THE STUDY OF THREATENING GLACIERS: *A paper read at the Afternoon Meeting of the Society on 19 November 1934, by*

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THE present paper is the outcome of an intermittent study of the movement of glacier snouts lasting over more than twenty years. It is intended primarily to summarize what we have learnt from the movements of glaciers in the neighbourhood of the Karakoram, and it is hoped that it will lead to a useful discussion by those who have studied glaciers in other parts of the world. I also hope to show how necessary it is to carry out further observations and research before it is possible with any certainty to lay down the laws that govern glacier movement.

It was in 1910, on my first visit to Kashmir, that the late Sir Henry Hayden, then Director of the Geological Survey of India, interested me in glacier movement; and from that year till now I have endeavoured to collect information and reports, tried to interest travellers in Himalayan and Karakoram glaciers, and studied their reports in conjunction with previous accounts.[1] It is not the normal flow of the ice-stream in a glacier that I intend to discuss. It is of course well known that the velocity of the ice-stream is dependent on various topographical factors, such as the general slope of the land surface, and in particular the volume of accumulated ice to be carried away from the feeding ground. Such ice-stream velocities vary from an inch to perhaps (though I doubt it) as much as 60 feet a day, according to text-books, and they are not constant in different parts of the glacier, nor at different seasons. This flow of ice is however a condition of all live glaciers, and it only ceases at the snout, where the supply of ice by flow is balanced by the sum total of destructive agencies, such as melting, evaporation, radiation, etc. It is therefore obvious that if either the volume of ice in the feeding-ground is altered, or if the destructive agencies at the snout are changed, there will be a variation in the snout position. Conversely, it would appear that measurements of snout variation should give some indication of climatic change. This is the theory underlying the projects that have been carried out during the last forty years of glacier snout measurement.

In attempting to investigate the results of measurements we may resolve the total movement of a snout into four possible components: (1) Secular, (2) Periodic, (3) Seasonal, (4) Accidental.

Secular change is the name given to changes distributed over long periods of time, due to world causes which overrule local factors of climate, weather, and topography. The retreat of glaciers since the last ice-age is a secular change.

Periodic change is the name given to changes believed by some to be due to climatic or weather cycles, such as the Brückner cycle, of comparatively short duration, say thirty-five years. To prove it, all glaciers in a given region should have the same period of advance and retreat. I may perhaps say at once that the Karakoram and Himalayan glaciers that have been studied show no

[1] A preliminary study of thirty-four Karakoram glaciers by the author of this paper appeared in the *Records of the Geol. S. of India*, vol. 63, pt. 2, pp. 214–278.

evidence whatever of any regular periodic change common to all that agrees with the periodicity of any supposed weather cycle.

Seasonal change is the name given to the changes between different seasons of the year. This is of considerable importance in India; and failure to appreciate the immense difference between the conditions of winter, when ablation is almost completely absent at the snout, and those of the months July, August, and September, when every factor of ablation is at a high maximum, has led many observers to false conclusions when applying observational tests of snout movement that may be applicable to glaciers in higher latitudes. In the Karakoram and Himalaya, unless a glacier is advancing strongly, we must expect to find some signs of degeneracy of the snout in August, but they do not necessarily denote retreat; and we must expect to find a more upstanding ice-front in winter, though active advance, other than a small seasonal one, is not necessarily indicated.

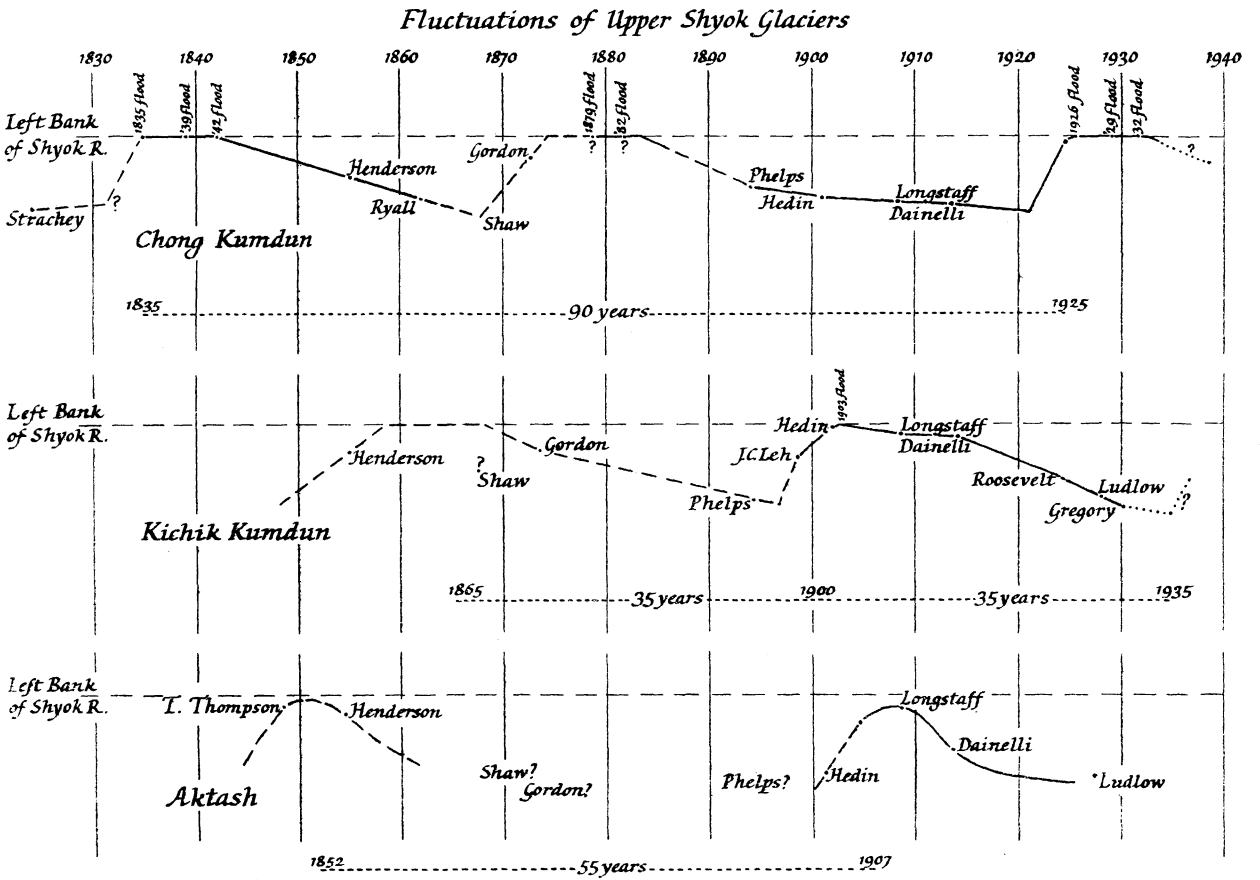
Accidental change in a glacier snout is the component of movement under which we group all other movements that cannot be resolved into either secular, periodic, or seasonal. It is this component that I now intend to discuss. Generally speaking I do not think that any other of the movements that I have mentioned are responsible for any of the major blocks of river valleys that have occurred in the past; such movements are slow, and rivers can be expected to keep a clear channel. With "accidental" movements, the advance of the snout is often extremely rapid, so rapid that a large valley becomes completely blocked, a great lake several miles long is impounded, and a great flood may occur when the waters are let loose.

I propose first to give a brief history of the movements of the following glacier-snouts, pointing out any special peculiarities possessed by each: the Chong Kumdun and the Kichik Kumdun glaciers of the upper Shyok; the Hasanabad, the Minapin, and the Yengutz Har of Hunza and Nagar; and the Karambar glacier of the Ashkuman district of the Gilgit Agency. I may also refer, if I have time, to evidence exhibited by other glaciers, such as the Kyagar and the Lungmo-che glaciers, which I have studied but the history of whose movement is not known.

The Upper Shyok glaciers

In an appendix to his paper read before this Society in 1910, Dr. Longstaff called attention to the positions and movements of the glaciers of the upper Shyok.[1] I found Dr. Longstaff's researches of very great value, and using them as a basis to work upon, carried them further. The collection and study of the history of these glaciers was a fascinating occupation. In the old volumes of the *Journal* of the Asiatic Society of Bengal I found the controversies that raged round the causes of the great Indus floods of 1841 and 1858, when so little was known of the detailed geography of the Gilgit district or of the mountain neighbourhood of the upper Shyok. It was absorbing to sift the evidence collected by men like Vigne, Alexander Cunningham, Henry Strachey, Becher, Falconer, Drew, Abbott, Henderson, Montgomerie, and Godwin-Austen, some of them ranged on one side of a controversy, some on the other. There were reports of floods in the Indus valley in the years 1826,

[1] *Geogr. J.*, vol. 35, p. 641 (1910).


Fluctuations of Upper Shyok Glaciers
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1835 flood
39 flood
42 flood
1879 flood
82 flood
1916 flood
29 flood
32 flood
Left Bank of Shyok R.
Strachey
Chong Kumdun
Henderson
Ryall
Gordon
Shaw
Phelps
Hedin
Longstaff
Dainelli
1835
90 years
1925
Left Bank of Shyok R.
Kichik Kumdun
Henderson
Shaw
Gordon
Phelps
Hedin
1903 flood
J.C.Leh.
Longstaff
Dainelli
Roosevelt
Ludlow
Gregory
1865
35 years
1900
35 years
1935
Left Bank of Shyok R.
Aktash
T. Thompson
Henderson
Shaw?
Gordon?
Phelps?
Hedin
Longstaff
Dainelli
Ludlow
1852
55 years
1907

1833, 1835, 1839, 1841, 1842, 1844, 1855, 1858, and 1865, almost all attributed by one writer or another to the bursting of the Shyok glaciers. In investigating the reports of these ten floods, I came to the conclusion that two were due to errors in date and are identical with others, two were due to blocks formed by landslides and not by ice, two were due to glacier blocks in the Gilgit Agency, and one to a small glacier block or landslide, probably the latter, near Gol on the Indus. Three floods only can be identified as definitely due to the upper Shyok glaciers, namely that in 1835, which was catastrophic, that of 1839, "of much less extent" according to Sir Henry Strachey, and that of 1842, which was small.[1] In recent years we have been able to investigate the upper Shyok glaciers in considerable detail. Dr. Longstaff and Major D. G. Oliver took a series of photographs of the Aktash, Kichik Kumdun, and Chong Kumdun glaciers in 1909; and another valuable series was taken by Professor Giotto Dainelli in 1914. In the winter of 1924–25 the Chong Kumdun glacier formed a complete block across the Shyok and impounded a lake upstream of it; this lake was released in October 1926 with catastrophic effects. The following winter the dam reformed and impounded another lake; this was released on 15 August 1929. Again the glacier healed its wounds during the next winter to impound a third lake. This lake was discharged on 10 July 1932, after considerable percolation during the preceding day. Besides Dr. Longstaff's and Professor Dainelli's photographs we have about forty photographs taken in 1928, 1929, 1931, and 1932 by Messrs. Ludlow, Gunn, Captain Gregory, and Mr. Durgi. The receipt of these during the course of investigation combined with our previous knowledge of the glacier's behaviour enabled us to forecast the future with very considerable accuracy. There is no doubt in my mind that in 1909 the Chong Kumdun glacier was in a fairly advanced condition of degeneracy, and that in 1914 it was more so. This state is shown by the comparatively low surface of the glacier, by the hummocky, black appearance of the surface, and by the fact that the glacier failed to reach even the right bank of the Shyok at any point. Dr. Longstaff's and Professor Dainelli's photographs show the Kichik Kumdun very different from the Chong Kumdun. From both downstream and upstream the extremity shows a broad high wall of ice stretching across the river-bed, under which the Shyok river escaped by means of a tunnel. The surface was much broken up by pinnacles. We know that throughout the nineties of last century this glacier was well clear of the river and that it advanced to the river-bed in 1899, finally blocking the river in the winter of 1902–03 and causing a minor flood the following summer.

In 1925, when the Chong Kumdun glacier had advanced to block the Shyok, the Kichik Kumdun was found to be greatly degenerate, and offered no obstacle to movement. Mr. Ludlow's photographs of 1928 and 1929 show comparatively low, detached ice-pinnacles at the snout and long bands of surface moraine covering the greater part of the last 2 miles of the glacier surface, a very different state of affairs from that of 1909 or 1914. On the other hand the Chong Kumdun showed every sign of active rejuvenation, and not

[1] I must refer those interested in the evidence and description of these floods and the location of the blocks that caused them to my paper in the *Himalayan Journal*, vol. i, p. 13, where I have given references.

till I received the photographs of 1929 could I detect any sign of incipient degeneration. Degeneration on the Chung Kumdun is more marked in the photographs of 1931, though it is still in its early stages, and I believe that it is now sufficiently degenerate to cause no further anxiety for some time to come.

Before leaving these two glaciers I must call attention to the close similarity of the three floods in 1926, 1929, and 1932 to those of 1835, 1839, and 1842, both as regards date and nature. Though I realized the possible repetition of the early events in 1928 and called attention to this likelihood before the flood in 1929, I tried to keep my examination of the data free from any bias. I also had the records of river-levels at Attock searched for other evidences of floods, with most interesting results. In August 1879, and on 29 July 1882 the river at Attock showed abnormal rises above normal summer flood-level: 28·72 on the first occasion, 33·82 on the second. The height for the Shyok flood of August 1929 is 28·75. From 1873 to 1889 I can find no record of any traveller having used the valley route of the upper Shyok. It may of course be coincidence that these two flood rises of 1879 and 1882 are so similar to those of recent years, that they occurred at a period when the Shyok was probably blocked, and that this period is almost exactly halfway between the periods 1835–42 and 1926–32. On the other hand there does seem to be some justification for supposing that the Chong Kumdun for some reason advances and blocks the Shyok valley at periods approximately forty-five years apart and remains a danger for the next eight or nine years.

The Kichik Kumdun also seems to fluctuate in a similar manner, but at present we cannot indicate a regular interval between the advances with any certainty. We have some important evidence in 1869 and 1873, but it is not enough, even if we could be absolutely certain that the Kichik Kumdun is the glacier referred to. In July 1869 Mr. R. B. Shaw found that the glacier pressed up against the great cliffs on the left bank, while one of his guides had passed the snout by the river-bed in April. In 1873 Colonel Gordon and other members of the Forsyth Mission found "a perfect wall of ice rising from the water about 120 feet and showing a surface covered with countless pinnacles and points." I believe these both refer to the Kichik Kumdun and that some time between 1862 and 1869 the glacier advanced to the river-bed; in this case the interval between the two advances is about thirty-five years, and if it is to be repeated another advance is already due or overdue. It is therefore most important that the Kichik Kumdun should be visited next year.

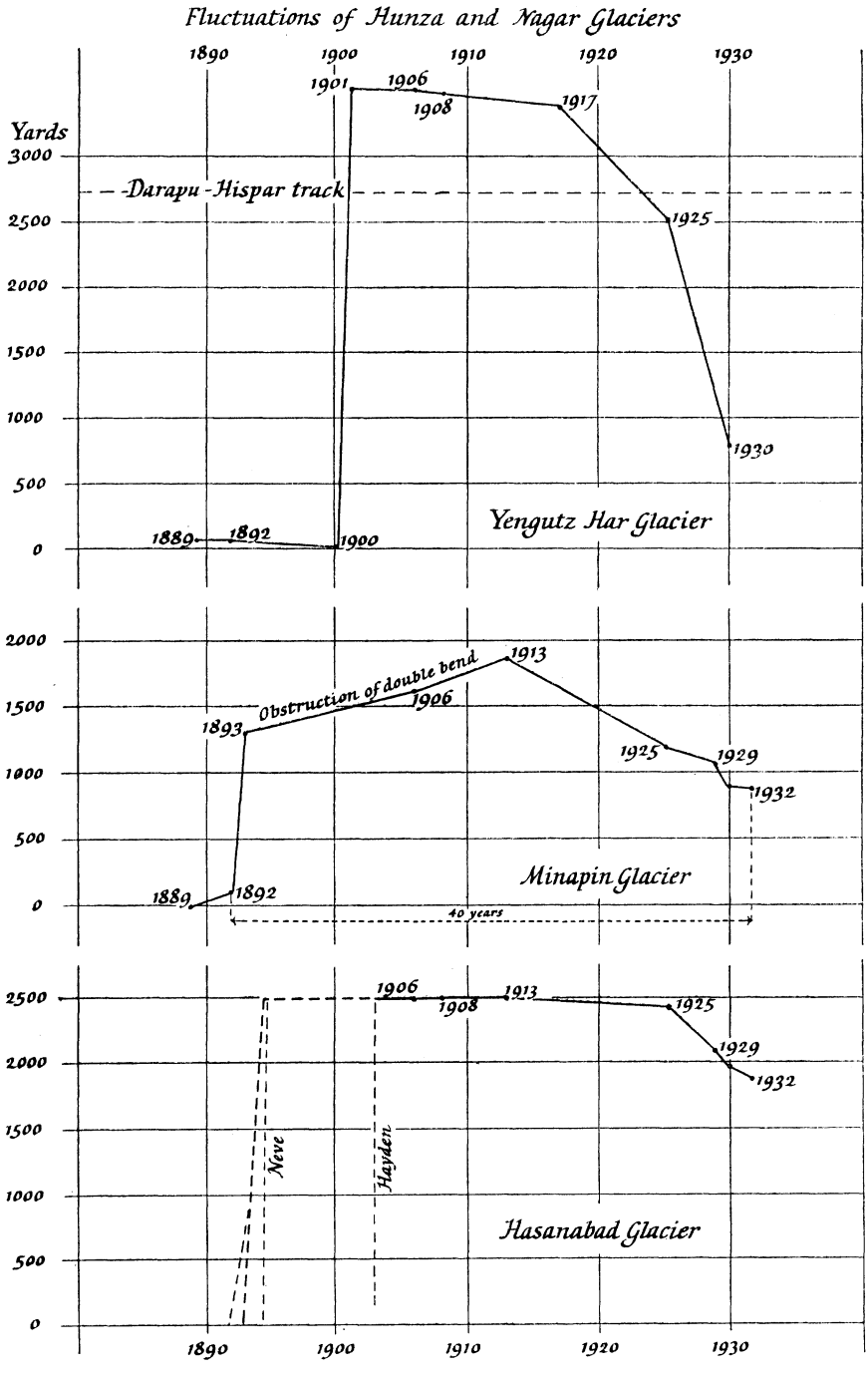
I should perhaps stress the fact that when the Chong Kumdun is advancing, its neighbour the Kichik Kumdun is degenerate and *vice versa*. The movements therefore must be, in my opinion, independent of local climatic causes, or at any rate, mainly due to properties possessed by each individual glacier. These two glaciers are in uninhabited regions, and no one has seen them actually moving forward. Slow movement forward between April and July has been recorded at the extremity of the Kichik Kumdun after both its advances, but it appears that the major part of the advance of the ice had already taken place and that the final movement was in the nature of settlement and spread of the snout.

The Hunza and Nagar glaciers

I am now going to discuss the movements of three most interesting glaciers in Hunza and Nagar, the Minapin, the Hasanabad, and the Yengutz Har. The Minapin glacier has been known to us for forty-five years, if we can believe the small reconnaissance map of Surveyor Ahmad Ali Khan dated August–September 1889. I see no reason why it should not be substantially correct. We then have Lord Conway's map of 1892 and Surveyor Khan Sahib Abdul Gaffar's in 1893. Hayden marked the position of the snout in 1906 and photographed it. I did the same in 1913, Visser in 1925, and officers of the Gilgit garrison, Mr. H. Todd and Captain Wooldridge, have visited it in 1929, 1930, and 1932.[1] The observations prior to 1906 must be accepted with reserve, but they seem to indicate either a slight advance or a position of stability between 1889 and 1892, when a rapid advance of about 1200 yards seems to have taken place. In 1906 the snout was apparently 300 yards in advance of its position of 1892, giving an annual average between 1893 and 1906 of 23 yards. Exact measurement in 1913 showed the snout a further 700 feet advanced since 1906, giving an annual average of about 33 yards. Unfortunately we do not know the year or position of its maximum advance. In 1925 the Vissers found it about 650 yards farther back than I marked it in 1913, in a position intermediate between its 1892 and its 1893 positions. Instead of the active end that I saw, the Vissers record "an insignificant narrow strip of ice, buried beneath rubbish" with the characteristic U-shaped trough valley deeply cut, with polished walls below the decrepit snout. In 1930 Todd recorded that the snout was still more attenuated and some 300 yards farther back from the position recorded by the Vissers; while Wooldridge in 1932 recorded still further degeneration, with the miserable tongue almost severed from the trunk still higher up. There are topographical features of its lower valley, particularly a great double bend with a protruding rock buttress, which may have checked the first rapid advance. But forty-two years have now passed since this glacier last began to come forward. It is of the utmost importance that it should be examined yearly now that it is so decadent.

The Hasanabad glacier is often quoted, though sometimes rather sceptically, as one which has advanced a great distance within a short time. There is no reason to doubt the rapidity, though the date is uncertain. In 1889 Ahmad Ali Khan showed the snout of this glacier about 6 miles back from the road crossing of the Hasanabad ravine. Lord Conway's map of 1892 shows the Hasanabad nala dotted, so presumably he did not survey it, though he shows the glacier about 8 miles from the crossing. Abdul Gaffar's plane-table shows the glacier in 1893 only 2 miles from the crossing. In 1895 Dr. Arthur Neve learned from native sources that the ice had advanced 2 miles that year and from 4 to 5 miles the preceding year. In 1906 Hayden was told that the glacier had advanced a distance variously estimated from 6 miles to a day's march in 1903. It is difficult to get at the truth, but some facts stand proved. All accounts, in 1895, 1906, and 1913, agree that advance was as much as about 6 miles in one winter and spring, that irrigation channels taking water from far up the glacier were thrown out of action by the advance, and that fields were left barren. I believe

[1] Details are given in the *Himalayan Journals*.


Fluctuations of Hunza and Nagar Glaciers
Yards
3000
2500
2000
1500
1000
500
0
1890
1900
1910
1920
1930
Darapu-Hispar track
1889
1892
1900
1901
1906
1908
1917
1925
1930
Yengutz Har Glacier
2000
1500
1000
500
0
1889
1892
1893
Obstruction of double bend
1906
1913
1925
1929
1932
40 years
Minapin Glacier
2500
2000
1500
1000
500
0
1906
1908
1913
1925
1929
1932
Neve
Hayden
Hasanabad Glacier
1890
1900
1910
1920
1930

Phot. Giotto Dainelli

1. Degenerate Chong Kumdun Glacier in 1914, showing free passage of river past snout and active condition of tributary glacier

Phot. Capt. C. E. C. Gregory

2. Chong Kumdun dam from above the lake, 15 July 1931; old lake levels in right foreground

3. Snout of the Juncal–Plomo Glacier, January 1910 (compare Plate 3 in Mr. King's paper, vol. 84, October 1934)

Phots. Dr. Reichert

4. Nevado del Plomo and Cerro I, January 1910 (compare Plate 1 in Mr. King's paper)

myself, though without definite proof, that the advance recorded by Hayden refers to the same advance recorded by Neve, and that it occurred in the winter of 1892–93, for the position marked by him is roughly 7 miles in advance of Lord Conway's position in 1892 and almost exactly 1 mile (1750 yards) from the position shown on Abdul Gaffar's map of 1893. In 1908 the Workmans reported no change from the 1906 position; and in 1913 my photograph, taken from the same spot marked by Hayden, showed no appreciable change. We know quite definitely that since that date the ice has very gradually degenerated and that the end is now about 600 yards farther back from its most advanced position. Forty-two years have passed since this glacier last started to advance. Is it a coincidence that it began its advance during the same year as the Minapin? If so, why was the Minapin's advance so protracted and that of the Hasanabad so sudden? And why has the Minapin become such a miserable specimen of a glacier while the Hasanabad is still far from miserable, though now deteriorating fast? It seems to me that only local topography can account for these differences of movement.

Of all the glaciers in this region perhaps the most exciting is the Yengutz Har. In 1889 a reconnaissance sketch by Ahmad Ali Khan showed the track between the villages Darapu and Hispar as crossing the gorge of the Yengutz over $1\frac{1}{2}$ miles north of the glacier snout. Three years later it was roughly at the same point, and Lord Conway, in 1892, wrote: "A deep nala . . . divides Darapu and Hispar. In its bowels some half a dozen mills find a footing. The path goes round by these and mounts to the fair fields of Hispar." In 1906 Hayden called attention to an advance: "Now the path," he wrote, "instead of descending, climbs arduously over a steep mass of black and slippery ice, the mills are gone, and their ruins hidden under the snout of the advancing glacier." The Vissers made no mention of this interesting glacier in 1925, but when I examined Khan Sahib Afraz Gul's survey made that year I noticed that the path was again shown as crossing the gorge some distance north of the snout. The glacier had therefore degenerated considerably. In November 1930 Captain Berkeley, of the Gilgit garrison, visited the glacier, whose snout he found after "an arduous climb of at least two miles" at about 13,000 feet, 2000 feet higher than its position in 1906. Berkeley recorded that the ice showed great deterioration and was difficult to identify, and he added these significant words: "Judging from the enormous amount of ice clinging to the almost perpendicular mountains which hem this glacier in, I should think that it is subject to frequent ice-avalanches." Is it possible that *frequent* is hardly the correct word, and that the surrounding mountains are preparing a bombardment of the valley below and so may create the conditions in the névé region for another onrush to the fair fields of Hispar? I think that there is every prospect of this and that the danger is not far distant, if it has not already occurred. As regards the rapidity of the last advance about 1903, I cannot resist quoting the circumstantial account of it given to Berkeley in 1930 by an old villager:

"The glacier was above where the present snout is. One day when the crops were about a hand's breadth high [*i.e.* May] we noticed that the water in the irrigation channels was very muddy and was coming down in greater quantity than usual. We went up the nullah to see what had happened and saw the

glacier advancing. It came down, like a snake, quite steadily: we could see it moving. There was no noise. At the same time water and mud gushed out from the ice while it was still advancing and flooded our polo ground and some fields. When an obstruction got in the way the ice went round it at first and then overwhelmed it. The ice was not clear, but contained earth and stones. All our mills and water-channels were destroyed. The ice continued to move for eight days and eight nights and came to a stop about forty yards from the Hispar river. As soon as the ice stopped, the mud and water, which had been coming out higher up, stopped too. The ice remained down for fifteen years, during which time one man to each house remained in the village. All our cultivation was spoilt and we could not bring another water-channel to our fields while the glacier was below them. The Mir fed us. Twelve years ago [1918] the ice began to go back. Each day a length of about fifteen yards would break off from the main ice and was washed away by the water. And once again water commenced to flow out of the glacier above the village, and we were able to make another water-channel. The ice continued to go back until about three years ago [1927] when it stopped where it is now."

Fantastic as it may seem, I believe that this report is substantially true, allowing for a certain descriptive licence natural to a completely uneducated villager speaking from memory. Hayden was there in 1906 and recorded the recent advance. He noted the desolation and hazarded a guess that the advance had occurred in 1901. After twenty-seven years or more a villager gives the date of the occurrence as 1903. I believe also that the rapidity of advance is also substantially correct, though perhaps not all the picturesque details. If so, this glacier must have come forward something in the nature of 3 miles in eight days, and I believe that nothing will stop it from doing the same again. There are many stories of rapid advance of glaciers in the Himalaya, where the snouts come down low enough to reach ground that is inhabited all the year round, as is the case with these glaciers in Hunza. The Minapin and the Hasanabad snouts, when advanced, descend as low as 7050 and 7290 feet respectively. One need not credit all the lurid details, such as those given of the Garumbar, which is said to have overwhelmed two old ladies fleeing before it; but I am convinced that there is plenty of evidence in support of extremely rapid advance where local topography permits it, and I believe that such rapid advance generally occurs during the late winter or early spring, owing to the accumulation of unstable ice unfettered by ablation during the preceding months, and to the rise in temperature assisting melting along shear planes roughly parallel to the bed.

These three glaciers are not dangerous to the inhabitants farther down the great valleys they serve, as is the Shyok, because even during their most extended advance they do not reach the main valleys, but the study of them can throw considerable light on the sudden movements of glaciers that are dangerous.

The Karambar glacier

I am only going to mention one other of these threatening glaciers, and that briefly. This is the Karambar glacier of the Ashkuman district in the Gilgit Agency. The details are not very certain because there are apparently two

glaciers that may project into the valley and the names used by travellers are not consistent. It is however significant that the native name of the one that causes most of the trouble is *Chhatiboi*, which, in Khowar, means *There will be a lake*. Colonel Lewis records that in Chitral there is another glacier also called *Chhatiboi*, and that this also blocks the valley below it. We owe our first information regarding blocks in the Ashkuman district to Drew. Hayward also stated that this region was the source of flood trouble, while records kept at Gilgit since the establishment of the Agency locate the origin of certain floods in the Ashkuman valley. My later information is from Mr. Todd, the late Political Agent at Gilgit, and from Dr. Longstaff, who was up the valley in 1916. Recent block dates for this valley are probably 1891–92, 1904–05, and 1929–30, giving intervals of approximately thirteen and twenty-five years. Dr. Longstaff supplied the information that he found the Karambar at its maximum advance in 1916 also. Taking into account a flood attributed by Drew to this same cause in 1865 and Dr. Longstaff's observations, we get intervals of 26, 13, 12, 13. It is, I am afraid, too much to hope for any evidence for the years about 1878, since the British Agency was not established at that date. But how comforting it would be to know that there was also a block in that year, so that we could establish the intervals 13, 13, 13, 12, 13!

I have drawn the following conclusions from a study of these and other glaciers: (1) Substantial advance follows an interval of considerable degeneration. (2) The rate of advance is governed by topography and not by climate. Advance is likely to be very rapid and long in steep, narrow, smooth-walled valleys, but the rate may be quickly checked by obstructions, and advance may then proceed more slowly. (3) After advance, the ice takes some time to settle, and if unenclosed the extremity of the glacier tends to spread. Glaciers tributary to a main valley, which have advanced across the main valley, as in the upper Shyok, therefore retain some forward activity for a considerable time, possibly for a few years, before they begin to deteriorate. This property accounts for the winter healing after an initial block and flood, and for subsequent blocks and floods. (4) The time taken up by deterioration or degeneration of the snout (ill-named "retreat of the snout") is considerably longer than that of the advance. (5) The interval between successive advances varies with each glacier; the date of advance varies with each glacier. Advance therefore cannot be due to climatic or weather cycles, and must, it seems, be due to local topographical factors. (6) There is some probability of fairly regular intervals between successive advances of the same glacier, but further evidence is necessary before any such regularity is proved. It seems however that a glacier which has once made a rapid advance is extremely likely to repeat the performance after some interval of time.

Can we yet say what is the reason of these advances? Perhaps we have not yet enough evidence. My own conclusions, arrived at gradually during this investigation, are that on certain glaciers the accumulation of ice in the feeding area is augmented in some way, either by ice-avalanches, or by the rapid advance of tributary glaciers, or maybe merely by annual snowfall, to an extent greater than can be carried away by the normal flow of the main ice-stream. It may be that the accumulation is quite slow and that during

the period of degeneration, the flow becomes obstructed, possibly by the accumulation of englacial moraine or for some other reason. Eventually the accumulation of obstructed ice becomes irresistible and it overcomes the obstruction. From the appearance of degenerate tongues it seems that the massed ice-pinnacles that are present on certain glaciers are features of glaciers that have recently advanced; it is impossible to believe that the great pinnacles of the Karakoram glaciers move forward with any great rapidity and maintain their equilibrium while doing so. My own belief is that they are formed soon after advance has taken place. The shear planes shown in the pinnacles themselves, probably caused during the advance, can be traced in adjacent pinnacles. On this point however further research is most necessary. From a study of the photographs of the upper Shyok glacier pinnacles, it seems to me that they grow in apparent size during the first years after advance, mainly through the melting of the glacier surface between them. Near the extremity of the glacier these pinnacles gradually range themselves in line with the crevasses; farther up the glacier they tend to align themselves with the direction of the ice-flow. I have measured some of the pinnacles on the Kyagar glacier and found them as much as 300 feet above the moraine surface. In the later stages of degeneration the pinnacles also lose height by evaporation and radiation from the increasing surface of exposed moraine, till they become detached at the snout or disappear on the body of the glacier. Examination of the height, alignment, and condition of the pinnacles therefore gives us an indication of the state of degeneration of the glacier.

The Nevado Glacier

It is most interesting to compare the Karakoram movements with those that have recently taken place in the Rio Plomo in the Andes. I do not think that Mr. King (*Geogr. J.*, vol. 84, p. 321) is correct in describing the advance of the Nevado glacier as due to an avalanche, certainly not in the accepted meaning of the word. The Nevado block bears an extraordinary resemblance to those of the Chong Kumdun and the Kichik Kumdun; and there is every reason why it should. The Nevado glacier is in latitude 33° S., the Chong Kumdun in 35° N. The aspects, bed-slopes, and local topography are not dissimilar, and the rugged, pinnacled surface of the extended Nevado bears a striking likeness to the Chong Kumdun block, though on a smaller scale. We do not know the date of the Nevado advance. Mr. King states that the last movement was probably in October 1933, in the southern spring. It burst in January 1934, the month in the southern hemisphere that corresponds with July in the northern, when ablation is severe. With the Chong Kumdun the interval between advance and flood is two or three years, possibly owing to the greater scale of the topography. But there is another point of similarity that is interesting. The Juncal and the Plomo glaciers have deteriorated considerably from their positions of 1909–11, just as the Aktash and Kichik Kumdun have done, while the Nevado has advanced similarly to the Chong Kumdun. The comparison must not be pushed too far however, for local factors of topography must influence the movements.

[*Professor Mason here gave a brief account of Dr. Helbling's views on the Rio*

Plomo ice-dam, a more extended summary of which by Mr. K. A. Goudge is printed immediately after the present paper.]

The whole of Dr. Helbling's report is of very great interest, and accords generally with what must happen in similar advances in the Karakoram. I do not believe myself that tributary glaciers entering below the neve line affect the movement. I do not think that dead ice-covers stranded on the grey trunk of a Karakoram glacier slide forward and cause blocks. But I agree most certainly that the movement starts in the uppermost névé; that after the creation of crevasses in an overloaded névé, "cover-ice" is formed to relieve the obstructed flow; and that this begins the movement by sliding. I feel convinced that Dr. Helbling is correct in stating that in the later stages, when the advancing ice has passed the degenerate snout, the movement is one of successive ice waves moving forward on successive shear planes roughly parallel to the bed; and that this was the movement so graphically described by the old villager of Hispar.

The question is often asked: What can be done to mitigate the effects of such catastrophes? "As regards the removal of the obstacle (when such an accident may occur again) by our scientific efforts," wrote Major Becher in India, as long ago as 1 July 1859, "I think it is impracticable: the labour of removing such vast masses of mountains or of glaciers would be immense." Nor do I believe that it would be effective with such large blocks as we encounter in the Karakoram, owing to the time taken for the fallen ice to settle. It does not seem practicable to me to keep open a channel through nearly 2 miles of ice by explosives even when there is no water held up. A by-pass tunnel would certainly not be justified financially in the Karakoram, and either a by-pass or a syphon would be extremely difficult to keep clear of obstruction.

In the Karakoram during the Chong Kumdun danger the Government placed watchers and beacons to signal to the nearest telegraph line, and there has been very little loss of life. No bridges of vital importance have been destroyed, though the destruction of minor ones has caused inconvenience. The Pertab Pul, near Gilgit, and the great railway bridge at Attock have stood the floods so far, and provided there is no abnormal flood independent of the Shyok bursts, they should be safe in the future; but once an important bridge or railway is destroyed by such a flood, I would certainly consider it most unwise to site a new work in the same spot.

What might be done, and should be done, is the yearly examination of all glaciers that are known to belong to the threatening group, so that the matter may be removed once and for all from the realm of speculation. In the Karakoram within the next few years I believe that we should be able to learn a great deal from the movements of all those glaciers which I have discussed, particularly the Yengutz Har, the Minapin, and the Kichik Kumdun. Fortunately the officers of the Gilgit garrison are keenly interested in the investigation and have during recent years been watching those that lie in that Agency.

DISCUSSION

Before the paper the PRESIDENT (Major-General Sir PERCY COX) said: The paper this afternoon is entitled "The Study of Threatening Glaciers." The movement of glaciers is a problem which has had a great deal of attention directed to it of late years, and it is one which exists wherever there are mountain ranges. In our own sphere we are most familiar with the Himalayan glacier which it will be remembered gave such trouble on the Shyok river and resulted in the bursting of a dam. These cataclysmic occurrences naturally give scientists food for thought, and Professor Mason, who as you know is a member of our Council and Professor of Geography at Oxford, is going to put before us the problem from his point of view. We have other Fellows and guests with us who can speak of particular regions, and they will give us the benefit of their comment in due course. I now call upon Professor Mason.

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

The PRESIDENT: The lecturer mentioned Mr. Goudge, who was associated with the Argentine Transandine Railway. His father is the Chairman of Directors of that Company and Mr. Goudge has personal knowledge of glacial effects in the region which we have seen depicted on the screen. I call upon him to address us.

Mr. K. GOUDGE: I have no personal knowledge of the actual glaciers, having been through the Andes only by rail, but I have studied Dr. Helbling's report. It is an interesting fact that the Nevado glacier after the movement almost exactly covered the old moraine. That is very suggestive, I think, of the catastrophe having occurred before. I am told that no comparable flood has occurred for the last fifty years at least, so that if there was another period it was probably longer ago than that, and that is probably all that one can say. It is interesting to note that conditions in the Andes in these latitudes seem to be very similar to those in the Karakoram, judging by the photographs: the same scree slopes, the same barrenness, and also the same pinnacles on the glaciers. It would be interesting to know if pinnacles form on all snow or ice in the Karakoram that lasts into the summer, as they do in the Andes.

I think there is possibility of another similarly situated glacier in the Aconcagua region, the lower Horcones glacier, causing some slight trouble, but I am glad to say that it could not hold up much water. This glacier snout appears to have advanced perhaps half a mile nearer the river between 1895 and 1924 according to photographs. But I think tourists go up there every summer; consequently there would be plenty of warning if anything were to happen. What we want to know most of all is whether a catastrophe in the Nevado region is likely to happen again and, if so, roughly when; is the glacier going to heal its own wounds? has it already done so, perhaps? and is it going to form another lake, only to let it burst again?

The PRESIDENT: I was hoping that Dr. Lauge Koch would have been with us this afternoon, but he is not able to come. Dr. Longstaff, will you come and offer some comments?

Dr. T. G. LONGSTAFF: I believe that Professor Mason's paper is a valuable contribution to glaciology. Had he wished to be controversial rather than constructive he could have drawn attention to several theories which have been advanced without any observational evidence to support them.

The secular sequence of glacial and interglacial episodes, or epochs, if you prefer it, is one of slow and gradual change. There are probably also climatic cycles of shorter period of which we know nothing at present. But the mere fact that these catastrophic outbursts of energy are out of phase with one another,

and only affect certain glaciers, indicates that the cause must be some inherent peculiarity of these particular glaciers.

I visited the Kumdun[1] glaciers in 1909 and the Karambar[2] group in the course of duty in 1916. I have more acquaintance with glaciers than with the literature of glaciology, and this theory put forward by Professor Mason of overthrusting by the surface ice, as against the more orthodox idea of solid advance *en masse* of the whole glacier, is new to me. Dr. Helbling I remember with pleasure in the Caucasus in 1903, with Rickmers: he is a man with great experience of Alpine regions in various parts of the world. Apparently he has advanced this theory. Professor Mason has come to practically the same conclusion, I understand almost independently, but, as I have said, it is new to me except in so far as Slater,[3] my companion in Spitsbergen in 1921, suggested something of the sort; but I am in a position to add a grain of evidence to the views advanced by Professor Mason.

In 1931 I visited the inland ice of Greenland—that is to say the main continuous 1300-mile ice-cap—camping at de Quervainshavn, north of Jakobshavn on the west coast, where access to the ice is easiest. My daughter and I gave up a day to visiting the Ekip glacier, a little north of our base camp. That glacier was very actively calving quantities of unusually small lumps of ice into the sea, making approach to the snout of the glacier by boat impossible, so that we could only get on to it by a walk of a mile or so inland. Here I expected to find easy ice conditions. Instead, the whole surface was broken up and toppling over in a way I had never seen anywhere before. There was neither regular crevassing nor the ridging usual in the lower part of such a glacier. In short, the surface conditions were so dangerous that we had to clear out.

I could not understand what I saw. On reading Professor Mason's paper last week it was borne in upon me that the top layers of the glacier ice were, in fact, sliding over the lower layers; that the upper fast-moving layer, becoming relatively thin, could not hold together but was literally crumpling as it moved. I think Professor Mason's is the only possible explanation—and I am glad to have had it—for phenomena of which I have never previously understood the cause.

Professor Mason's suggestion that snow or ice avalanches falling on the *firnfield* may be one cause of these icefloods may sound rather heretical to some; but mountaineers are familiar with relatively small detached hanging glaciers that would fill the part. I allude, for example, to the well-known "ice-wall" on the north ridge of the Mönch, which for the latter half of last century was almost unscaleable, but which gradually became lower and lower as the ice-bulge which formed it sagged down the mountain side. Another example could be given on the east face of the North Col of Everest. Such masses of ice which periodically, either quickly or slowly, join their main glacier must upset the balance of normal flow and, given the right topographical factors, could easily be a cause of these icefloods, as Professor Mason suggests. But I would by no means rule out the probability that in some cases a secondary lateral glacier, formerly ending short of the main glacier, but for some accidental reason of its topography periodically liable to sudden advances, by suddenly joining its main valley-glacier might produce in the main ice-stream such phenomena as we are discussing.

I agree that the evidence points to these advances being very rapid and to subsequent degeneration and retreat very much slower in phase. The actual

[1] *Geogr. J.*, June 1910, vol. 35, p. 647.
[2] *Alpine Journal*, Nov. 1920, vol. 33, p. 159.
[3] *J. of Geology*, May, June, 1925, vol. 33, pp. 438, 444.

formation of ice pinnacles I look on as due to meteorological conditions, owing to the very limited localities in which they occur in the typical form—always in a dry and relatively cloudless region. I think that the lecturer has demonstrated that these recurrent catastrophic advances—or icefloods, as I would prefer to call them—cannot be due to climatic or secular change, and must be due to topographical peculiarities.

May I stress the point that the mere observing of the position of the snouts of glaciers is of little value unless the thickness of the ice is also measured? Further, that our knowledge of the real topography of any glacier is very incomplete until we know something of the depth of the ice over all parts of it. In fact, our present knowledge of glaciers and their mechanics is still extremely fragmentary.

Another point: seldom, if ever, do mountaineers meet with crevasses that penetrate the whole depth of a glacier. I believe that it will be found that the rate of movement of glacier ice is normally greater on the surface than at deeper levels. This is to say, that the overthrusting postulated by Professor Mason to account for the abnormally rapid movements with which he is dealing to-night may be only an exaggerated form of a normal process which becomes catastrophic owing to topographical peculiarities in some glaciers.

The PRESIDENT: Mr. Pilditch is the Resident Engineer of the upper section of the Transandine Railway, the particular section which the glacier conditions affect. I will call upon him.

Mr. E. PILDITCH: I fear that I am somewhat of an interloper here this afternoon, not being a glaciologist, but merely a civil engineer, whose duties necessitated my being connected at first hand with the recent flood catastrophe in the Andes mountains. Consequently I am here now more with a view of obtaining information on this class of phenomenon than of propounding theories. As oon as I heard of the catastrophe I was anxious to discover not only the extent of the material damage caused, but also the real cause of the flood. Early reports mentioned loss of life, destruction of villages, of the Argentine Transandine Railway, of the Mendoza electrical power station, irrigation works, etc. These reports eventually proved to be, unfortunately, not greatly exaggerated.

The "Panagra" Air Line immediately placed at the disposal of the Argentine Government authorities a powerful aeroplane, and I was fortunate in receiving an invitation to accompany the Government engineers on an aerial reconnaissance to discover and establish the cause of such disastrous floods; an ice-dam of sorts was suspected, as large blocks of ice had been seen coming down on the flood waters. Owing to the height to which the machine had to climb, about 23,000 feet, very little could be seen of the damage incurred; but after about an hour's scouting round the glacial region at the headwaters of the Mendoza River, the cause of the trouble was located, viz. an ice-dam across one of the rivers of the Plomo valley. A few aerial photographs of this obstruction were successfully obtained. Then a more detailed study of the ice-dam was carried out by King and Yorke Eliot[1] who, being shown its approximate position on the map, were able to reach it, after a somewhat hazardous journey overland. Owing to the inaccessibility of the emptied lake basin, they were unable to descend into it, to examine the ground for traces of previous flood levels; the ice-dam was about 250 feet high, and the mountain sides of the basin precipitous.

What interests me now, of course, as being of first importance to the Transandine Railway, is whether a similar flood is likely to recur in the near future. This railway, which is the only direct line uniting the capitals of Argentina and Chile, is built over the greater part of its extension along the gorge of the Mendoza

[1] W. D. V. O. King, "The Mendoza River Flood of 10–11 January 1934—Argentina," *Geogr. J.*, vol. 84, p. 321.

River. That part of the line which was recently destroyed was constructed between forty and fifty years ago upon the banks of the river, mostly on rock screes, low terraces, and sand-flats; it crossed the main river in ten places with heavy bridges; seven of these crossings have been completely swept away.

Professor Mason has interested me extremely in the question of periodicity of the floods caused by ice-dams in the upper Shyok valley, where there appears to be an almost definitely proved interval of time between the major glacial movements in the different valleys. Unfortunately, in the case of the Plomo valleys, no such records have been made, but it would appear that the periodicity of abnormal floods is certainly not so short as those recorded in the Upper Shyok. Had a similar flood occurred, say, within the last century or so, then those screes, terraces, and sand-flats would not have existed to the same extent when the line was built on them. From their depth, extension, and the vegetation growing on them it is quite obvious, even to a layman, that their accumulation must have extended over a period of many centuries. This recent flood, which was discharging at the rate of some 3000 cubic metres per second for about six hours, simply purged the valley of all these screes and sedimentary deposits, leaving the cliffs at the side rising sheer out of the river-bed, to a height in some places of over 200 feet. As the glacier field in which this ice-dam is situated lies in a remote region rarely visited, nothing whatever is known of any major ice movements which must have taken place there in past years.

It is interesting to note that in October 1933, *i.e.* during the spring, a week of the hottest weather ever recorded for that month was experienced, the maximum sun temperature reaching 16° C. above normal. When King and Yorke Eliot visited the ice-dam in February 1934, the disintegration of its surface and the height of the névés were sufficient evidence to prove that the ice-dam had already been in existence for about three months. From this it may be inferred that its final movement took place in October or November. This leads me to believe very strongly that during the October heat wave, water must have percolated through the crevasses in the "white" ice, which overlies the "black" ice, and acted, as it were, as a lubricant between these two distinct layers, thereby lessening their frictional adhesion, and upsetting the equilibrium of the "white" ice, which must have slipped with considerable rapidity into the lower valley. Whether a discharge tunnel was formed under the ice-dam, when the latter became stationary, or whether water storage commenced as soon as it had reached the opposite side of the valley, is a matter for conjecture. Personally, I am inclined to favour the former possibility, and consider that storage commenced only when the roof of the tunnel fell in, as shown in the aerial photographs. I even go further and suggest that ice-dams have occurred at this identical spot at fairly regular intervals, like those in the Upper Shyok; but have not, until the present instance, succeeded in entirely blocking the river-flow for many centuries.

And so, Mr. President and Professor Mason, I came to this meeting thirsting for such information as may help us to decide our engineering problems on the Transandine Railway; and, after what I have just heard from such expert glaciologists, I have learnt much that will be of great use to us.

Dr. K. S. SANDFORD: Professor Mason's paper has made two things abundantly clear: first, we realize that glaciers in intertropical mountains are capable of movements that we have never seen nor suspected in temperate and polar lands; secondly, it is of paramount importance that such abnormal glaciers as Professor Mason has described should be studied and judged by their own standards, not with preconceived ideas learned in the Alps. Annual observation, measurement, and photography from fixed points are the most pressing needs. The officers

of the Gilgit garrison have made a serious start in this work, and it is to be hoped that every facility will be given them to carry out annually a more detailed programme of recording. The next stage must be detailed research with the most modern methods and equipment. A special set of instruments for serious measurements of precipitation, ablation, evaporation, radiation is being rapidly evolved in this country and in Scandinavia at the present time. In another five years we shall be in a far better position to take the pulse of collecting ground and glacier than we are at the present day.

The paper has also rubbed in what many of us already know but have not said, namely that in a given field the majority of glacier snouts may be stationary but some may be advancing and some retreating. There is no short period oscillation that we can yet claim to have established, and I doubt if such exists. If the majority of the snouts of a given field are stationary over a period of years, it suggests to my mind that the net amount of ice passed to the glaciers from the collecting ground is regular, within certain limits. If this is so the rapidly advancing glaciers surely owe their advance to peculiarities in the topography of their beds or collecting ground. We may admit that avalanches may be more abundant in some years than in others, but I doubt if such accidents are responsible for threatening glaciers. The regularity of the extreme advances after marked retreats suggests that there is an accumulative instability, *i.e.* snow or ice masses approach the angle of repose slowly; during these years there is a reduced flow of ice, but once the critical angle is exceeded the stored-up surplus is released. I have in mind in this matter the angle of repose of a glacier, *i.e.* the failure of gravity to induce flow until a certain surplus is achieved.

These advances are known in most parts of the world, and I may recall Tyrrell's and Wordie's notes on the Gregory glacier in Barents Island, which at some time between 1901 and 1920 advanced 2 miles and buried the Anderson Islands on which hunters used to winter. In this case the collecting ground is flat, avalanches are impossible, and the majority of the glaciers of the region have retreated or held their own in the interval. Certain other glaciers have indeed advanced in harmony with the Gregory glacier, but the Chinese walls reported by Garwood and Gregory have disappeared. One feels that a study of the topography would explain the continued advance during these years. In the interval precipitation, as far as we know, has not increased, rather the reverse. Most of the glaciers of Spitsbergen passed through a phase of activity and advance thirty years or more ago, and since 1900 their snouts have been stationary or recessive.

We might also recall the Lillehöök glacier in Western Spitsbergen. Adolf Hoel measured its rate of movement and found that between 1909 and 1912 the rate fell by 40–50 per cent.; the snout retreated. In high latitudes, maybe, a certain angle of bed allows the glacier to advance under its own momentum rather than by the excess of "push" from the collecting ground. The deep saucer-shaped depressions at their heads may thus be explained. If now we carry our minds to mountain valleys with varied and locally severe slopes we can realize that glaciers may advance when there is no apparent reason for them to do so. If moreover we add the vast body of melt-water available at certain seasons in intertropical mountains, we can appreciate that the repose of a mass of ice may suddenly be destroyed by the addition of unlimited lubricant, and the mass may move like a ship from well-greased stocks. If, above all, the shear-planes in the mass of the ice are similarly lubricated one can imagine that the results may be far reaching.

To my mind it seems especially significant that the flow of mud and water from the Yengutz Har ceased when the rapid advance of the glacier came to an

end. I cannot help feeling that accumulation till a critical angle is reached, plus lubrication by water on a scale that we do not appreciate in temperate and polar lands, form essential parts of the mechanism that Professor Mason has described so vividly. I am prepared to believe that some of the extraordinary movements may affect the collecting ground comparatively little, and that the deficiency may be most felt in the higher reaches of the glacier. We should not lose sight of the observation that the dates of rapid advance vary with the glaciers, and that each glacier may have its own period, while the field as a whole may show no change.

The PRESIDENT: Having regard to the hour, I think we must close the discussion now. It must be obvious to all who have listened to the very interesting paper that the problem discussed is one of vital importance. There are, it seems to me, so many ramifications of it that there is endless room for scientific investigation. Speaking as an ignoramus it seems to me that not only may the cause be climatic in one case and topographic in another, but that both influences may well be acting on the same glacier, and on the other hand that every or any glacier may be moving or behaving from quite different causes from its neighbour a few miles away. I have not the knowledge on which to discuss this vital question more than superficially, so I can only ask you now to join with me in thanking Professor Mason for his paper, and the other speakers, Mr. Goudge, Mr. Pilditch, Dr. Longstaff—whose remarks were particularly interesting—and Dr. Sandford, for kindly joining in the discussion.

THE ORIGIN OF THE RIO PLOMO ICE-DAM

DR. ROBERT HELBLING

The material secured by Messrs. King and Yorke Eliot (see the Geographical Journal for October 1934, *vol.* 84, *p.* 321), *at the Rio Plomo ice-dam which caused the disastrous flood, was submitted by the Argentine Transandine Railway Company to Dr. Robert Helbling, of Flums, who had explored and surveyed this region with Dr. Reichert in the years* 1908–12. *Dr. Helbling has made a report on the subject and the following is a summary by Mr. K. A. Goudge, of the part of the report dealing with the ice movement which caused the dam. Dr. Helbling's full report, in German and English, the photographic material* (73 *plates*), *and his maps have been deposited for the time being in the Map Room of the Society.*

IN these regions the presence or absence of glaciers is determined by the exposure. The prevailing winds are westerly and very strong. Snow accumulates on slopes sheltered from the wind, usually slopes facing east, whilst snow on slopes facing west is blown off and carried to more sheltered spots (see Plate 3). The influence of the sun is also great: compare the ice- and snow-covered north-east flank of the Nevado del Plomo with the adjoining face of the Cerro I (see Plate 4). The tributary glaciers overlie the main glacier when they reach it, and do not unite with it till far below the junction. Two glaciers are not lying side by side, but one upon the other.

In the melting region, streams of clear or white névé-ice, which come from the névé regions or from the tributary glaciers, overlie the grey glacier ice.