THE GLACIATION AND SOLIFLUCTION OF MINYA GONGKAR: *A paper read at the Afternoon Meeting of the Society on 10 February 1936*

PROFESSOR ARNOLD HEIM

UNTIL the year 1930 practically nothing was known of the eastern Tibetan frontal ranges and of the highest mountain of China, here called Minya Gongkar. This holy mountain was first designed and measured on long distance by Kreitner of the Szechenyi Expedition [1] in 1877–80 under the name of Bokunka. The height was determined as 7600 metres. Forty-five years later the missionary J. H. Edgar,[2] apparently not knowing of this observation, published a rough sketch from the same point at Yinkwantshai, and called the mountain Gang ka.

The excellent map of Yünnan by Davies 1906 [3] does not show the glaciated frontier wall, and the Map of India only gives the name Mount Koungka.[4]

In 1929 J. F. Rock,[5] on behalf of the National Geographic Society of Washington, made the first photographs from the western side of Minya Konka. The result of his measurements is 25,600 feet or 7800 metres. The following year H. Stevens, of the Roosevelt hunting expedition, published his 'Sketches of the Tatsienlu Peaks.' [6]

After Rock followed the writer's expedition [7] of 1930–31, and the admirable ascent of the summit by Burdsall and Moore of 28 October 1932.[8] Their book contains numerous careful measurements and photographs of geographical importance.

Professor Ed. Imhof, of the writer's expedition, by photogrammetric surveying came to an elevation of 7700 metres for Minya Gongkar, while Burdsall and Emmons, by direct triangulation, found 24,900 feet (7590 metres). If we consider that all measurements are based on barometric pressure, the differences for such a remote region are not surprising. The figures given by Rock seem to be all too high. If we accept 7600 metres, we will not be far off.

Besides the writer's book 'Minya Gongkar,' which in his opinion gives the correct spelling, several papers and reviews have been published, amongst which a few are cited below.[9] The aim of this paper is to give a general view

[1] 'Die wissenschaftlichen Ergebnisse der Reise des Grafen Szechenyi in Ostasien.' Wien, 1893, Bd. I.

[2] Journal of the West China Border Research Soc. Chengtu, 1922/23, p. 58.

[3] Major H. R. Davies, Map of Yünnan 1 inch to 20 miles (1 : 1,267,200).

[4] Map of India 1 : 1,000,000 Sheet No. 100.

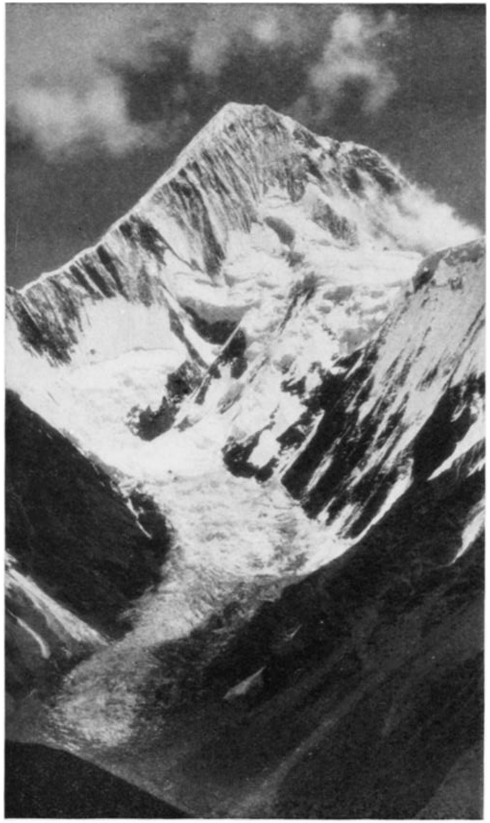
[5] J. F. Rock, "The Glories of Minya Konka." *Nat. Geogr. Mag.* October 1930.

[6] *Geogr. Jour.*, vol. 75, p. 345.

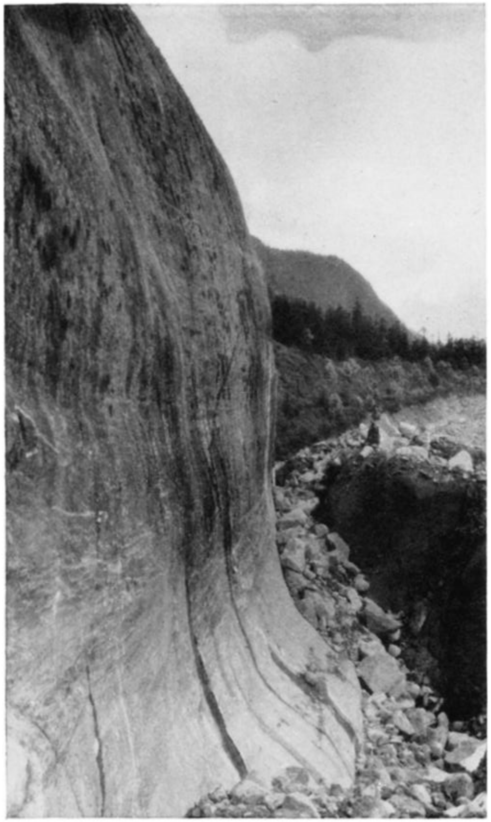
[7] Arn. Heim, 'Minya Gongkar, Forschungsreise ins Hochgebirge von Chinesisch Tibet.' With 26 designs, maps, panoramic view and 146 photos, amongst which 6 plates in colours. Hans Huber, Bern.

[8] R. L. Burdsall and A. B. Emmons, 'Men against the Clouds. The conquest of Minya Konka.' Harper and Brothers, New York and London, 1935.

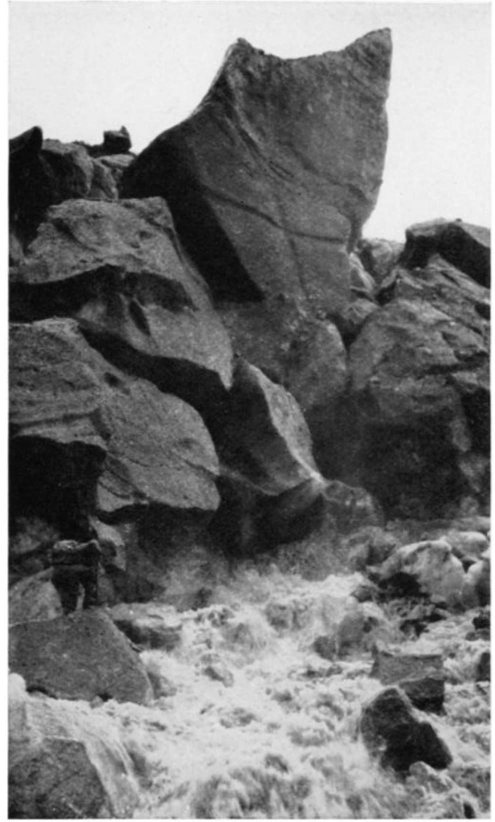
[9] Arn. Heim, "Szechuan–Tibet Expedition der Sunyatsen Univ. Canton." *Zeitschr. d. Ges. f. Erdkunde,* Berlin 1931. "The structure of Minya Gongka. Preliminary sketch." *Bull. geol. Soc. of China.* Peking 1931. Tectonical sketch of the Yangtse



1. Minya Gongkar (7600 m.) and Small Gomba Glacier, from W.



2. Polished granite at knee of Hailoko Glacier, looking E.



3. Dirty block-ice at mouth of Great Gomba Glacier, 3800 m.

4. Great Gomba Glacier: Mount Chu (6500 m.) on left and Nyambö (6200 m.)

5. Minya Gongkar and Gomba Glaciers from the west

6. Stratified ice with cleavage and diagonal bands, Great Gomba Glacier on the glaciation, while the main geological work with a geological map will follow later.

The present glaciers

The main glacier on the west side is the Great Gomba Glacier. It was first photographed by Rock and called by mistake Nyambö Glacier. The ice is collected on the south side of Minya Gongkar. The stream has a length of about 10 kilometres. The tongue is only 2 kilometres north-east of the monastery Gongkar Gomba, at 3800 metres above sea-level (Pll. 3, 4).

The Small Gomba Glacier derives from the north-west side of Minya Gongkar and joins Great Gomba Glacier at nearly a right angle without contributing to it. It is cut off by the greater neighbour. Both Gomba Glaciers are largely covered with blocks, especially of granite from the highest peaks. Several small green lakes are found on the surface of the moraine-covered ice stream.

On both sides the ice tongue is separated from the slate rock by deeply cut V-shaped glacial streams. The one to the south partly runs on ground moraine and is cut 100 metres deep below the middle part of the glacier. It seems that the glacier is overriding its own ground moraine, unable to remove this abundant detrital material.

The glaciers on the north and east side of Minya Gongkar were discovered by the writer in 1930, the eastern one being the largest of all the glaciers of the range, and the only one which extends down into the forest region.

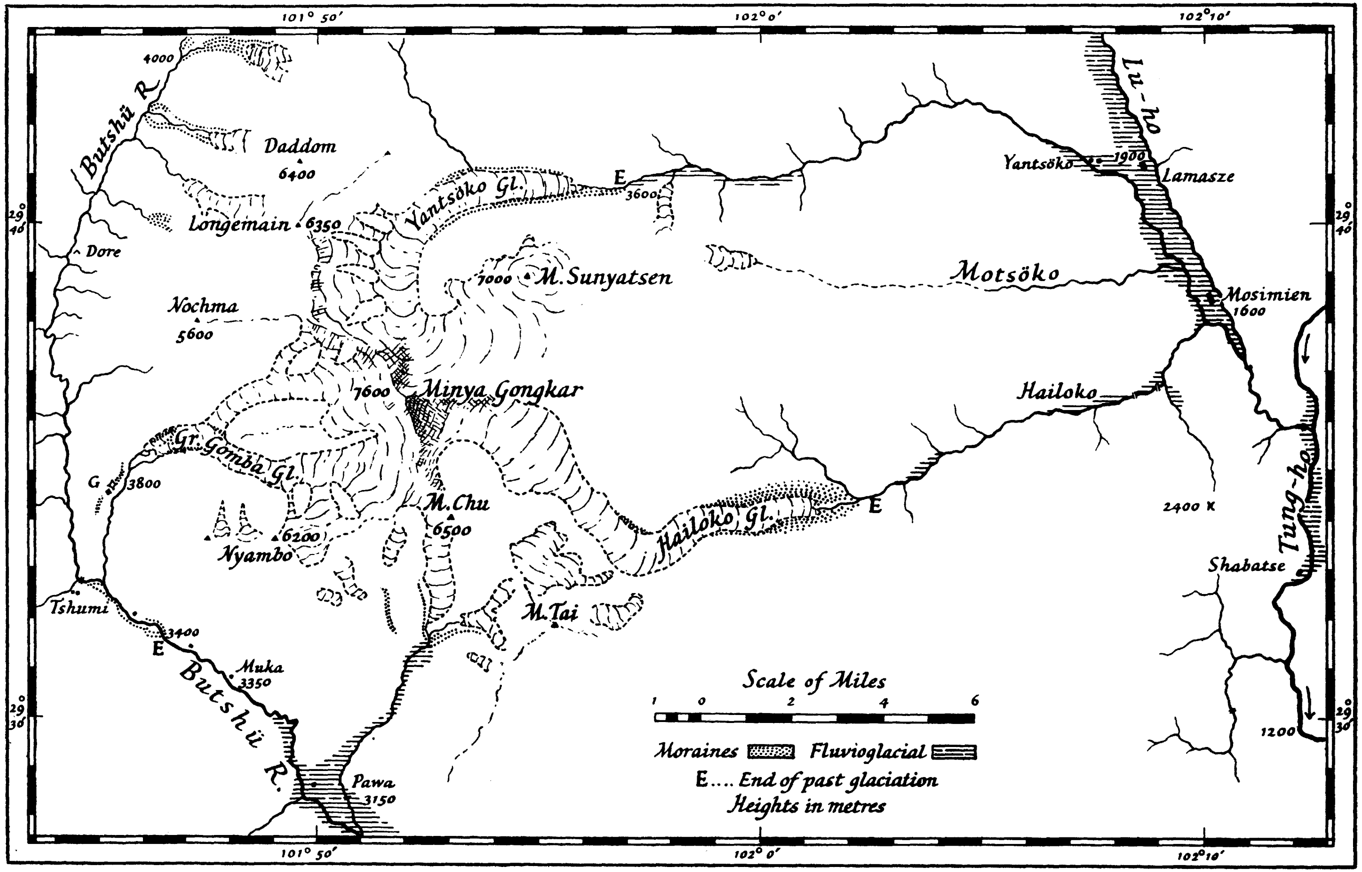
The Yantsöko Glacier derives from the great snow trough between Minya Gongkar and Mount Sunyatsen (7000) and bends around like a snail towards west, then to north and east. A tributary stream of 3–4 cubic metres per second coming from the valley in the north-west falls into a cave of ice and comes out again at the glacier foot 3–4 kilometres farther down, together with the melt-water of the Yantsöko Glacier. In contrast to the Gomba Glaciers, the side moraines are well-defined crests with sharp scarps towards the glacier, 10 to 20 metres in height (Pl. 7, left side). They are probably of pleistocene age.

The Hailoko Glacier has a length of about 16 kilometres and reaches the fir-tree jungle in the shape of a rounded tongue (Pl. 10). It has two ice falls, one just below the knee (Pl. 10), and a larger one with a strongly convex surface of some 500 metres drop in the upper part (Pl. 11). Like Yantsöko, it is accompanied by pronounced ridges of old moraine which are scratched by the actual ice flow. Some very pretty glacier tables are found in the lower part. The glacier gate is surrounded by jungle of firs, beeches, and rhododendron. On account of broken instruments, the elevation could not be measured, but is guessed as about 3000 metres or less.

The next largest known glacier of Gongkar Range is the Djaze Glacier (Pl. 14), 20 kilometres north of Minya Gongkar. Adjoining it is the Reddomain Glacier (Pl. 9). The supposed glaciers on the east side of Djaze Gongkar

from Ichang to the Red Basin. Geol. Survey of Kwangtung and Kwangsi, Spec. publ., No. XIV. Canton 1933. "The Batholiths of Minya Gongkar and Lamoshé, Chinese Tibet." *Eclogae geol. Helv.* 1934.

Albr. Penck, "Minya Gongkar." *Zeitschr. d. Ges. f. Erdkunde* 1934.


101° 50′
102° 0′
102° 10′
29° 40′
29° 30′
Butshü R.
4000
Daddom
6400
Longemain
6350
Dore
Nochma
5600
Yantsöko Gl.
E
3600
M. Sunyatsen
7000
Motsöko
Yantsöko
1900
Lamasze
Lu-ho
Mosimien
1600
Minya Gongkar
7600
Gr. Gomba Gl.
G
3800
M. Chu
6500
6200
Nyambo
Hailoko
Hailoko Gl.
2400
Tung-ho
Shabatse
1200
M. Tai
Tshumi
3400
Muka
3350
Butshü R.
Pawa
3150
Scale of Miles
1 0 2 4 6
Moraines
Fluvioglacial
E.... End of past glaciation
Heights in metres

are yet unexplored. Little also is known of the glaciers between the Tatsienlu Peaks (Lamoshé Glacier, Tatsienlu Glacier, see map 1 : 275,000 in 'Minya Gongkar').

Snow fall and hoar ice

In the upper region the snow falls chiefly during the later part of summer and in autumn, especially in August, September, and October. September seems to be the worst month for travelling. For months the mountains were hidden in clouds. During winter we had only one snowfall of importance, namely on November 22. It was snowing again a little on January 14. Some more snow may fall in early spring. As a whole the winter is dry and clear, and little, if any, snow is found on the Tibetan highland behind the great front ranges. As already pointed out by Edgar, the summer floods of the Yangtse cannot derive from snow melting in the interior, and they are connected only to a very small extent with ablation of ice and snow of the Tibetan front ranges.

Hoar ice seems to be of special importance in the highest regions of Asia, where it may be formed even in summer. Pl. 7 shows Minya Gongkar from the north, with its summit completely covered by a mantle of bright white ice. It sticks even on the vertical walls, where no ice could be formed of snow. Hoar ice produces rounded surfaces. By this and the cleanness it can be distinguished at long distances. In Pl. 7 the lower limit is easily traced between 5800 and 6000 metres; in Pl. 8 (M. Tai) it is at the same level however, without forming a level line.

Even when the sky in winter is clear, all around the highest peak of Minya Gongkar is capped with a white streamer. Sometimes it is made of snow drift, but frequently it must be fog which produces hoar-ice crystals.

The snow line, on account of bad weather, could not be determined accurately. On the west side of Minya Gongkar it seems to be between 5200 and 5400 metres.

Ablation and drainage

As a result of the writer's observation we can state that all the water of Minya Gongkar is drained to the east by the Tung-ho. The glacier water from the west side is collected by the Butshü river. It was estimated at Pawa at the beginning of September 1930 as yielding 40 cubic metres per second. About 80 per cent. of this amount seems to derive from ablation. A similar amount may be produced on the eastern side of Gongkar range. We thus come to a total of roughly 100 cubic metres per second. This figure is still very small as compared with the enormous amount of water carried by the Yangtse in times of flood.

The tropical form of snow melting called *nieve penitente* was observed in Pawa Valley at 5200 metres (October 30) and on Haitseshan on the north-east side of Mount Jara, 50 kilometres north-west of Tatsienlu, at 4400 metres (6 January 1931). (Pl. 15)

Extension of former glaciation and of fluvioglacial terraces

Let us first record some observations on terminal moraines and erratic blocks. The greatest difference between recent and old moraines was found on the west side of Minya Gongkar. Indeed, the slope at Tshümi (Tsemi) is strewn with huge blocks of granite derived from the summit of Minya Gongkar. The last erratics were noted about half-way between Tshümi and Muka, at about 3400 metres. The pleistocene glacier thus had a length of about 18 kilometres as compared with the actual 10 kilometres, the glacial tongue reaching about 400 metres farther down.

In the Pawa valley the side glaciers just came together. There the old moraines pass into a vast fluvioglacial fan deposit which extends far down below Pawa in the Butshü (Tienwan) Valley (Sketch-map).

The old moraines of Yantsöko Glacier only extended 2–3 kilometres below the block-covered ice of the present time. There the fluvioglacial terrace commences about 40 metres above the glacial river, its surface dipping 8–9 degrees in the direction of the valley. Some 4 kilometres farther down, the terrace is at 50–60 metres, dipping 6–8 degrees towards east.

At the villages of Lamasze and Mosimien the same fluvioglacial terrace is widely extended and cultivated. Its general slope is 5 degrees to east. The rivers on both sides have cut out deep channels down to more than 100 metres below the table terrace. The thickness of the fluvioglacial deposit in places may exceed even 100 metres. Frequently large blocks of several cubic metres are enclosed in the coarse gravel. On the surface of the terrace some granite blocks of 10–20 cubic meters were observed, and one of even 100. It is difficult to explain their position. Possibly they fell down from the slopes before the side ravines were formed.

On Hailoko Glacier little, if any, signs of a larger extension of the former glaciation are left in the uppermost part (Pl. 12). Above the knee a left side moraine is preserved, which reaches 15 to 20 metres above the ice. The granite forming the knee is nicely polished up to about 20 metres (Pl. 2). In the lower part of the glacier the left side moraine is overgrown with jungle of fir trees, larches, and rhododendron.

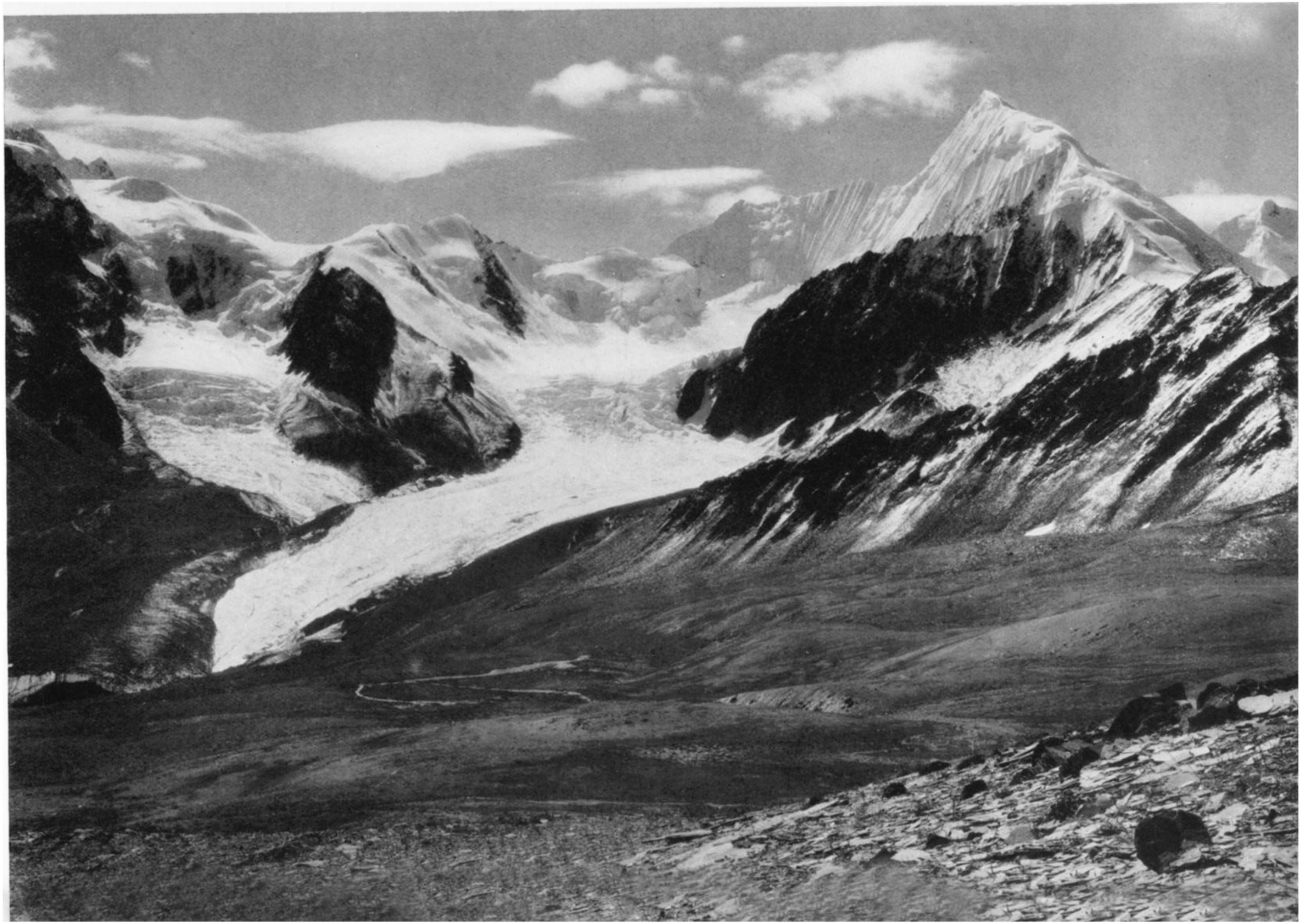
Two crests may be distinguished here, an inner one 15–20 metres above the ice, and an outer, still older one at about 25 metres. Near the glacial gate this old moraine is 60–80 metres high, but seems to reach its end already 2–3 kilometres farther down stream. No connection was seen with the fluvioglacial terrace so well traced at Yantsöko Valley. It seems that the passage zone has been washed out by side streams. But 10 kilometres farther down, at Hailoko (Chinese mountain farms), the fluvioglacial deposits are well developed.

The gravel terrace corresponding to that of Mosimien is at about 70–80 metres above the river. Above it two more terraces were observed. They seem to be terraces of erosion, one at about 130 and one at about 300 metres above the river.

The continuation of the terrace of Mosimien (Mosimien stage of glaciation) is interrupted by a granite gorge, but is recognized again along the Tung-ho. There, in the region of Shabatse, low terraces of 35 and 45 metres above the river were noted, while the high terrace is at 60–70 metres. It is the latter that seems to correspond to the widest extension of pleistocene glaciation (Mosimien stage).

7. Minya Gongkar and Yantsöko Glacier from N.

8. Mount Tai, from 5000 m., showing hoar ice on the crest, looking E.



9. Ice horn and glacier of Red-domain. Fore-ground under solifluction

Solifluction

It is generally known that in cold regions where the temperature frequently changes around the freezing point, the slopes of talus are gradually slipping. Most beautiful examples of this kind were observed by the writer on the Nugsuak peninsula in Greenland. Even the bottoms of the side valleys there are slipping in the shape of a glacier, although there is no snow field above to collect ice. Solifluction also is known from the Alps, as for instance in the flysch region of the Segnas Pass.

Chinese Tibet in greatest part is made of slates and sandstones of the flysch type. The most characteristic solifluction in this region was observed on the north side of the Rutshe Pass, 20 kilometres north-north-west of Minya Gongkar, at elevations from 5000 metres down to 4200 metres (Pl. 9). More than 5 square kilometres are slowly moving downwards. The plates of slate, especially in the ravines, are frequently raised up (Pl. 9, black spots at right foreground). The cushion plants which cover the ground are torn by cracks which illustrate directly the amount of slipping. Frequently also the stone plates are found in a geometrical order.

Other places of widely extended solifluction are the north-west side of the Cheto Pass west of Tatsienlu at 4600–4000 metres, and Haitseshan Pass at 4500–4200 metres.

In the background of the Pawa valley at 3800 metres, and on the Yatsiaken Pass, at a similar elevation, huge fields of angular blocks were encountered. They have neither the shape of moraines nor of a mountain slide. Rain and fog at Yatsiaken made careful observation impossible. On the north-west side of this pass some small lakes dammed by ground moraine were noted down to about 3600 metres. As a rarity it contains some pebbles of striated Serpentine, a rock not yet known *in situ* in the whole region. Bad weather did not allow me to determine whether this moraine has slipped down by solifluction.

Usually the striæ of solifluction are easily distinguished from those of glaciers. They are more superficial and chiefly or exclusively found on softer and angular rock fragments like slates and sandstones, while those from glaciers, on account of the higher pressure below the ice, may be found on the hardest rocks which frequently are rounded and polished.

Von Lóczy of the Szechenyi Expedition has accepted a very large extension of former glaciation. It seems to the writer that he has confounded striation by solifluction with true glacial striation. In every case it is of greatest importance to give most careful attention to these pseudo-glacial deposits in regions of frozen ground.

Morphological features

The morphological observations are conformous with the determination of the end moraines. Rock polishing so general in the Alps, in Scandinavia, and in North America is rather exceptional on Minya Gongkar. None of the valleys shows the signs of glacial erosion. All the main features are those of water erosion. The old side moraines in the Pawa valley and in the upper Butshü valley just reached the valley bottoms at 3800 and 4000 metres without extending farther down (Sketch-map and Pll. 1, 4, 5, 11, 12). Already the distant view of the Butshü valley with its sharp crests is characteristic of a non-glaciated valley (Pl. 12).

In vain also the writer sought striated pebbles in the Tatsienlu valley. Neither the Lamoshé nor the Tatsienlu Glacier seem to have ever reached the bottom of the main longitudinal valley.

The above observations show that the former glaciers were more widely extended than they are now, but not to compare with the pleistocene glaciation of the Alps. The former glacier tongues reached 200 to 500 metres farther down at the most. Taking the length of the present stage as 1, the former glaciers reached 1·1 to 1·6 (Gomba 1·6, Yantsöko 1·2–1·1, Reddomain 1·3). In the Alps, where the present glaciation is of the same type, the proportion is from 1 : 12 to 1 : 30, the early glaciation thus twenty times stronger.

The great feature of the pleistocene glaciation is the fluvioglacial deposit. The terrace gravels washed off from the former moraines have a more gentle slope than the actual valleys. The Yantsöko and Hailoko glacial rivers have cut themselves into the gravel terrace 30–40 metres deep in the upper part, 50–60 in the middle, and 70–110 metres in the lower part (Mosimien). The deposition of the vast fluvioglacial material that fills the valleys must have occurred at a time of lesser fall of the rivers. The cause of the accentuation of erosion in recent time must be the general uplift of the Tibetan mountain region. This result already was derived from a study of the platform of Chinese Tibet which must have been formed at lower levels. It was a semi-mature landscape lifted recently into higher levels. The vegetation also points in the same direction. The extreme abundance of semitropical plants mixed with alpine types is explained by the lack of glacial destruction and by this quaternary uplift. Thus the subtropical forms became gradually adapted to the cooler climate, while the nival forms had to migrate downwards and to join hands with their companions from below. All such reflections result in the conclusion that the general cold climate of the pleistocene ice age at the eastern Tibetan front ranges was nearly counterbalanced by its formerly lower position. This is the writer's explanation for the relatively small extent of past glaciation.

DISCUSSION

Before the paper the PRESIDENT (Major-General Sir PERCY COX) said: The paper this afternoon is on the "Glaciation and Solifluction of Minya Gongkar." Professor Arnold Heim, who is reading the paper, has travelled over a great part of the world and was for some years Professor of Geology in the University of Canton. He is the distinguished son of a distinguished father, who also was a great geologist.

As those of you who have attended recent meetings of the Society know, a great deal of attention has been paid to the movement and behaviour of glaciers, and Professor Heim proposes to address us on this subject. The word "solifluction" was new to me when I heard it recently. I could not find it in the dictionary, and when I asked a friend the meaning of it he said that he was not sure whether the "soli" element in the word referred to melting from the heat of the sun or to movement of the soil. Professor Heim tells me that, so far as he is concerned, it is a word introduced by Gunnar Andersson: and that it relates to the fluctua-

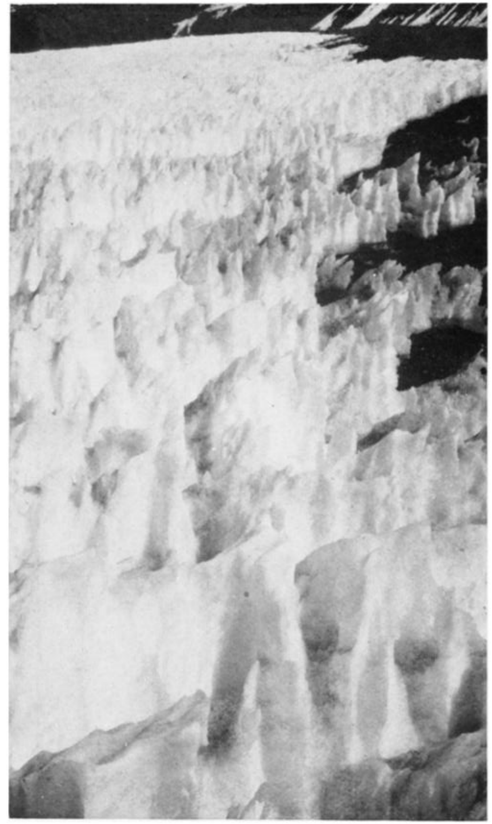
10. Lower Hailoko Glacier, looking down stream

11. Upper Hailoko Glacier and Minya Gongkar from S.E.

12. Upper Butshü Valley shaped by water erosion, looking N.E.

13. Banded ice near end of Great Gomba Glacier

14. Chiburongi (6000 m.) and Djaze Glacier



15. Nieve penitente, Haitseshan (4400 m.)

tion or movement of the soil, and not to melting by the sun. With this brief digression I will ask Professor Heim to read his paper.

Professor Heim then read the paper printed above, and a discussion followed.

The PRESIDENT: Before we go further I should like to ask you to join me in congratulating Professor Heim on the extraordinary perfection and fluency of his English. And now I call upon Professor Boswell, Professor of Geology at the Imperial College, to add a word or two.

Professor P. G. H. BOSWELL: I thank you, Mr. President, for the privilege of being able to join in the tribute to my friend, Professor Heim. As the hour is getting late I will be brief and refer only to two of the geological questions which he raised.

First, his main thesis is that on the evidence of the morphology, the absence of extensive ice scratching, and the mixture of the plant life, this area has, unlike certain other mountain ranges with which we are familiar, risen in comparatively late geological times. Professor Heim is well familiar, of course, with the fact that the extent of glaciation depends not only upon elevation but on the amount of alimentation, and thus on the proximity to ocean waters and the direction of moisture-bearing winds. Although I feel that he has established his thesis on several grounds, probably he will be able to tell me that he has definitely ruled out all possibility that past glaciation here was the result of the non-arrival of moisture-bearing winds.

I feel that the remarks on solifluction—the second point I wish to make—are going to be of very great value to us when we are able to read them in detail. Studies of solifluction phenomena at the present time are far too few. We happen in this country, and of course we share that condition with certain other European countries, to be just on the position of the oscillating ice margins of the great Ice Age, with the result that here where we are standing at the moment we can imagine glaciers reaching perhaps as far as Finchley to the north, and solifluction phenomena, soil creep, and so on, going on in the area southwards to the English Channel. Those deposits have puzzled geologists for many years. They have been attributed to frost and soil movement, but with some caution, and it is not surprising that geologists were afraid of getting cold feet. If we can have present-day evidence of solifluction described from such regions as those that Professor Heim has visited, then such evidence will be of great use to us in the interpretation of solifluction phenomena during the later stages of our own Ice Age here.

There are many other interesting points that Professor Heim has touched upon, but I feel that I must finish with the expression of great pleasure and satisfaction at the success which Professor Heim has achieved in his expedition and in his lecture.

Professor HEIM: The President has asked me to reply to Professor Boswell, and, in doing so, I would point out that when the whole mountain range was lower than it is at present, the alimentation of the moisture was also less, so that is only a further point in my favour.

Professor BOSWELL: Let us not assume that the range is higher now than it was.

Professor HEIM: Yes; but then I do not know whether there was any evidence that the moisture previously was less, so we need not even in that case accept that the mountain was less high because it was so little glaciated.

Mr. PATERSON: I have listened with great interest to Professor Heim's lecture, in view of the work in which I have been engaged during the last three years. I was with Mr. Wordie on his expedition to Baffin Land in 1934, and there paid particular attention to this very phenomenon of solifluction which Professor Heim has called to our notice. During the summer of 1935 I was busy in the North West Himalaya studying these same phenomena and the glaciations there, so that Professor Heim's observations, though they be in a region fairly far removed from those where I have been working, certainly are of importance to my particular study. I found there many parallels which one might draw.

In the first instance, I am interested to hear and to see Professor Heim's evidence for the action of ice and how much one can attribute to that factor, because I found in the Himalaya that the major part of the erosion is due to the action of water proceeding from the glacier and not to erosion by the glacier itself. Secondly, in Lower Pleistocene times the Sind glacier, now measuring less than two miles in length, was then 60 miles long, a comparison of the order encountered in the Alps. But in the Middle Pleistocene the Pir Panjal or Outer Himalaya was elevated almost 4000 feet and subsequent glaciations nearer the core of the main range were much smaller, which may be due in part to the blanketing effect of the newly risen mountain range, where also corresponding later glaciations were much more extensive. That may help to solve the question which Professor Boswell has raised.

As a third point, the matter of solifluction is deserving of attention because I find in the regions north of Kashmir large areas of *Felsenmeer* similar to those described by Arctic travellers. In Baffin Land these enormous areas of stones extend for as many as 30 square miles, reaching finally to a base angle of slope as small as 5°. Even then stones many tons in weight can move. In the Sind Valley of Kashmir I have seen deposits up to 200 feet thick composed entirely of solifluction material. Solifluction it seems, then, is a factor in geographical development which cannot be ignored and therefore excellent observations such as those of Professor Heim assuredly are of value to a study of that factor.

Professor BARBOUR: In expressing my thanks to Professor Heim I need only add that his picture of the glacial history appears to accord perfectly with recently developed ideas regarding the topographic changes connected with the evolution of the Yangtze, more particularly with its diversion from a previous southerly course during the Pleistocene Period. May I add to the appreciation already expressed by others my own gratitude for a lecture of such interest so well presented.

The PRESIDENT: We should like to have heard Professor Mason, but he has had to leave to catch a train. He has however left a few notes which I will ask Mr. Hinks to read.

The SECRETARY then read the following from Professor MASON: I should like to say how much I have enjoyed Professor Heim's extraordinarily instructive paper. The detailed exploration and survey of this region must have an important bearing on the question of the extension of the Himalaya east of the Tsangpo–Brahmaputra gorge.

In this connection I think there are certain pointers of great interest in Professor Heim's paper. He has, I understand, concluded that the mature landscape of this region of late Tertiary times has been uplifted in Pleistocene times, a conclusion derived from the vast fluvioglacial deposits of an earlier epoch, by the subsequent rejuvenation of streams, and by certain vegetational evidence.

Far away from Minya Gongkar Dr. de Terra has come to a precisely similar conclusion from a study of the terraces and deposits in the region of the Pangong lake and eastern Karakoram. In that region Dr. de Terra has suggested a post-mature landscape in late Tertiary times, with four subsequent periods of uplift, separated by three pleistocene ice advances and followed by dissection.

The same general morphological features at such widely separated intervals of course proves nothing; but, taken in conjunction with other evidence which is gradually accumulating, it does seem more and more probable that these Tibeto–Chinese ranges, with their strongly marked north–south trends, bear the same relation to the supposed flexure of the eastern Himalaya as the Karakoram–Hindu Kush ranges do to the western Himalaya.

In the north-west we have the resistant horst of ancient India projecting northwards and influencing the trends of all the mountains north of it as far as the Pamirs. In the east there is the resistant block of the ancient Shillong plateau projecting north-eastwards, similarly influencing the trend of the mountains north-east of it. In the north-west the Himalaya have been moulded, with a sharp flexure, as Wadia has shown, round the horst. Beyond the Himalaya the flexure of the Karakoram–Hindu Kush is less acute and, as de Terra has shown, the Karakoram–Tibet region has been raised in very recent times. Wadia, Misch, and de Terra have all shown in different parts of this northern region that even the most recent deposits have been tilted, a fact that shows that these mountains are not yet at rest.

In the east our scanty evidence all points the same way. The ancient Shillong plateau is so stable that the Tertiary deposits lie horizontal and undisturbed along its southern flank. But to the north-east and east there is unrest. The younger outer ranges seem to have been moulded with an even greater flexure round this block than in the north-west; their trend changes sharply from east-north-east in the Abor hills to north–south, and then to north-east–south-west round the head of the Assam valley. Behind them and farther to the east we see an apparently gentler flexure of the Tibeto–Chinese ranges which, in the region examined by Professor Heim, show characteristics identical with those of the Karakoram.

I very much hope that Professor Heim will be able to continue his studies in this field.

The PRESIDENT: It only remains for me to thank Professor Heim most warmly for his interesting and valuable paper. I am sure the experience of many here will lead them to agree with his when he says that on these arduous journeys the tendency is to forget the difficult and unpleasant parts, and to remember only the bright patches. Indeed while he was displaying those beautiful pictures the thought was in my mind what an infinity of toil and perseverance it must have cost him to reach his objective. We must compliment him too on the very clever imitations he gave of the cries made by the Tibetans as they go over the higher passes.

I ask you now to join me once again in thanking Professor Heim for his most interesting lecture, and at the same time express the hope that fortune will enable him to continue his studies of these glacial problems.

Dr. KENNETH SANDFORD sent the following contribution to the discussion: Professor Heim's paper reintroduces from another angle the question of the relative efficacy of rivers and glaciers as valley-eroding agents in mountains. Professor Garwood sifted the evidence and revived this long-standing controversy, so far as it concerned the Alps, in his Presidential Address to the Geological Society in 1931: the tendency in the Alps and Himalaya seems to be toward crediting rivers during glacial minima with profound vertical erosion, and glaciers at their maxima with smoothing and steepening of the valley sides.

In the valleys around Minya Gongkar down-cutting seems to have preceded the deposition of the great fluvioglacial gravels, for Professor Heim quotes from the vicinity of Lamasze and Mosimien gravels possibly more than 100 metres thick and now eroded by rivers to that depth. But there are two terraces of erosion, at 300 and 130 metres above the river in the Hailoko district: there are therefore at least three periods of river erosion, and now a fourth, and one, at least, of great fluvioglacial accumulation. These recall in some measure de Terra's results, and both authors attribute one or more periods of river erosion to general uplift.

Professor Heim proves the striking contrast between the present and former lengths of glaciers in the Alps, ratio 1 : 12 to 1 : 30, and in this part of Tibet, ratio 1 : 1·1 to 1 : 1·6; he attributes the small ratio of Tibet to lower elevation during the Ice Age than at the present day. While welcoming the further demonstrations of Pleistocene elevation and valley deepening in Tibet and the Himalaya, which may still be in progress, I would like to ask Professor Heim whether the geographical position of Minya Gongkar with relation to the distribution of monsoon rains would not fully account for the small ratio of Pleistocene to present glaciation. In this region there seems to have been no glacial overloading at any time, and it is unlikely therefore that the progress of elevation has been hindered by any extrinsic factor.

Why, then, has elevation halted at intervals? Have there in fact been pauses? If we assume, as it seems we must, that the causes of checks in elevation in this region are geophysical, we must not be too ready to assume that glacial overloading has played a part in punctuating uplift of other parts of the mountain arcs and plateaux.

To conclude therefore even if some of us may be unwilling to accept the ratio of glacier length as evidence of recent uplift, there is abundant evidence of general elevation in the trenching of the valleys. The periods of elevation, pause, or even reversal of movement, here and elsewhere, may be the cause and not the effect of variation of glacial load. Our thanks are due to Professor Heim for this further demonstration of the danger of dogmatizing about Quaternary climate and ice ages from as yet insufficient meteorological and geological data.