Annals of Glaciology 16 1992

Investigation of glacier bursts of the Yarkant River in Xinjiang, China

ZHANG XIANGSONG
Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou 730000, China

ABSTRACT. The jökulhlaups in the Yarkant (Yarkand) River are usually caused by the sudden drainage of glacier-dammed lakes through rapidly expanding subglacial channels. The lakes are dammed by Keyajir (Kyagar) Glacier and Telamukanli (Singye) Glacier which are situated in the upper reaches of the Keleqin (Shaksgam) River. In recent years the glaciers have become thinner, and the glacier-dammed lakes and their outbursts have become smaller.

INTRODUCTION

In scientific and technical documents, a glacier lake burst is usually called a jökulhlaup. Such glacier-related floods have caused disasters in such countries as Iceland, Peru, Switzerland, Canada, the USSR, the USA and Nepal, and have attracted widespread attention.

Glacier lake outburst floods of the Yarkant River in the Xingjiang and Xizang region are so dangerous and happen so frequently that only similar events in Alaska can be compared with them. This paper discusses the cause of the glacier floods in the Yarkant River, the prediction of their development, and other related problems.

THE ANALYSIS OF FLOOD DISASTERS AND THEIR CHARACTERISTICS

The Yarkant River in south Xinjiang mainly originates from the north side of the Karakoram mountain chain and the southern part of the Tarim basin. The Yarkant River is the largest river in the Kashi (Kashgar) region of south Xingjiang. The annual normal runoff amounts to $63.75 \times 10^8 \, m^3$. Since 1953 the average discharge at the Kachun hydrometric station (1420 m a.s.l.) has been $202 \, m^3 s^{-1}$ and the specific annual runoff depth for the drainage basin 132.6 mm (Fig. 1a, b).

Since 1953, when the Kachun hydrometric station was established, up to 1987, fifteen jökulhlaups have taken place in the Yarkant River. Figure 2 shows the years that these jökulhlaups occurred and the respective peak discharges. Figure 3 shows a typical hydrograph for the glacier bursts. These jökulhlaups have the following characteristics: rapid rising rate, high peak discharge, small volume compared to peak discharge, short duration, single peak hydrograph and main occurrence in the later period of the flood season. In that respect they are quite different from ice–snow melt floods and storm floods.

THE SOURCE OF THE CATASTROPHIC FLOODS IN YARKANT RIVER

Three years' field work (1985–87) proved that the cause of the flood disasters in the Yarkant River basin was the sudden drainage of lakes dammed by Keyajir Glacier and Telamukanli Glacier in the upper reaches of the Keleqin River. Other causes of flash floods, such as cloud-bursts and landslides, can be ruled out. Floods that have happened many times in the past all originated at the Keleqin River but not down the main stream of the Yarkant River nor at its western tributary, the Taxkorgan River.

The main points supporting this conclusion are as follows:

1. On 14 August 1986 and on 5 August 1987, floods were recorded at the Kachun hydrometric station and at a temporary hydrologic station near the terminus of Telamukanli Glacier (see Fig. 1). The respective peak discharges at Kachun were approximately 2130 and $1500 \, m^3 s^{-1}$. After the floods it became known that the ice-dammed lake of Keyajir Glacier had drained.
2. The geomorphic survey shows that the valley of the Yarkant River, as well as its tributary, Keleqin River, is 1 to 2 km wide. The valley is so wide that it is impossible for a landslide or landslip to block it. On the valley slopes there are no traces of gullies washed out by cloudbursts. There is very little rainfall, as the annual precipitation is not more than 200 mm. The area has the appearance of a desert landscape.
3. No surging glaciers prone to rapid advances have been identified. Drainage events occur from intra- and subglacial lakes as well as from lakes at the edge of the glacier, but these only form small floods.
4. The flood survey and the vegetation show that the

https://doi.org/10.3189/1992AoG16-1-135-139 Published online by Cambridge University Press

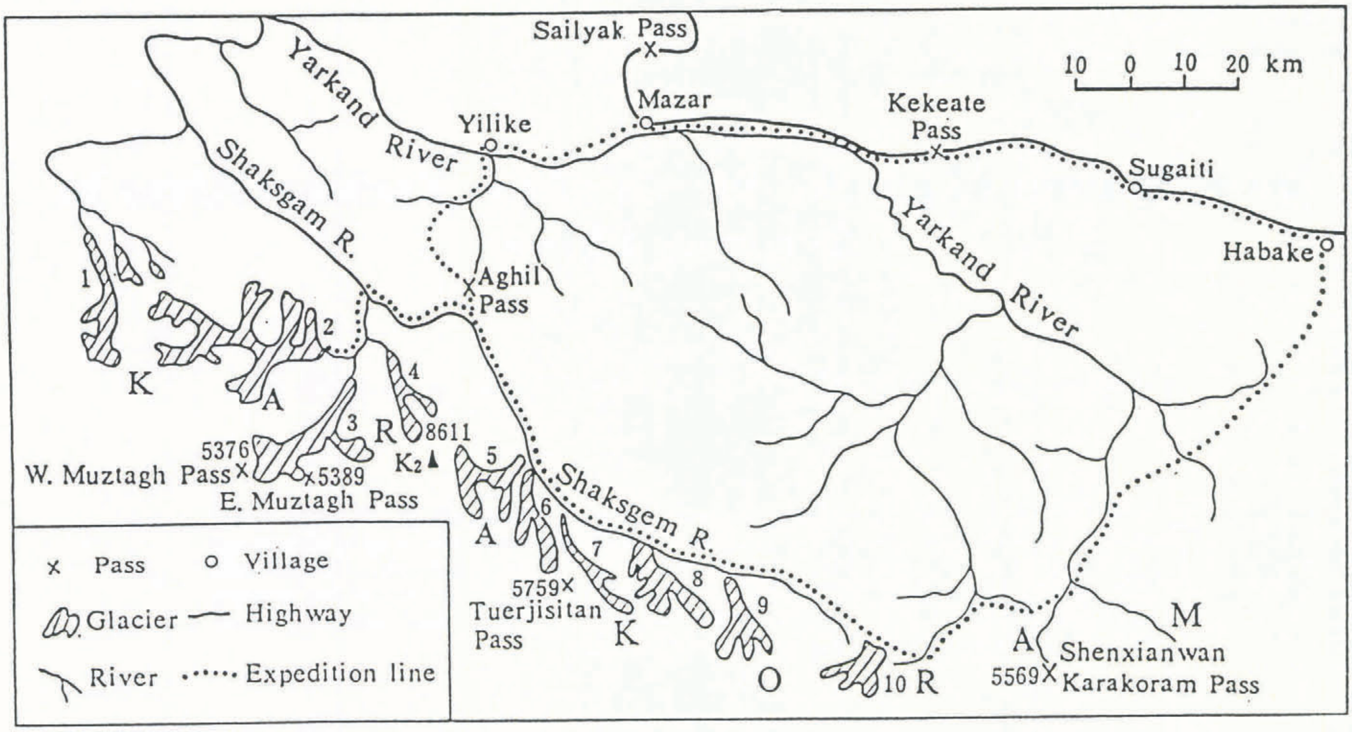

Fig. 1a. The distribution of the big glaciers in the Keleqin River on the northern slope of the Karakoram mountains. 1, Braldu Glacier; 2, Insukati Glacier; 3, Sarpo Laggo Glacier; 4, Qogir Glacier; 5, Jiaxuebulumu Glacier; 6, Wurduoke Glacier; 7, Sitanger Glacier; 8, Telamukanli glacier; 9, Keyajir Glacier; 10, South Victory Pass Glacier.

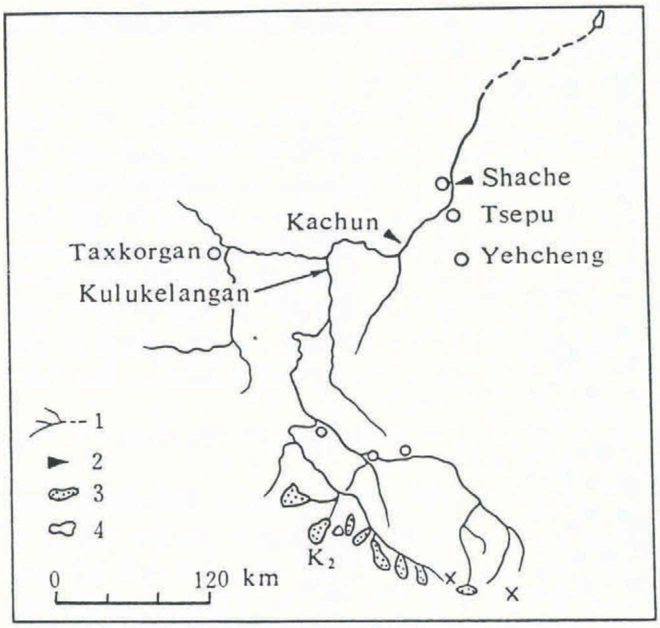

Fig. 1b. The Yarkant River system: 1, Yarkant River; 2, Keleqin River; 3, Taxkorgan River.

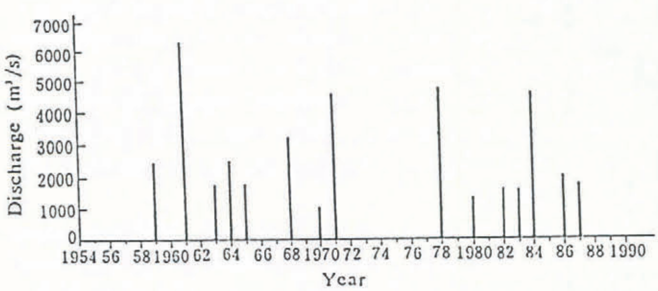

Fig. 2. Peak discharges in the Yarkant River during bursts from glacier lakes.

violent floods originate from the upper stream of the Keleqin River valley. Traces still remain of the floods in that valley. We have taken advantage of favourable conditions to make a flood survey. In particular, the river channel, more than 400 m long, at the terminus of Sitanger (Staghar) Glacier is suitable for calculations of the flood discharge. In May 1985 we measured four sections of the flood marks. The Chezy–Manning formula was used to calculate the flood discharge of each section. The results are: Q_{1-2} = 8483 $m^3 s^{-1}$, Q_{2-3} = 7613 $m^3 s^{-1}$ and Q_{3-4} = 8185 $m^3 s^{-1}$. The average is 8080 $m^3 s^{-1}$. Considering the decrease of the discharge peak on its way down-river, the flood discharge corresponds to 4570 $m^3 s^{-1}$ measured by the Kachun hydrometric station on 30 August 1984. Further, according to aerial photographs from different periods of time, the topographic map and the account of the expedition, we find that the "Litte Ice Age" terminal moraines of five big glaciers (Keyajir, Telamukanli, Sitanger, Wurduoke (Urdok) and Jiaxuebulumu (Gasherbrum)) at the upper stream of the Keleqin River, have been destroyed by flood erosion. Only a large number of half-buried boulders is left in the valley. After the 1984 flood, ice cliffs stood in places where no rock waste or debris accumulation had occurred at the termini of Telamukanli and Jiaxuebulumu Glaciers (Fig. 4). Near the ice cliffs there were depressions of different sizes in the ground (Fig. 5). The valley was strewn with gigantic chunks of glacier ice. The surface of the half-buried boulders looked clean and there was no dust accumulated at all. Vast backwater pits appeared at the rear of the big boulders and there was a large number of tipped rose willow bushes on both sides of the valley. All this was evidence of the recent flood wash.

A survey made of the main stream of the Yarkant River shows that, above the junction with the Keleqin

https://doi.org/10.3189/1992AoG16-1-135-139 Published online by Cambridge University Press

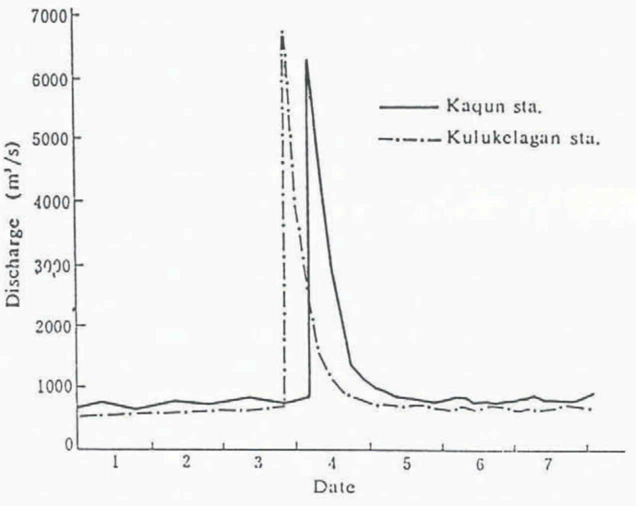

Fig. 3. Hydrograph of a jökulhlaup in September 1961 in the Yarkant River.

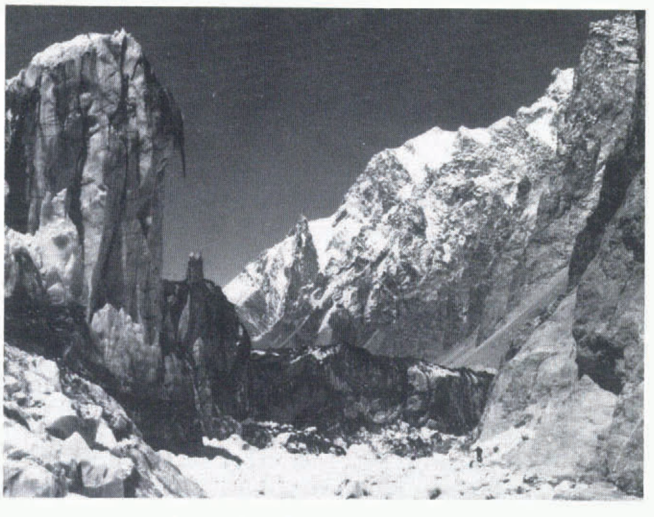

Fig. 4. Ice cliffs at the terminus of Telamukanli Glacier after the flood in August 1984.

Fig. 5. Depressions of different sizes near the ice cliff at the terminus of Telamukanli Glacier after the flood of 5 August 1987.

River, the highest flood peak in history was only around 1000 $m^3 s^{-1}$. Furthermore, floods in the past had nearly the same travel time between the Kulukelangan and Kachun hydrometric stations. Hence, they did not originate from a tributary between these stations.

THE RELATION BETWEEN THE GLACIER BURSTS AND THE VARIATIONS OF THE GLACIERS

The Keleqin River flows in a valley whose direction runs almost parallel to the main ridge of the Karakoram mountains. Therefore, the glaciers originating from the north side of the main ridge are oriented more or less perpendicular to the main valley. When the glaciers advance they block up the main valley and ice-dammed lakes form. Recession of the glacier or local thinning of the ice dam may increase the frequency of the glacier bursts. Therefore, variations of the glacier termini have a direct relation to the formation and destruction of the ice-dammed lakes. In the upper reaches of the Keleqin River, there are five major glaciers which are likely to cause flash floods. Some features of these glaciers are shown in Table 1.

Table 1. Some features of the glaciers in the upper part of the Keleqin River

Glacier	*Length*	*Area*	*Terminal altitude*	*Altitude of firn line*	*Highest altitude*
	km	km^2	m	m	m a.s.l.
Keyajir	22	105.6	4700	5400	7720
Telamukanli	24	124.5	4550	5400	7250
Sitanger	24	83.5	4430	5200	6460
Wurduoke	23	97.6	4370	5350	8068
Jiaxuebulumu	20	119.8	4350	5350	8047

By studying the change with time of these glaciers, based on the records contained in 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 advance occurred in the 1920s (Mason, 1927; Desio, 1930). The second occurred in the 1970s, as evidenced by aerial photographs taken in 1976, the aerial topographic map in 1978 and satellite images. The formation of ice-dammed lakes in the Keleqin River valley during the advances of Keyajir Glacier resulted in flood disasters that may be compared with the floods caused by the glaciers of the upper Shyok River and those on the south side of the Karakoram mountains (Hewitt, 1982; Mason and others, 1930).
2. The ice-dammed lake of Keyajir Glacier changes with the seasons. In 1986 the water level rose 1.34 m d^{-1} from

https://doi.org/10.3189/1992AoG16-1-135-139 Published online by Cambridge University Press

Fig. 6. Shore lines on the north slope of Keleqin River valley.

Fig. 7. Glacier-dammed Keyajir Lake and shoreline on the valley slope of Keleqin River. A pole indicates horizontal width of shoreline.

Table 2. ^{14}C dating of sediments on shorelines of old lakes dammed by Talamukanli Glacier

Sample no.	*Height of shorelines above the bottom of the valley* m	*^{14}C-dated (BP)*
13	12	29720 ± 590
17	50	24420 ± 310
11	52	19795 ± 170
14	54	5975 ± 65
16	64	19045 ± 365

20 to 25 July and the length of the lake increased by 75 m.

3. Shorelines have formed at different periods on the slopes of the Keleqin River valley above Keyajir Glacier and Telamukanli Glacier. In the case of the former, for example, the difference in height from the highest water level to the bottom of the valley is 74.5 m (Fig. 6). A total of 134 shorelines was counted, their separation decreasing with depth from top to bottom. The horizontal width of shorelines range from 1 to 1.4 m on average, with a maximum of over 4 m (Fig. 7). Most shorelines have formed in limnic sediments, but some higher ones of the old lakes are incised in bedrock (siliceous shale), with a largest horizontal width of 1.5 m. The large number of well-developed shorelines of the old lakes reflects the long history of the repeated formation and disappearance of the lakes and the frequent fluctuations of the glacier termini and the height of the ice dams.

4. The radiocarbon dating laboratory of the Geography Department of Lanzhou University has dated the shoreline sediments of the old lakes which lie on the north side of the Keleqin River valley above Telamukanli Glacier. The absolute chronology is shown in Table 2. Table 2 proves that the glacier, at least since the ice age of the Late Pleistocene, was located close to the north wall of the Keleqin River valley and glacier-dammed lakes existed and drained in jökulhlaups.

THE DRAINAGE MECHANISM OF THE KEYAJIR GLACIER-DAMMED LAKE

Glacier-dammed lakes of various types have different methods of drainage. Field reconnaissances in 1985 and 1987 showed that the burst of glacier-dammed Keyajir Lake drained through rapidly expanding subglacial channels (Fig. 8) until the lake became dry. The inlet and outlet of the subglacial channel could be clearly seen. Not long after the outburst, they were blocked up again because of the ice deformation. From the air photographs taken in October 1976 as well as the 1:50000 topographic map published in 1981, we can clearly see an ice cliff 73 m high and about 850 m long, on the up-

Fig. 8. The subglacial tunnel at the terminus of Telamukanli Glacier.

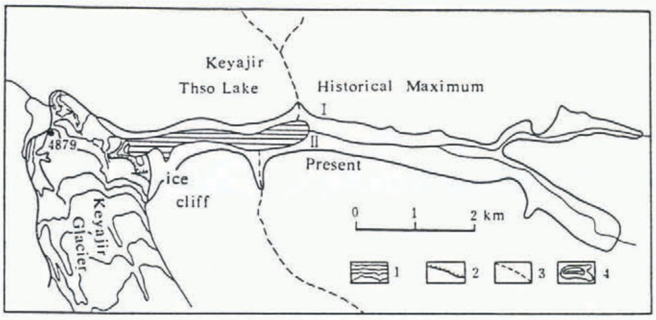

Fig. 9. The Keyajir Thso Lake and the lower reaches of the Keyajir Glacier. 1, superglacial contour; 2, ice cliff; 3, approximate position of subglacial channel; 4, Keyajir Thso Lake.

stream side of the main valley under the lower section of Keyajir Glacier (see Fig. 9). Obviously it was formed by collapse of the subglacial tunnel that drained the lake. In the lower reaches, the Keyajir Glacier is temperate. A subglacial drainage system collected all the meltwater and drained it through outlets at the terminus or margin of the glacier. This type of drainage is entirely different from that of lakes impounded by terminal moraines in the Himalayas (Vuichard and Zimmermann, 1986; Ives, 1986). Those lakes release the water rapidly due to failure of the morainic dam. Differences also exist in the classical jökulhlaups from the Grimsvötn lake of Vatnajökull in Iceland (Thorarinsson, 1953; Björnsson, 1974).

From analysis of meteorological conditions since the 1950s, we conclude that conditions preceding the glacier bursts in the Yarkant River are intensive melting during extended periods of high temperature rather than heavy continuous precipitation.

PREDICTION OF TRENDS IN GLACIER BURSTS IN THE YARKANT RIVER BASIN

Observations show that during the past few years Keyajir Glacier and Talamukanli Glacier have receded and begun to get thinner. By the end of the century, the termini will probably reflect the fact that, from the 1960s to the 1970s, the monsoon precipitation of the Indian Ocean was the smallest for about 100 years. With a rise in air temperature due to CO_2-induced warming and a small replenishment, the glaciers will continue to recede and become thinner. The size of the glacier bursts from the glacier lake depends on the height of the ice dam, viz. the thickness of the glacial ice. Accordingly we predict the following trends in glacier bursts in Yarkant River:

1. By the end of this century, the magnitude of the flash floods caused by the drainage of glacier lakes will decrease.
2. Meltwater will increase and sudden drainage of englacially stored water may cause small and frequent gushes. One would not expect the water stored in the intra- and subglacial cavities to be reduced with the glaciers becoming thinner and retreating.
3. No indications have been recognized for glacier surges, so the risk of exceptional glacier bursts caused by a surge can be ruled out.

CONCLUSIONS

1. The glacier lake outburst floods in the Yarkant River in Xinjiang have the following characteristics: rapid rising rate, high peak discharge, small volume compared to peak discharge, short duration, single peak hydrograph and main occurrence in the later period of the flood season.
2. A survey of the floods in the Yarkant River valley from 1985–87 showed that the glacier-dammed lakes in the upper streams of the Keleqin River were the source of the glacier bursts.
3. The bursts from glacier-dammed lakes in the upper part of the Keleqin River valley drain through rapidly expanding subglacial channels.
4. The occurrence of glacier bursts depends on the advance and retreat of the five transverse glaciers at the north side of the Karakoram mountains. A large number of geomorphic features and ^{14}C-dated sediments indicate that, since the last ice age, glacier bursts have occurred repeatedly in the Yarkant River valley. In this century, glacier-dammed lakes have formed during two periods, i.e. from the 1920s to the 1930s and from the 1960s to the 1980s.
5. By the end of this century, with the climate becoming warmer, glaciers would retreat and get thinner. The height of the ice dam would gradually decrease, or even vanish, so that the harm caused by glacier bursts in the Yarkant River valley would be reduced or eliminated.

REFERENCES

Björnsson, H. 1974. Explanation of jökulhlaups from Grímsvötn, Vatnajökull, Iceland. *Jökull*, **24**, 1–26.

Desio, A. 1930. Geological work of the Italian expedition to the Karakoram. *Geogr. J.*, **75**(5), 402–411.

Hewitt, K. 1982. Natural dams and outburst floods of the Karakoram Himalaya. *International Association of Hydrological Sciences Publication* 138 *(General Assembly at Exeter 1982 — Hydrological Aspects of Alpine and High-Mountain Areas)*, 259–269.

Ives, J.D. 1986. *Glacier lake outburst floods and risk engineering in the Himalaya*. Kathmandu, Nepal, International Centre for Integrated Mountain Development (ICIMOD). (ICIMOD Occasional Paper 5.)

Mason, K. 1927. The Shaksgam Valley and Aghil Range. *Geogr. J.*, **69**(4), 289–332.

Mason, K., J.P. Gunn and H.J. Todd. 1930. The Shyok flood in 1929. *Himalayan J.*, **2**, 35–47.

Thorarinsson, S. 1953. Some new aspects of the Grímsvötn problem. *J. Glaciol.*, **2**(14), 267–275.

Vuichard, D. and M. Zimmermann. 1986. The Langmoche flash flood, Khumbu Himal, Nepal. *Mountain Research and Development*, **6**(1), 90–94.

The accuracy of references in the text and in this list is the responsibility of the author/s, to whom queries should be addressed.