

Note.—There can be little doubt that another eruption is imminent in the Kivu volcanic region, for both the great volcanoes of Namdagira and Ninagongo are showing unwonted activity. During my stay at Kissenyies the other white inhabitants as well as myself suffered inconvenience from headaches several days when the fumes drifted in our direction.

THE GLACIATION OF CHINESE TIBET

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IN a paper read before this Society I pointed out that there are records of extensive glaciation on the high ranges which enclose the Yangtze, Mekong, and Salween rivers, in the neighbourhood of lat. 28° N. (*Geog. Journ.*, September 1920, 63, 186). Further, that the retreat of these glaciers is more pronounced on the eastern than on the western ranges, close as these are to one another; on the former indeed they are generally extinct. There was thus reason to believe that deglaciation had proceeded gradually, and might still be proceeding, from east to west. Partly in the hope of throwing more light on this interesting question, I selected Muli, on the Litang river, and well to the east of the Yangtze, as a base for plant collecting in the summer and autumn of 1921.

The ranges in that neighbourhood are composed almost entirely of limestone, but occasionally of slate and other metamorphic rocks, which latter reappear in the river-bed. The strata dip east or west at high angles, the strike being nearly always due north and south, except in the gorges, where the rocks are crumpled; overthrusts also occur.

The main ranges, which clearly are folded, trend north and south, exactly as they do west of the Yangtze, and this apparently determines the course of the rivers, which flow from north to south. The tributary streams also tend to flow along the strike of the rocks, so that the rivers may be younger than the synclines along which they flow.

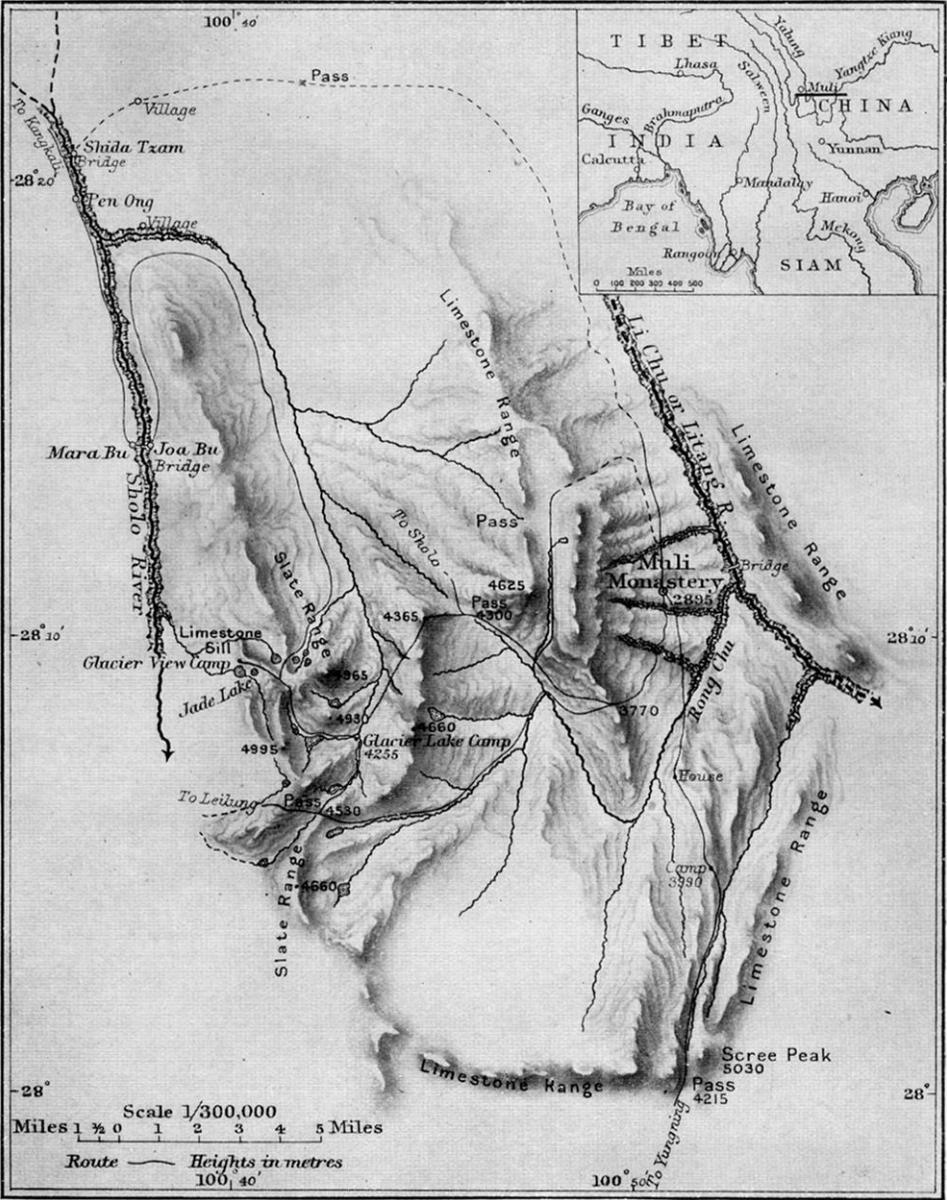
Approaching Muli from the south one crosses a high limestone range, an offshoot of the Litang river divide to the west. Though even here there is unmistakable evidence of former glaciation, so feebly does limestone retain the impression of ice that it becomes a difficult matter to trace its effects. In the first place, owing to the violent weathering this rock undergoes, no moraines are to be seen. Instead, at the foot of each tower are piled up huge screes, which must long ago have buried any moraines. In the second place, owing to the porous nature of limestone, the glacier lakes have long since been drained, though I came across silted-up basins exactly resembling the lakelets to be described presently. The valleys, however, are of typical ice-worn form, being U-shaped in section, with the spurs smoothed off and many of the rock surfaces rounded.

From the summit of this range, which rises to peaks of about 15,000 feet, I ascertained the direction of the nearest permanent snow. There were isolated snow peaks far to the north, and also in the south, where the vast bulk of a great snowy range was visible. This is not the Likiang snow peak, but a massif west of Yungning. Westwards at no great distance towered three snow pyramids, close together. Arrived at Muli, therefore, it was in this direction I now proceeded.

Muli itself lies far down in the valley between two mountain ranges, that to the west forming the watershed between the Litang and Sholo rivers; the latter flows direct to the Yangtze. To the east is the Yalung divide. Although I crossed the Litang river, and proceeded several days' journey over the mountains in the direction of the Yalung, finding always the same evidence of previous glaciation, in what follows I shall confine my remarks to the mountain range lying due west of Muli, for it was there that my chief observations were made.

Immediately west of the Sholo gorge, in about lat. 28° , rises the group of snowy peaks already referred to. The Sholo river itself divides into two streams a little to the north of Muli, one branch flowing from Kangkali, behind the snow peaks, the other from a plateau called Döpa, further north. The divide between the Sholo and the Litang river nowhere reaches the snow line, though one limestone peak near Muli attains over 16,000 feet; it is necessary to cross the profound gorge of the Sholo before permanent snow is found, on the divide between that river and some unknown stream to the west.

The first day's ascent of the range took us round the huge limestone cliff overlooking the monastery of Muli; and on the second day we crossed the divide by a pass 14,110 feet above the sea, and descended into a broad alpine valley. This valley trended from north to south before the stream turned west to join the Sholo river, a range of lofty crags, separated by deep ravines, forming the western boundary. The basin form of this valley, its level boggy floor, the absence of lateral spurs, and a number of smoothed rock hummocks which ended abruptly in scarps facing down valley, at once suggested the work of ice; a suspicion abundantly confirmed when, ascending the valley, we presently crossed a well-preserved medial moraine. This moraine, beginning at the foot of a high cliff where the valley forked, had been cut through by the stream below, but could be traced for a distance of about 2 miles; and on its flank I picked up ice-scratched stones. Caught up amongst the fragments of this moraine were several marshes occupying depressions now silted up. I next turned my attention to the western boundary range, three peaks of which rose about 16,000 feet above the sea. Behind this range—which it may be noted was not the main divide—lay the gorge of the Sholo river itself. Here the rock was slate and schist dipping west at angles which approached the vertical; but a belt of limestone carrying the highest peak of all cropped out west of the two



SKETCH-MAP OF THE MOUNTAINS WEST OF MULI, FROM SURVEYS BY MR. F. KINGDON WARD

nearer peaks. These metâomorphic sedimentaries were of the utmost value, because they retained the records engraved on them by ice as though they were scored but yesterday. Here were all the familiar signs. The whole region was pitted with deep lakelets, the water from which cascaded over cliffs. One valley contained five such basins one above the other.

The cliffs separating basin from basin might represent successive stages in the retreat of the ice. If the glacier foot were to remain stationary for a time, the issuing stream, charged with rock splinters, would soon grind down the valley level below, leaving a cliff protected by ice above. As the cliff grew, a basin would be dug out at its foot. Thus lakelet and cliff are formed together and are always associated. Such cliffs once formed tend to persist, the glacier stream merely cutting a groove for itself.

I may here digress for a moment to point out the significant part played by these lakelets; for apart from their direct effect on the scenery, they play an important rôle indirectly. In the first place they act as reservoirs, so controlling the water supply to the lower valleys that even during the heaviest rains, or the most rapid melting of the snow in spring, floods are unknown. In short, they help to promote a constant and steady flow of water.

In the second place they are filters which so effectually draw the sting from the water during the most active stage of its descent, that for a long time after issuing from the last lake its corrosive power is almost *nil*. The deep gorges which the tributary streams, after turning east or west, have cut through the divide, doubtless date from the time when, laden with sharp glacier grit, the water was able to saw straight down through the rock with rapidity and ease. They must have been formed before the lakes. All the tributary valleys, terraced as described, and thus generally "hanging" valleys, open into the main valley by bottle-necked mouths, forming with it an acute angle; but this is due rather to the tendency of the streams to follow the strike of the rocks than to ice action.

Under the watershed, however, these valleys widen out into circular basins, sometimes containing several lakelets. Such a "circus" at the valley head, surrounded by a sierra-like wall, is typical of ice action. It appears to be caused by equal erosion on all sides while the head of the valley is filled with snow and ice. Water-eroded valley heads are always V-shaped in section, due to greater erosion in the centre than on the flanks. Along the shores of the lakelets, and on the slopes separating one lake terrace from another, the rocks are planed and carefully rounded off at the summit though their down-valley faces may be scarped. Occasionally a perched boulder is seen, balanced on one of these smoothed inclines.

I have said that the record left by the ice on a limestone foundation is almost entirely effaced. A good example of this occurs on the west flank

of the slate range, where a big limestone sill crops out. In the schists above is a jade-green lake. Formerly the ice must have flowed over the limestone cliff, in which it has cut a deep notch; for the schists which appear again immediately below the cliff are ice-worn. But the stream from the lake above, instead of flowing down the groove already prepared for it, prefers to burrow beneath the sill, gushing from its foot. Had the jade lake itself been scooped out in the limestone probably no vestige of it would now remain. This limestone band, its strata standing on edge, runs for several miles in a north-and-south direction, occupying a syncline in the metamorphic rocks, and is one of the most remarkable features in the country. The slate range in fact is flanked by parallel limestone ranges.

How far the ice has retreated on this range cannot be determined off-hand; possibly in the lower reaches its record has been obliterated. But in the main valley described, the last fragment of moraine is about 4 miles from the valley head, measured in a straight line.

So much for the facts, interesting enough in themselves, of deglaciation in this locality. It is, however, when we came to inquire into the reasons of such retreat, and its possible bearing on recent changes in the topography of the country, that the main interest lies. Bound up with this again are many puzzling features in the distribution of the flora on which it may be possible to shed some light.

Scattered over the whole of Chinese Tibet, a region comprising the entire south-west corner of Szechwan between 27° and 30° north latitude and 99° and 102° east longitude, are a number of snow peaks more or less isolated from one another; and it would appear certain that at one period, not very remote, the whole of this region was glaciated. Baber, Johnston, and other travellers have remarked ancient moraines in various parts of western Szechwan.

As we travel westwards we find these isolated peaks gathered into definite ranges of snow-clad mountains, where deglaciation, though evident, is less pronounced; until after crossing the Mekong river, the glaciers show little more symptoms of retreat than could be accounted for by periodic fluctuation, common to all glaciers. This progressive diminution of glaciation from west to east suggests that deglaciation has crept westwards from the interior, whatever the ultimate cause may be. It is clear we cannot dissociate deglaciation west of the Yangtze from the same phenomenon east of that river; geographically the region is one.

Now there are three possible causes which might bring about deglaciation on a large scale: a general rise in the mean annual temperature, a change in the seasonal distribution of precipitation, and a general decrease in the amount of that precipitation.

The first possibility may be dismissed. It would require a considerable and long-sustained rise in temperature to abolish glaciers of the size indicated, and we have no evidence for any such climatic change. We

have reason to believe that deglaciation is still proceeding throughout this region; hence the cause which has operated in the past must still be in operation. A general rise in temperature, however, could hardly be confined to this comparatively insignificant corner of Asia; it could be brought about only by fundamental causes, and would affect a wide area. We must therefore seek some more local cause.

In considering the second we must bear in mind that the area over which deglaciation has taken place is, compared with the great bulk of Asia, very small. A change in the seasonal distribution of rainfall is not a factor which alters locally or rapidly. Long periods of time are required to bring about climatic changes, which likewise affect wide areas; and again, there is no evidence for such a change. On the contrary, there is every reason to suppose that the monsoon, which brings the summer rain to this part of China, prevailed before these changes took place.

We must therefore fall back on the third explanation—a general decrease in precipitation over this region. Here we have a cause which might operate locally. Moreover, to a certain extent this condition includes the second, for if the rainy season is curtailed, or begins later, the dry season is correspondingly prolonged.

Deglaciation might by this means be brought about rapidly, and judging from the state of preservation of the moraines they cannot be very old. This then appears to be the only reasonable explanation of deglaciation in far western Szechwan.

It receives some support from the distribution of floras in that part of Asia, for we find in the valleys a few plants of Indo-Malayan affinity; indeed some of the species are identical with those found in Burma. Such genera as *Hedychium* (1 sp.), *Strobilanthes* (3 spp.), *Chirita* (2 spp.), *Impatiens* (5 spp.), *Ficus* (1 sp.), *Begonia* (2 spp.), *Leptocodon* (1 sp.), *Ceratostigma* (1 sp.), etc., betray their origin. They are aliens. They must either be survivals of a previous flora which was in direct communication with the Indo-Malayan region to the west or south, or they must have arrived here by chance from that region.

With the possible exception of *Ficus* none of the plants mentioned above possess seeds provided with special means for transportation, and it is difficult to see how, under present circumstances, they could have arrived here from outside. Moreover, Indo-Malayan species whose seeds are better adapted to long journeys—for example, *Æschynanthus*—are lacking. All the plants mentioned belong to orders and genera whose representatives increase in numbers as we go westwards. Hence we conclude that these Indo-Malayan plants of Muli are remnants, not waifs; and that an originally more extensive Indo-Malayan element has dwindled to its present proportions. At present the summer temperature in the valleys is quite sufficient to maintain a monsoon flora such as is found on the north-east frontier of Burma; nor are the winters too cold. Only sufficient moisture is lacking. Were the rainfall greater, and more

equally distributed throughout the year, there can be no doubt that we should find a more pronounced Indo-Malayan element in the flora. No peak on the range with which we are dealing much exceeds 16,000 feet. Allowing 2000 feet of permanent snow to give rise to glaciers of the size indicated—no excessive estimate—the snow line must have lain at about 14,000 feet, and the alpine belt would then lie between 12,000 and 14,000 feet. This corresponds to the present alpine belt on the north-east frontier of Burma, where an Indo-Malayan flora flourishes in the valleys. It would require a much heavier rainfall and a more curtailed dry season than prevails to-day to support glaciers as low as 14,000 or 13,000 feet.

Turning to the alpine region we find, it is true, a flora very similar to that of the snowy ranges further west; indeed, many Himalayan alpinists such as *Myosotis Hookeri*, *Isopyrum grandiflorum*, *Diapensia himalaica* occur; perhaps 70 per cent. of the alpine flora is found at least as far west as the Mekong-Salween divide. This however need not surprise us. Conditions in the high alpine region towards the limit of plant life are very much the same everywhere. Given some former bridge connecting these ranges, many plants would tend to spread over the entire mountain system, and would be little affected by subsequent changes of climate.

On the other hand, it is in the high alpine belt on these several ranges that the majority of endemic species are found, a fact which is in accordance with the disappearance of permanent snow and ice over a large area.

Thus the fact of deglaciation, while being fully in harmony with the appearance of new alpine species, is not hostile to the survival of old. So long as the permanent summer mist bath in which many of these plants dwell prevails, there is no reason why they should vary or disappear though long isolated on their respective ranges. The presence of identical alpine species as far apart as Muli and Sikkim merely serves to emphasize the fact that these regions were formerly in direct communication; that such communication has subsequently broken down scarcely affects the plants in question. Moreover, many of these alpinists, living at 15,000 or 16,000 feet in western Szechwan, are found in the corresponding alpine belt at 13,000 feet on the north-east frontier of Burma. Mere altitude is of no great significance; it is altitude in relation to the snow line that counts.

There is another circumstance which suggests a gradual desiccation of the region as responsible for the disappearance of these glaciers. On the limestone cliffs of Muli are found a few plants which appear to be doomed to die out altogether in this region—species of *Primula*, *Campanula*, *Delphinium*, *Didissandra*, and perhaps also *Pinguicula*, *Rhododendron*, *Gentiana*, and a few others. They are found for the most part lurking in crevices and niches, forming a thin network of vegetation on a vast continent of naked rock. All are more or less rare, and set scarcely any seed. Though the autumn of 1920 was unusually wet, I found most of these plants shrivelling up in the bright November

sunshine. Scorched by day and frozen by night, life for them was brief. Their empty capsules, stunted and barren, told a tale of suffering and struggle, all in vain. Not one or two only, but the great majority set no seed. The inference is, that these plants are not at home under present conditions. Once upon a time no doubt they were common on these stark cliffs; now they are rare, and year by year are growing rarer. Finally they will disappear altogether. Incidentally, some light is thrown on the production of rare plants.

We have, then, good reason to believe that decreasing precipitation has brought about the changes noted in this region; and lastly, I must briefly refer to the problem of *how* this decreasing precipitation has come about. Here we are on much more controversial ground. There are, however, certain significant facts. East of the Yangtze we find these north and south ranges of uniform elevation persisting over great distances, till a solitary snow peak, far outstripping its neighbours in altitude, breaks the comparative uniformity. Here it may be remarked that the high peaks of Chinese Tibet appear to be composed, not of granite as in the Himalaya, but of limestone. These snow peaks, regarded by themselves, seem to lack any definite arrangement; they are as it were scattered fortuitously over the country, though were the entire region from the Yangtze to the Yalung glaciated as formerly, we would surely perceive some more regular arrangement than is now visible.

It would be premature to attempt an explanation of this phenomenon until the positions of all these snow peaks—there are scores of them—have been fixed on the map, and their alignment scrutinized. But I cannot refrain from suggesting that, though they at present dominate north and south axes, they may eventually prove to be but the surviving stumps of shattered ranges which trended in quite a different direction, serving as nuclei round which the newer uplifts oriented themselves. The change of front thus effected, by frustrating the west winds, may have brought about the deglaciation observed. That there has been such recent uplift is, I think, indicated by this progressive deglaciation and elevation of the snow line from west to east, which must be attributed to a gradual decrease of precipitation in the same direction; and we may suspect that the period of deglaciation throughout Chinese Tibet corresponds with the uplift of the high ranges on either side of the Yangtze, cutting off the moisture-bearing winds from the south-west. Whatever the age of these latter ranges may be, all the evidence goes to show that they are distinctly post-Himalayan.
