Vol. 33 No. 8 SCIENCE IN CHINA (Series B) August 1990

THE RESEARCHES OF GLACIER LAKE OUTBURST FLOODS OF THE YARKANT RIVER IN XINJIANG*

ZHANG XIANG-SONG (张祥松), LI NIAN-JIE (李念杰),

(Lanzhou Institute of Glaciology & Geocryology, Academia Sinica, Lanzhou 730000, *PRC)*

YOU XI-YAO (由希尧) AND WANG WAN-XIANG (王万祥)

(General Hydrologic Station, Water Conservancy Bureau, Xinjiang Uygur Autonomous Region, PRC)

Received May 11, 1989.

ABSTRACT

The Jokulhlaup of the Yarkant River (Yarkant He) is usually caused by the sudden discharge of the glacier-dammed lake and the mode of the discharge is the rapid expansion of the subglacial channel. Keyajir (Kyagar) Glacier and Telamukanli Glacier are on the upper reaches of the Keleqin (Shaksgam) River, the chief birthplaces of this kind of flood. Up to the end of this century, since the global climate has become warmer, the glaciers have accordingly shrunk and become thinner, with the result that the size and dimensions of the glacier-dammed lakes and their outburst floods have diminished. All these simply reveal the mystery of the Jokulhlaups of the Yarkant River in Xinjiang.

Keywords: Yarkant River, glacier lake outburst flood, variation of glacier advance and retreat, dewatering way of glacier lake.

In scientific and technical documents, glacier lake outburst flood is usually called Jokulhlaup. It is also called GLOF which is the abbreviated form for Glacier Lake Outburst Flood. Since GLOF has caused disasters in such countries as Iceland, Peru, Switzerland, Canada, Russia, the United States and Nepal, this problem has drawn widespread attention in these countries.

Glacier lake outburst floods of the Yarkant River in Xinjiang and Xizang region are so dangerous, disastrous and happens so often that only the Alaskan region of USA in the world can be compared with it. This paper discusses the cause of the glacier flood in the Yarkant River. the prediction of its development and other related problems.

* This article is one of the research results of the scientific fund subjects of the Chinese Natural Science. Zhang Xiang-song did the actual writing. In addition to the four of us, those who participated in the field work of scientific investigation and offered the research data are: Wang Yan-long, Wang Wen-ti, Feng Qing-hua, Ma Qiu-hua, He Yang-qing, Ding Liang-fu, Yu Xin-zhi, Liu Zheng, You Gen-xiang, Shi Wei-ling and Liu Jing-shi (Lanzhou Institute of Glaciology & Geocryology, Academia Sinica); Zhou Yu-chao, He Wen-qin, Gong Fang-run, Zhang Shu-ming, Kai Se-er (Xinjiang Water Conservancy Bureau); Wang Zhi-chao, Cheng Ya-ning and Cheng Xi-fei (Xinjiang Institute of Geography, Academia Sinica); Li Jiang-feng, Ma Li (Xinjiang Meteorology Bureau); etc.

I. The Analysis of Flood Disaster and Its Characteristics

The Yarkant River in South Xinjiang mainly originates from the north side of Karakorum Mountains and the south of the Tarim Basin. The Yarkant River is the largest in the Kashi (Kashgar) region, South Xinjiang. The river supplies plenty of water and the annual normal runoff amount is 63.75×10^8 m^3. For many years the average runoff volume at the Kachun Hydrometric Station (1420 m a.s.l.) at the outlet of the lower reaches of the Yarkant River is 202 m^3/s and the runoff depth is 132.6 mm (Fig. 1).

Since the establishment of the Kachun Hydrometric Station in 1953, fifteen Jokulhlaups have happened to the Yarkant River during 1953—1987. Fig. 2 shows the times of these Jokulhlaups and their flood peak discharge.

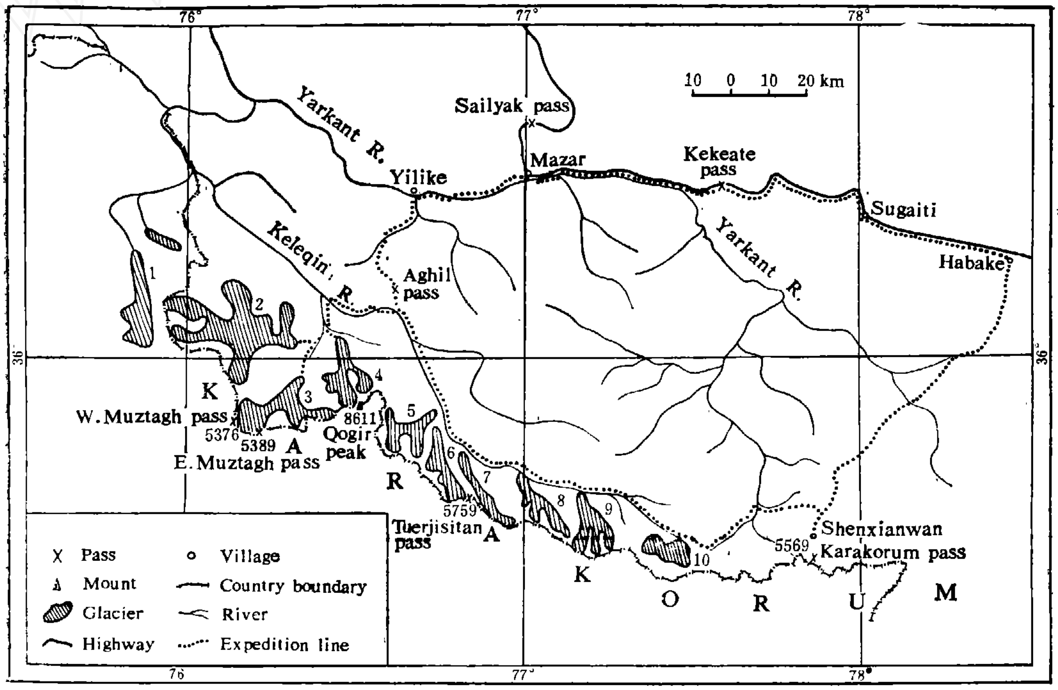


Fig. 1. The distribution of the big glaciers in the Keleqin River on the northern slope of the Karakorum Mountains.

1, Braldu Glacier; 2, Insukati Glacier; 3, Sarplaoggo Glacier; 4, Qogir Glacier; 5, Jiaxuebulumu Glacier; 6, Wurduoke Glacier; 7, Sitanger Glacier; 8, Telamukanli Glacier; 9, Keyajir Glacier; 10, South Victory Pass Glacier.

From 4 o'clock on 4 Sept. to 3 o'clock on 5 Sept., 1961, the discharge increased very rapidly and steeply from the initial 806 to 6270 m^3/s within the short 20 min at the Kachun Hydrometric Station (see Fig. 3). This kind of Jokulhlaup has the following characteristics: rapid flood rising, giant flood rise rate, high flood peak, small flood volume, short flood duration, hydrograph in shape of sharp, thin, single peak, main occurrence in the later period of flood season and great danger. It is quite different from ice-snow melt flood and storm flood either in the meteo-

Table 1
Comparison of Characteristics of Flood With Different Causes

Types of Causes / Characteristics	Glacier Lake Outburst Flood	Ice-Snow Melt Flood	Storm Flood
Associated with meteorological condition	Incessant hot and fine weather helps the glacial lake suddenly discharge its water.	In summer incessant hot weather causes ice and snow to melt violently. The discharge evidently decreases during precipitation.	Short and violent downpour of rain
Hydrograph features	Flat at the beginning of flood rising, then up to its peak very sharply. After flood peak, it declines steeply. Instantaneous hydrograph is entirely the same with the daily flow hydrograph.	Discharge has the obvious regular daily change. Each day the time of the occurrence of the maximum and the minimum does not change. With the rising of air temperature the discharge increases too. Rising and dropping change slowly. Hydrograph shows a fat shape. The duration is long.	Time and intensity of the occurrence correspond to that of storm, with a sharp flood peak. It takes the same length of time for flood to rise and subside. Sudden occurrence is followed by rapid ending.
Relation between flood peak discharge and the flood volume	Flood peak discharge is immense, yet the flood volume is not necessarily large.	Flood peak discharge is smaller than the amount of GLOF, yet flood volume is larger than the amount of GLOF.	There is big difference in the relationship between flood peak discharge and flood volume, because it depends on whether the land surface is frozen and because the location, intensity and durion of storm are different. It has the characteristics of both GLOF and ice-snow melting flood.
Time of flood occurrence	It mainly happens in late summer and early autumn, non-regional, main occurrence in later period of flood season.	In hot summer ice and snow melt violently, showing obvious regional features.	Mainly in summer and autumn, within the small- and medium-sized region.

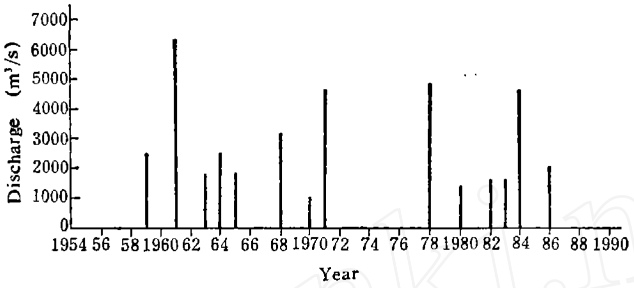


Fig. 2. Flood peak discharge and occurring date of GLOF in the Yarkant River.

rological condition of the flood occurrence, in features of hydrograph or in the relationship between the flood volume and flood peak discharge (see Table 1).

II. What Brings About the Flash Flood

The flash flood, in addition to the cause of the cloudburst, includes the flood caused by the burst of any natural levees (glacier dams or other blocking levees formed due to some other causes such as the landfall, landslide and mud-rock flow) and man-made dams.

The field fact finding of three years running (1985—1987) proved that the cause of the flood disaster in the Yarkant River basin was the sudden dewatering of the Keyajir Glacier and Telamukanli Glacier blocking lakes in the upper stream of the Keleqin River. Other causes of the flash flood can be basically left out. The floods that happened many times in the past all come from the Keleqin River but have nothing to do with the main stream of the Yarkant River as well as its west tributary the Taxkorgan River. The glacier blocking lake in the upper stream of the Keleqin River is the major source.

The chief proofs are as follows.

1. On 14 August, 1986 and on 5 August, 1987, there happened the flood at the Kachun Hydrometric Station and near the hydrologic section at the end of Telamukanli Glacier respectively. whose flood peak discharges were 2130 m^3/s and 1500 m^3/s more or less. After the flood it was borne out that the blocking lake of Keyajir Glacier had been drained away and that the flood certainly came from the blocking lake of the above-stated glacier.

2. The geomorphic survey proves that the width of the valley in the Yarkant River as well as its tributary-Keleqin River basin comes from 1 to 2 km. The valley is so wide that it is impossible for the landslide or landslip to block it up. There is very little rainfall, and the annual precipitation is not more than 200 mm. It appears a view of desert landscape. On the slopes of valley there are no traces of gullies washed by the cloudburst.

3. By the identification based on the geomorphic feature, all the glaciers, small or large, are normal ones. There are no rapidly advancing surging glaciers which engender in a short time. It is true that there exists the dewatering of the intra-

and subglacial lakes as well as the lakes at the edge of the glacier, but between summer and autumn it only forms a small flood which consists of hundreds of different discharges.

4. The flood survey and the vegetation show that the violent flood also originates from the upper stream of the Keleqin River valley. There still remain the traces of the flood in the Keleqin River valley. We can take advantage of the favourable conditions to make a flood survey. In particular, the river valley of more than 400 m in length at the end of the ice tongue in Sitanger (Staghar) Glacier is fit to calculate the flood discharge. In May 1985 we measured four sections of the flood mark respectively. We used Chezy-Manning formula to calculate the flood discharge of each section. The results are: $Q_{1-2} = 8483\ m^3/s$ $Q_{2-3} = 7613\ m^3/s$ and $Q_{3-4} = 8153\ m^3/s$. The average based on them is 8080 m^3/s. In consideration of the decrease in the flood discharge on its way, the flood discharge basically corresponds to 4570 m^3/s measured by the Kachun Hydrometric Station on 30 August, 1984. Besides, according to the aerial photograph at different periods of time, the topographic map and the account of the expedition, we find that the "Little Ice Age" terminal moraines of five big glaciers at the upper stream of the Keleqin River, Keyajir Glacier, Telamukanli Glacier, Sitanger Glacier, Wurduoke (Urdok) Glacier and Jiaxuebulumu (Gasherbrum) Glacier are destroyed by the flood erosion. Only a large number of half-buried boulders are left in the valley. After the flood at the end of the glacier which extends as far as the Keleqin River valley there stand upright ice cliffs before which no rock waste or debris cumulate there. Near the ice cliffs there are depressions of different size. The valley is strewn with gigantic glacier ice. The surface of the big boulders looks smooth and crystal and there is no dust cumulated at all. The vast backwater pits appear at the rear of the big boulders and there are a large number of tipped rose willow bushes on both sides of the valley. All this bears the evidence of the recent flood wash.

The survey made of the main stream of the Yarkant River shows that the flow of the highest flood peak in history is only around 1000 m^3/s. All this proves that, with hundreds of different volumes of flow, the flood cannot originate from the main stream. Furthermore, the floods that happened in the past. with nearly the same transmissive time between the Kulukelangan Hydrometric Station and the Kachun Hydrometric Station show that the floods do not flow out of or into this area. This proves that the flash flood all comes from the Keleqin River but has nothing to do with the Taxkorgan River.

III. The Relation Between the Glacier Lake Outburst Floods and the Variations of the Glacier (Plates I and II)

The Keleqin River is a longitudinal valley whose direction of flowing almost runs parallel to the main ridge of the Karakorum Mountains. Therefore the glaciers originating from the north side of the main ridge of the Karakorum Mountains are all broadwise. The advance of the glacier blocks up the chief valley, the glacier blocking lake takes shape accordingly. The recession of the glacier or the local destruction of the ice dam will bring about the glacier lake outburst floods. Therefore the variations of the glacier terminus have direct relation to the formation and destruction of the glacier blocking lake. In the upper reach of the Keleqin River, there are five gigantic glaciers which are very likely to block up the main valley only to form glacier blocking lakes, and in that case, there exists a lurking threat of the flash flood. Some features of those glaciers are shown in Table 2.

Table 2

Some Features of the Glaciers in the Upper Stream of the Keleqin River

Glacier	Length (km)	Area (km^2)	Terminal Height (m)	Height of Firn Line (m)	Highest Altitude Above Sea Level (m)	Reaching-down Space of Ice Tongue (m)	Surmount of Glaciation (m)
Keyajir	22	105.6	4700	5400	7220	700	2520
Telamukanli	24	124.5	4550	5400	7250	850	2700
Sitanger	24	83.5	4430	5200	6460	770	2030
Wurduoke	23	97.6	4370	5350	8068	980	3698
Jiaxuebu-lumu	20	119.8	4350	5350	8047	1000	4137

By studying the change of the said glaciers and comparing the scientific literature and pictures at different stages we find that:

1. Since the 1920s, Keyajir Glacier has moved forward at least twice. The first was in the 1920s, K. Mason[2] and A. Desio[3] had their accounts of it and the topographic map as the evidence for it. The second was in the 1970s, and there were some aerial photographs taken in 1976 and the topographic map by air survey in 1978 and the image from the land satellite as the evidence for it. Keyagir Glacier which has moved forward twice so far has blocked up the Keleqin River valley and resulted in Keyajir Glacier blocking lake which has brought about a lot of flood disasters. All this goes with the flood caused by the glaciers of the Upper Shyok River and those on the south side of the Karakorum Mountains.

2. The size of Keyajir Glacier blocking lake often changes with the change of seasons. When hot summer comes here, the glacier melts immensely and a large amount of meltwater is supplied for the glacier blocking lake which will certainly expand rapidly with the opulent supply of meltwater, and as a result its water level will rise higher, for instance, from July 20 to 25 in 1986, the water level of the blocking lake rose 1.34 m per day and the length of the blocking lake increased by 75 m.

3. The water lines of the old lakes formed at different periods have engendered in the Keleqin River valley on its slopes in Keyajir Glacier and in the upper stream of Telamukanli Glacier. Take the former for example, from the highest water level to the bottom of the valley. The difference of the height is 74.5 m and there are 134 water lines which gradually become thicker and thicker. The width of the water line ranges from 1 to 1.4 m on the average. The widest amounts to over 4 m. The loose deposits of limnetic facies engender most of the water lines of the old lakes, but some higher water lines of the old lakes consist of bedrocks (sili-

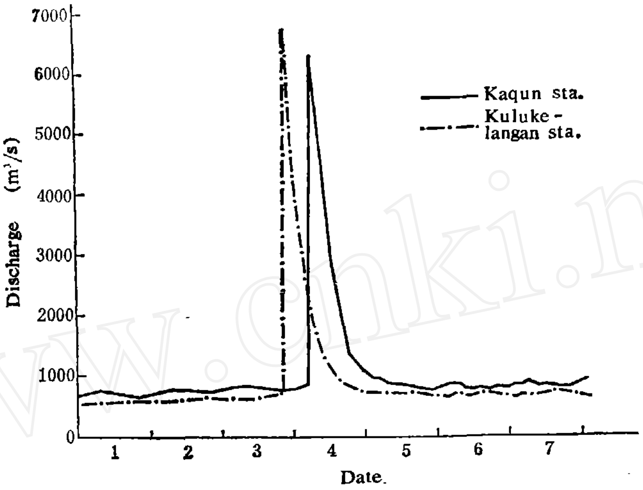


Fig. 3. Hydrographs of GLOF in 1961 in the Yarkant River.

ceous shale) and the widest amounts to 1.5 m. A large number of enormous water lines of the old lakes not only reflects the history of the long, repeated formation and disappearance of the old glacier blocking lakes but also indirectly proves the frequent change of the glaciers which sometimes move forward and at other times recede, and moreover, the change of thickness of the glaciers, viz. the change of the height of the ice dams.

4. The ^{14}C laboratory of the Geography Department of Lanzhou University once ^{14}C-dated the sediments on the water lines of the old lakes which lie on the north side of the Keleqin River valley in the upper stream of Telamukanli Glacier. The absolute chronology and the results measured are shown in Table 3.

Table 3, Wurduoke Glacier whose end height is 60—70 m, viz. the monadnock of the dressed rocks, Sitanger Glacier whose end height is 80—90 m, viz. the gorge of 500 m long and the subglacial gorge at the end of Talamukanli Glacier all prove that these glaciers, at least since the ice age of the late Pleistocene, lean close against the wall of the valley and that the old glacier blocking lakes have long since existed and brought about the flash flood disasters for a long time.

Table 3

^{14}C Dating of Sediments on Water Lines of Old Glacier Blocking Lakes of Talamukanli

Sample No.	Water Lines of the Old Lakes Are Higher Than the Valley (m)	^{14}C-dated (Away From A.D. 1950)
13	12	29720±590
17	50	24420±310
11	52	19795±170
14	54	5975±65
16	64	19045±365

IV. The Dewatering Way of Keyajir Glacier Blocking Lake (Plates I and II)

The glacier blocking lakes caused by various factors have different dewatering ways, even the glacier lakes brought about by the same cause can be quite different due to the difference of concrete conditions. The field reconnaissance in 1985 and 1987 showed that the dewatering way of Keyajir Glacier blocking lake was caused by the rapid expansion of subglacial channels. All water flowed out rapidly until it drained dry. After the flood, the ice dam was none the worse for it. In addition, the inlet and outlet of the subglacial channel could be clearly seen. Not long after that, the inlet and outlet were blocked up again because of the deformation of the plasticity and the collapse of above-covering ice layers. This dewatering way is entirely different from that of moraine blocking lakes in the Himalayas. Those moraine blocking lakes discharge water rapidly due to the collapse of the terminal moraine dam and also quite different from that of the Grimsvötn lake of Vatnajökull Ice Cap in Iceland.

The chief cause is that the lower section of Keyajir Glacier covers the valley of the Keleqin River. On the glacier bed there are small or large Nye-Channels which run in the same direction as the blocking lake. This helps the blocking lakes discharge water under ice. From the air photos taken in October 1976 as well as the 1:50,000 topographic map of air photos published in 1981, we can clearly see an ice cliff, 73 m high and about 850 m long, on the upper stream side of the main valley under the lower section of Keyajir Glacier. Obviously it is a tearing of under-ice dewatering caused by gravity. The approximate position can be clearly seen from the outline of contour on the surface of ice.

According to the analysis of meteorological condition under which the flash flood of the Yarkant River has broken out since the 1950s, we think that the favourable meteorological condition which can rapidly enlarge the subglacial channels is the strong melting factor. Besides, the weather will tend to keep a higher temperature for a long period of time. The occurrence of the flash flood of glacier lakes has no direct relation with the continual precipitation.

V. Numerical Simulation Calculation of Keyajir Glacier Lake Outburst Flood

Since the late 1970s, by making scientific researches on the floods caused by the glacier, the calculating model which simulates the events of the flash flood has been developed. Researchers have offered quite a few models.

According to the concrete conditions of the Kayajir Glacier blocking lake and the Talamukanli Glacier blocking lake, we have chosen G.K.C. Clarke's model[9] to work out the flood hydrograph of 30 August, 1984 under the common action of two dammed lakes.

The results of the value simulation show that the maximum flood peak discharge under the common actions of the Kayajir dammed lake and the Talamukanli Glacier dammed lake is 10,420 m^3/s, the diameter of subglacial drainage channel is 20 m.

It is very close to the maximum flood peak discharge for 10,480 m^3/s according to the flood survey result at the terminus of Talamukanli Glacier in April 1985. The variations of peak discharge (Q), cross-sectional area of the subglacial channel (S), lake water volume (V) and lake level (Z) with time in the flood process can be seen in Fig. 4. The shape of the hydrograph comparatively accurately reflects the whole process of the flash flood.

All things considered, G.K.C. Clarke's flood model proves to be universal. The key to the application of Clarke's model lies in the accurate measurement of the input variables concerned in simulation calculation as well as the conditions of the boundary and the choice of parameters, for example the roughness coefficient and initial cross-sectional area of the subglacial channel.

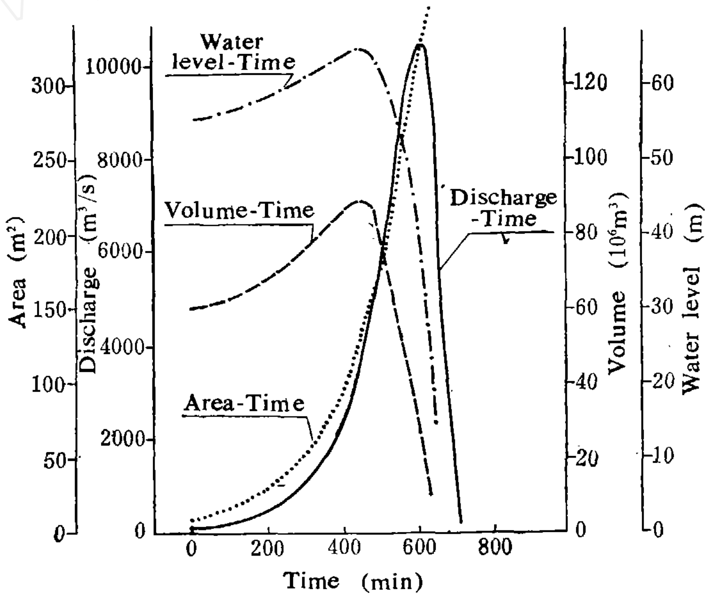


Fig. 4. Hydrographs of simulation calculation of glacier lake outburst flood on 30 August, 1984 at the ice dam of the Talamukanli Glacier blocking lake.

VI. The Prognostication of the Varying Trend of Glacier Lake Outburst Flood in Yarkant River Basin

According to the conjecture of the varying trend of the global climate by the end of this century, the advance and retreat trend of the glacier in the Karakorum Mountains, and in particular, through the analysis of the relation between the varying climate and the advance or the retreat of the glacier, we can prognosticate that, with the global climate tending to become ever warmer and a steady increase in ablation of glaciers, the end of the glacier will recede and the thickness of the glacier will become smaller. The glacier variations that exist on time scales between 10^2 and 10^3 years generally tend to recede. Besides, the minor glacier advance of 10 years time scale in this century has just passed. So far as Keyajir Glacier and Telamukanli Glacier are concerned, their advancing climax has passed. It seems that they only begin to get thinner and recede, in other words, they have become relatively steady. Because the change of the glacier does not always go with the change of the climate, or rather, the glacier reacts to the change later, by the end of this century, the end of the glacier will probably reflect such a fact that from the 1960s to the 1970s, the monsoon precipitation of the Indian Ocean is the least in about 100 years. With a constant rise in air temperature and a little replenishment, the glacier will for certain recede and become thinner, furthermore, the scale of the flash flood caused by the glacier lakes depends upon the height of the ice dam, viz. the thickness of the glacial ice.

Accordingly we think:

1. By the end of this century, the scale of the flash flood brought about by the glacier lake will have become ever smaller. We might almost say for sure that it is quite impossible for the flash flood of thousands of different discharges to happen again.

2. The water stored in the intra- and subglacial holes will not become less with the glacier being thinner and retreat. On the contrary, during the deglaciation, the meltwater will increase because of the large ablation of snow and ice, besides, it should be noted that the glacier moves more slowly than before and the water stored in the intra- and subglacial holes will obviously increase. Consequently, the sudden dewatering of the holes storing water will lead to small floods of hundreds of different discharges more frequently than ever before.

3. There exist some potential threats of the glacier lake outburst floods in Keleqin River valley, they are considered to be Keyajir Glacier, Telamukanli Glacier, Sitanger Glacier, Wurduoke Glacier and Jiaxuebulumu Glacier which are mainly composed of two great ice flows of almost the same scale. Even if the glacier would constantly shrink for a long time, it is calculated that there should not appear what is called Alaskan "Tulsequah Lake" like that existing in Alaska in North America. In fact, after the branch glaciers shrink and leave some empty valleys behind, the ice of the main glaciers block up the empty valleys.

4. The main ridge of the Karakorum Mountains almost runs parallel to the Keleqin River valley, which will not change radically due to the advance and recession of the glacier or the change of climate. Therefore, at any time, the transversal glacier which engenders on the north side of the main ridge of the Karakorum Mountains will advance forward with the result that the transversal glacier blocks up the Keleqin River valley and then the glacier blocking lake comes into being. The potential threat of the flash flood in the glacier lake will remain for a long period of time.

5. After the analysis of the geomorphology of the surging glacier which periodically and rapidly advances, the glaciers in this area prove to be normal ones, and so there is no need to worry about the glacier lake outburst floods brought about by the sudden advance of the surging glaciers, for the advance and retreat of the normal glaciers depend on the change of climate.

VII. Conclusions

To sum up, from what we say about the flash flood in the Yarkant River in the Karakorum Mountains, we can come to the following conclusions.

1. The glacier lake outburst floods in the Yarkant River in Xinjiang are post-nate floods whose flood peaks are hig hbut their flood volume small, their hydrograph looks a steeple, single-peak type. The glacier lake outburst floods rise up very fast but do not last for long. Authings considered that they are characteristic of greater harmfulness, but they are quite different from the flash flood caused otherwise.

2. The cause of the flash flood in this area is that the glacier blocking lake in the upper stream of the Keleqin River suddenly discharges water in a way that the subglacial channels rapidly expand, hence it can be called GLOF.

3. A survey of the floods from 1985 to 1987 showed that in the Yarkant River valley, the glacier blocking lake in the upper stream of the Keleqin River was the source of GLOF and had no direct relation to the main stream of the Yarkant River and Taxkorgan River.

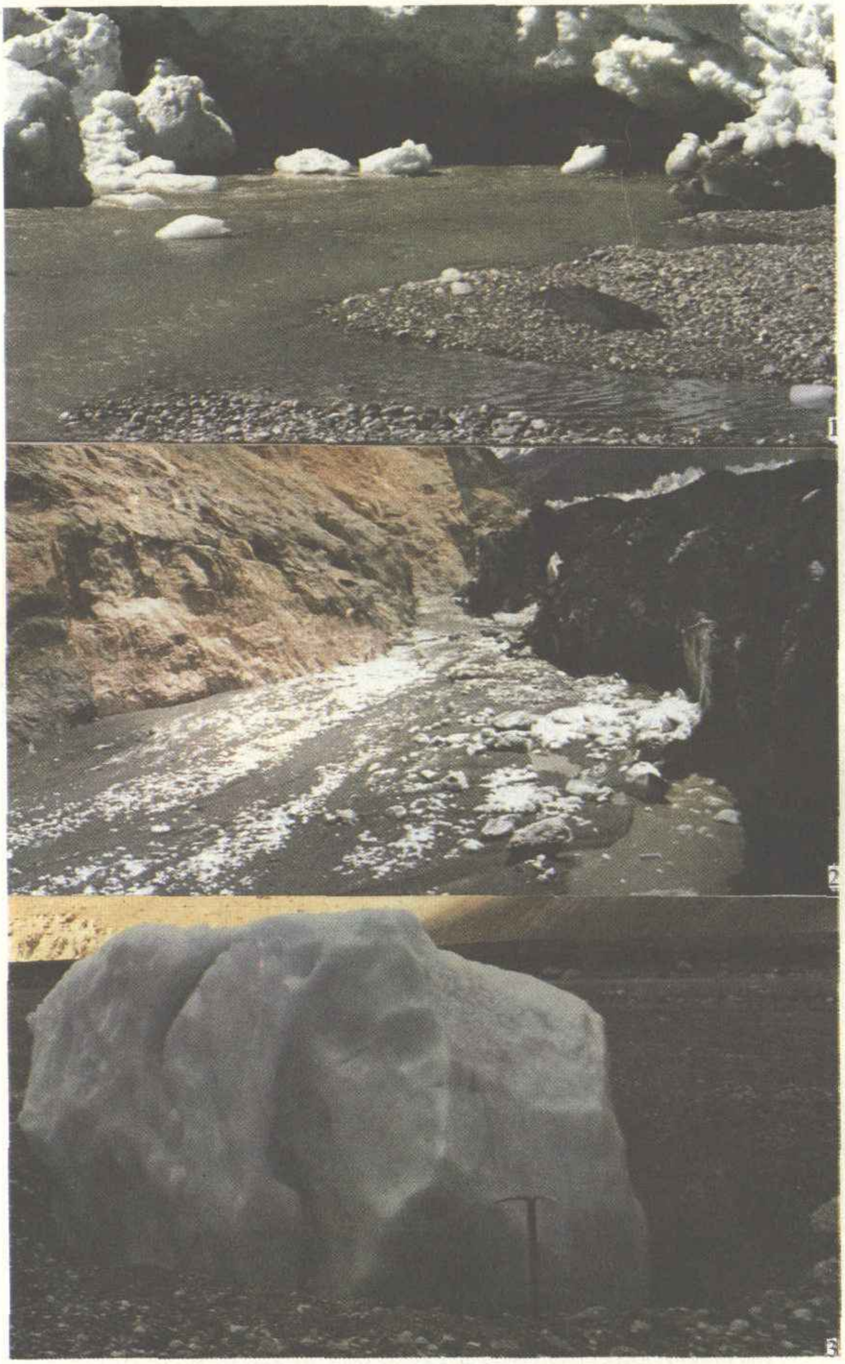
4. The advance and retreat of the five transversal glaciers that originate from the north side of the Karakorum Mountains has a very close relation to GLOF, and what is more, a large number of geomorphic phenomena as well as sediments ^{14}C dated evidence that since the last ice age in the Quaternary, to say the least of it, GLOF in question in the Yarkant River valley has always occurred repeatedly, and that within this century there exist two periods, from the 1920s to the 1930s and from the 1960s to the 1970s in which the glacier blocking lake forms.

5. The results of the computer simulation calculation show that the hydrograph and the discharge of the flood peak can be forecast by means of the theoretical model first set forth by J. F. Nye in 1976 and then developed by G.K.C. Clarke in 1982.

6. At least by the end of this century, with the climate getting warmer, the glacier retreat and get thinner, the height of the ice dam will fall little by little, or even vanish, so the harm done us by GLOF in the Yarkant River valley will be mild by degrees.

References

[1] IAHS-UNESCO-WMO, *Flash Floods. Proc. Paris Symposium*, Bartholomew Press, Dorking, Surrey, U.K., 1974.
[2] Mason, K., *Record Surv. India*, **22**(1927), 182.
[3] Desio, A., *Geogr. J.*, **75**(1930), 402—411.
[4] Hewitt, K., *IAHS, Publ.*, **138**(1982), 259—269.
[5] Mason, K. et al., *Himalaya J.*, **2**(1930), 35—47.
[6] Vvichard, D. & Zimmermann, M., *Mountain Research & Development*, **6**(1986), 90—94.
[7] Ives, J.D., *ICIMOD, Occasional Paper*, No. 5, Kathmandu, Nepal, 1986.
[8] Thorarinsson, S., *Jokull, Ar.*, **4**(1954), 34—37.
[9] Clarke, G. K. C., *J. Glaciol*, **28**(1982), 3—21.
[10] Stone, K. H., *Ann. Ass. Am. Geogr.*, **53**(1963), 332—349.
[11] Nye, J. F., *J. Glaciol.*, **17**(1976), 101—207.



1. The subglacial channel of the Keyajir Glacier dammed lake. The lake is empty after the GLOF.
2. Carrying a lot of glacial ice in the flood of 5th August, 1987.
3. The giant glacial ice on the Keleqin Valley left by the flood of 30th August, 1984.