, it is not so much the size of a hanging glacier, but physical reasons that result in avalanches of almost cataclysmic dimensions which sweep far across the level glaciers beneath. Until the Alpine-trained mountaineer learns to appreciate this fact, he will not be safe in the Himalayas.

That the quality of ice is affected by climatic conditions is borne out by the different formations and structures it exhibits. The ice scenery at the head of the Jonsong Glacier and the Lhonak Valley is very different from that of Kangchenjunga. The Lhonak Glacier is in its lower portion broken up into pinnacles, similar to those of the Everest glaciers. It is not so easy to find an explanation for these pinnacles, but in view of the fact that the districts where they occur get a comparatively small precipitation of snow and a drier climate it seems probable that evaporation is the cause and that they are formed in a similar manner to *nieves penitentes.*[1]

As regards movement of the glaciers, it was unfortunate that we took no observations of it. The downward movement of the hanging glaciers is very rapid and that of the main ice streams must be rapid too. I am, however, no glaciologist, and have only touched on one subject which interested me especially. There are many other equally interesting points to be investigated in connection with the glaciers of the Kangchenjunga district, and of these the most interesting is the determination of their present rate of movement, and what relation this bears to the precipitation of snow.

Evaporation plays a very important part in determining the size of Himalayan glaciers. I have already had occasion to mention the surprising smallness of the glacier streams ; apart from the rainy seasons, or periods of rapid melting they are usually little larger than Alpine streams. This is due to the fact that the rate of evaporation is far greater in the Himalayas than in the Alps. As we frequently observed,

[1] See page 318.

the surface drainage of a glacier is negligible, and the familiar streams and *moulins* such as are common on Alpine glaciers are almost entirely absent. Evaporation is the only reasonable explanation, and if the rate of evaporation in the Himalayas was the same as that in the Alps, it is certain that their glaciers would be very much larger than they are.

Perhaps I should make it clear that when I speak of evaporation, I do not necessarily mean that the snow or ice is melted first, and then evaporated, but that evaporation also takes place at temperatures below freezing-point. Such evaporation is probably due to the direct rays of the sun, and not to air temperature, which at high altitudes is usually below freezing.

Evaporation also plays an important part in determining snow conditions. It clears off new snow from rocks with extraordinary rapidity, so much so that even after a heavy snowfall, a rock mountain may be in climbing condition within twenty-four hours. Snow slopes sheltered from the sun should, however, be suspected of avalanches for a day or two. Owing to this partial clearance of snow by evaporation, the mountaineer may be led into thinking that because one portion of a mountain is safe, the mountain is safe everywhere else. But this by no means follows, and each slope and couloir must be studied on its merits. In this respect Himalayan mountaineering involves a closer study of snowcraft than Alpine mountaineering.

On account of the great temperature range, Himalayan snow varies between powdery snow such as may be found in the Alps in mid-winter, and the slushy, or wet crystalline snow found on an Alpine snow-field on a hot summer's afternoon. In fact, it is safe to say that almost every variety of snow may be experienced in the space of twelve hours. On this account a man cannot climb safely in the Himalayas until he has learnt to appreciate the rapidly changing conditions, and in snowcraft at least experience of winter mountaineering in the Alps is invaluable. A party of purely summer trained Alpine mountaineers, however skilled they might be in mountain craft and summer snow conditions, would be by no means safe in the Himalayas, where conditions more closely approximate to Alpine winter snow conditions. At least one avalanche disaster in the past could have been avoided if the party had been experienced winter mountaineers.

Heavy snowfalls on Kangchenjunga are usually accompanied by wind, and it is tolerably certain that wind slabs are formed on the leeward sides of ridges. The gravest objection to the proposed alternative route to avoid the steep portion of the North Ridge would have been danger from this particular form of avalanche, for so much snow is always blowing from the North Ridge that it probably compacts into wind slabs on the east or leeward side of the ridge. The same danger applies to Everest, and after a heavy snowfall from the west, the danger of wind slab avalanches will exist on the slopes leading to the North Col. After a heavy night's snowfall the mountaineer must expect to find wind slab, or powdery snow avalanche conditions in the early morning, but after the sun has been at work for an hour or two wet snow avalanches must be expected.