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Characteristics of Glacier Outburst Flood in the Yarkant River, Karakorum Mountains

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Introduction

A catastrophic flood caused by activities of glaciers is called a "glacier outburst flood", or a "glacier outbreak flood" (Rabot, Ch. 1905; Richardson, D. 1968; Vinogradov, Yu. B. 1977). Normal hydrological conditions of the river are disturbed when a glacier outburst flood happens. The flood usually bursts out all of a sudden in summer and autumn with tremendous peak discharge and is initiated by unexpected drainage from supraglacial, englacial or subglacial water bodies as well as from moraine lakes and glacier dammed lakes. In some cases,the flood may be caused by strong glacier ablation during the eruption processes of volcanoes (jökulhlaup). In addition, retreat, advance or surging of glaciers, as well as convergence of complex superglacial streams may also be the factor starting the outburst floods. The study of glacier outburst floods has become a very important research subject in glaciology, especially hydroglaciology, during the past decades. A number of monographical works have been published (edited by Young, J. 1985; Vinogradov, Yu. B. 1977).

Some research was done and several reports were published about the floods in Xinjiang and Tibet (Lai Zuming 1984; Lu Ruren et al. 1986; Xu Daoming 1987). Floods on the N slope of the Karakorum mts. have attracted much attention since the 1920's (Mason, K. 1927; Spoleto, H. R. H. 1930; Desio, A. 1930; Hewitt, K. 1982).

Using the related up-to-date research achievements of scientists from China and other countries, the author analyzed and studied hydrological characteristics and mechanisms of the glacier outburst floods in the Yarkant river.

Hydrometeorological Conditions in the Yarkant River Basin

The basin is situated at the center of Eurasian continent. The climate in the basin is extremely dry, owing to the blockade of the Pamir plateau and the Karakorum mts. The differences of the main meteorological elements on both slopes of the Karakorum mts. reflected clearly the screen effects of the mountains (Tab 1). The area, covered by the glaciers, occupies 11% of the Yarkant basin (above Kagun hydrologic station); glacier meltwater is the major source of the river. Tab 2 shows the main hydrologic features of the river.

The Shaksgam basin, a tributary of great importance in the glacier outburst flood of the Yarkant river, occupies 8223 km^2, in which the area covered by perennial snow and glacier constitutes for 32.4%. The height of snow line is about 5100–5400 m with the glacier tongue at 4200–4700 m. The largest valley glacier in China, the Yengisogat glacier (Crevasse glacier, 42 km long; 380 km^2 in square), is situated in this area. The Shaksgam valley has been disturbed by several large glaciers in the upper reach, and

Stations at north side	long. / lat.	alt. (m)	Annual mean precipitation (mm)	Temperature (C) annual mean	Temperature (C) max.	Temperature (C) min.	Stations at south side	long. / lat.	alt. (m)	Annual mean precipitation (mm)	Temperature (C) annual mean	Temperature (C) max.	Temperature (C) min.
Kangxiwa	36°12'N 78°46'E	3986	36.6	−0.6	24.8	−28.8	Mishar	36°47'N 74°46'E	3102	101.7	5.7	32.2	-18.9
Task Kurghan	37°47'N 76°13'E	3090	71.1	3.3	29.7	-32.9	Batura	36°31'N 74°54'E	2563	126.9	10.0	(34.1)	(-10.9)
Langan	37°44'N 76°13'E	1850	96.4	10.2	36.2	-14.0	Gilgit	35°55'N 74°20'E	1488	126.9	15.8	45.0	- 9.4
Kagun	37°59'N 76°54'E	1420	53.7	11.1	37.6	-20.1	Chiles	37°25'N 74°06'E	1180	198.9	19.8	46.7	- 6.7
Yehcheng	38°16'N 77°16'E	1231	53.1	11.3	37.9	-22.7							

Tab 1 Contrast of the main meteorological elements in Karakorum mts. (1960–1971)*

*Data of the south flank is taken from Liu Guangyuan 1980

in history has occasionally been blocked by glaciers. At present, the Kyagar and Tram Kangri glaciers are still blocking the Shaksgam valley. The Kyagar glacier dammed lake has been existing for a long time. It is the source region for the glacier outburst flood in the Yarkant river.

Cause Classification of the Flood in the Yarkant River

The annual runoff varies greatly in the Yarkant, 80% of it is concentrated at the flood period (June–September). From July to early September the floods happen frequently. Among them, the glacier outburst floods are particularly destructive due to their special dynamic properties. The oases in the lower reach are usually the disaster areas.

Chief Elements Influencing the Floods and Sources of Floods

1. High-altitude heat conditions. In the Yarkant basin, the area above 5000 m asl, occupies one third of the whole basin, perennial snow and glaciers are mainly concentrated in this area. Temperature is usually taken as the parameter reflecting the integrated heat condition. The higher are the accumulated and maximum temperatures, the greater is the flood volume. Generally, meltwater floods occur frequently in July–August.

2. The catastrophic floods result from the abrupt outburst or drainage of a glacier dammed lake, supraglacial lakes and englacial water bodies. The Karakorum mountains is an area where large glaciers are concentrated; it is also an area with largest scale glacier outburst floods.

Tab 2 Hydrologic characteristics of Kagun station in the Yarkant river

Area of the km²	Annual mean (m³/s)	Mean runoff depth (mm)	Mean runoff mean (10^8 m³)	Annual runoff (10^8 m³) max tot.	max year	min tot.	min year	Runoff modulus dm³/s. km²	Cv
50248	205	133.5	64.6	88.1	1973	44.7	1965	4.08	0.17

3. The flood caused by rainstorm. Precipitation in high mountain areas usually exists in a solid form and has no significant influence on the flood. But summer rainstorms in middle-lower altitude and piedmont may result in torrents and form bigger peak flows, in particular when they converge with ablation flood.

Besides, other physico-geographical factors impose certain influence on the floods at low latitude. Seasonal snow covers and river ice above 3000 m asl melt rapidly in early summer while air temperature sharply increases. Since most areas of the basin are situated in the arid desert zone, the extremely sparse plant cover has little retarding effect on the passing floods. However, in some river valleys (such as the upper reach of the Shaksgam river), large moraines exist, the deposits on the bed are very thick, and many sections of the bed are quite wide, providing ample room for the flood.

According to the above analysis, the floods in the Yarkant river may be divided into three types:

1. Meltwater floods. This kind of floods happens in summer while the ablation is strong due to the rise of air temperature (Fig 1). Generally speaking, the peak flow of such a flood is not very large but its total volume is rather big, its duration is long. Meltwater floods, with apparent daily fluctuation in discharge, usually happen in late June to mid August.

2. Rainstorm floods. At middle-lower altitudes, rainstorms may cause floods. In the Yarkant basin, about 50% of the annual precipitation concentrates in June to August (monsoon), which just coincides with the ablation period. Thus, the rainstorm flood often overlaps the meltwater flood and strengthens its intensity.

3. Glacier outburst floods. They mainly appear on the upper reach of the Shaksgam river. There are several colossal valley glaciers interfered with the Yarkant river for several times during the historic period (Fig 2). The terminus of Gasherbrum glacier in 1985 was laying in a 500 m wide gorge, nearly in the same position as Younghusband saw it in 1889 (Younghusband, F. E 1896).

As early as in June, 1929, A. Desio found that the Gasherbrum glacier had advanced to the cliff on the right slope of the main river valley, the water was forced to flow underneath the glacier and, meanwhile, a deep pond was formed (Desio, A. 1930). In 1953 he found again the Gasherbrûm and Urdok glaciers barring the Shaksgam valley (Desio, A. 1955).

The terminus of the Urdok glacier in 1985 was nearly at the same place as in 1929 (Desio, A. 1930). On an isolated hillock near the glacier snout moraine debris remained. On the right slope (100 m above the valley floor) of the main river valley, moraines were also found, which shows that the glacier had once dammed the river.

A. Desio found that the Tram Kangri glacier dammed the main river valley in 1929 (Desio, A. 1930), 1971 (surveying), 1976 (aerial photo) and 1985 (expedition), but no lake was formed in front of the dam. The bottom of the valley from the glacier dam upwards was composed of sand

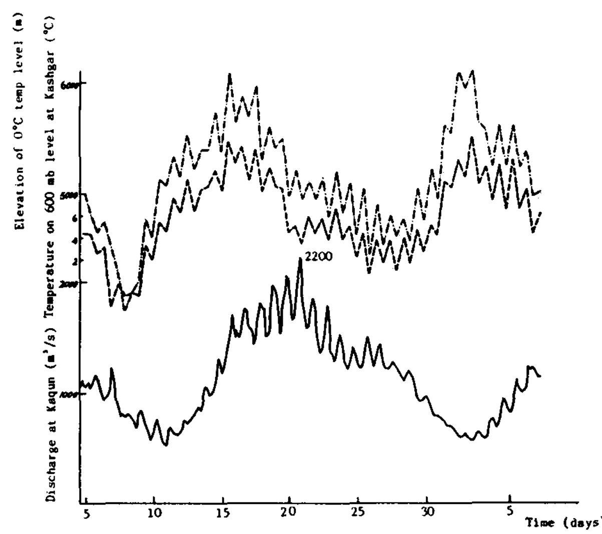
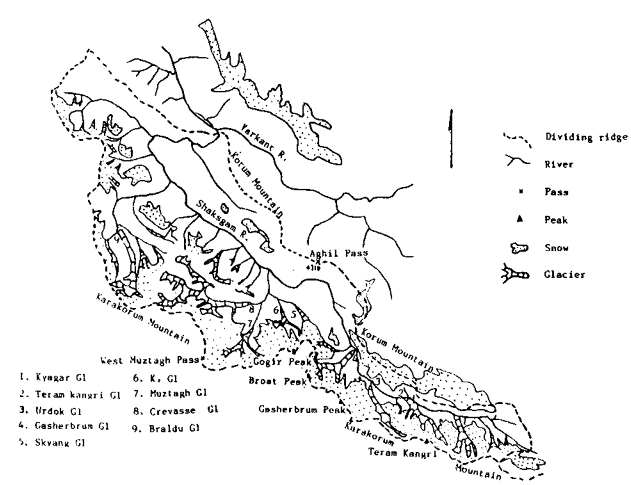


Fig 1 Hydrograph of melt flood at Kagun and high-altitude temperature at Kashgar (July–August, 1793)

deposits, and lacustrine terraces were located on both sides (Desio, A. 1930), which means that a lake had once existed there. The drainage form of the lake determined many characteristics of the flood hydrography observed at Kagun.

Besides, the Kyagar glacier dammed the main river valley in 1926 (Mason, K. 1927), 1929 (Desio, A. 1930), 1976 (aerial photo), 1978 (surveying) and July 18, 1978 (satellite image, Hewitt, K. 1982), and a lake was formed. Its maximum volume may amount to 3×10^8 m^3. This lake has

Fig 2 Distribution of glacier in Shaksgam basin



No.	Date of peak	Peak discharge (m^3/s)	Rising time (hr.)	Total duration (hr.)	Flood volume (10^8 m^3)	Qp/Qr	Rising rate (m/h)	Rate of flood travel (Langan–Kaqun) (km/h)
1	29 Aug. 1959	2460	3:30	34:00	0.46	2.88	0.35	12.2
2	4 Sep. 1961	6270	0:30	27:20	1.50	7.78	5.84	14.2
3	24 Jun. 1963	1690	2:00	32:00	0.48	6.04	0.56	11.3
4	16 Sep. 1963	1320	4:30	43:00	0.40	6.35	0.22	12.7
5	6 Sep. 1964	2450	2:30	34:00	0.67	6.12	0.54	11.7
6	21 Aug. 1965	1770	1:45	60:00	0.52	3.82	0.41	12.2
7	29 Jul. 1966	1480	2:35	29:00	0.28	2.20	0.17	12.1
8	10 Aug. 1968	3150	3:12	25:00	0.50	2.29	0.40	
9	2 Aug. 1971	4570	6:00	22:00	0.73	2.43	0.17	16.6
10	16 Jul. 1977	2670	11:00	26:00	0.42	1.92	0.07	15.5
11	6 Sep. 1978	4700	1:30	62:00	1.36	10.93	1.36	12.6
12	30 Aug. 1979	1960	2:12	40:00	0.46	4.59	0.44	11.2
13	21 Oct. 1980	802	1:00	40:00	0.20	4.46	0.78	11.1
14	16 Nov. 1982	856	1:30	22:00	0.19	2.53	0.42	11.1
15	28 Oct. 1983	854						
16	30 Aug. 1984	4570	0:20	42:00	0.84	4.95	5.30	14.6
17	15 Aug. 1986	1980	4:42	22:30	0.51	3.05	0.24	12.5

Tab 3 Characteristics of the glacier outburst floods at Kagun

been existing for a long time. There are lacustrine terraces formed at different time. The drainage was mainly subglacial. The quantity of the water in this dammed lake is crucial to the flood of the lower reach. Fig 3 shows a typical hydrography of a glacier outburst flood in the Yarkant river. Such flood is closely related to the storage and drainage forms of various glacier lakes on the upper reach, but not so closely related to high-altitude temperature.

Hydrologic Characteristics of Glacier Outburst Flood

On the basis of hydrographical data (1954–1986) at Kagun, 17 flood processes showing clear characteristics of outburst were selected (Fig 4, Tab 3), some of which are not pure glacier outburst floods. Hydrographical characteristics of the glacier outburst flood may be described as following.

1. Most of the floods appear during late summer to early autumn, and certain regularities in the time and

Fig 3 Outburst flood hydrograph at Kagun in August–September 1961

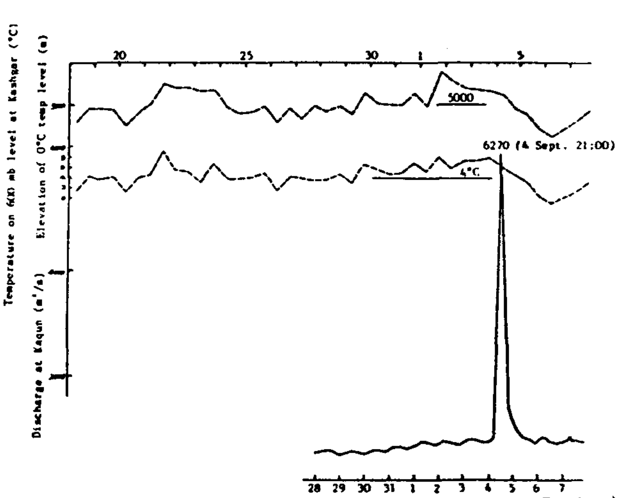
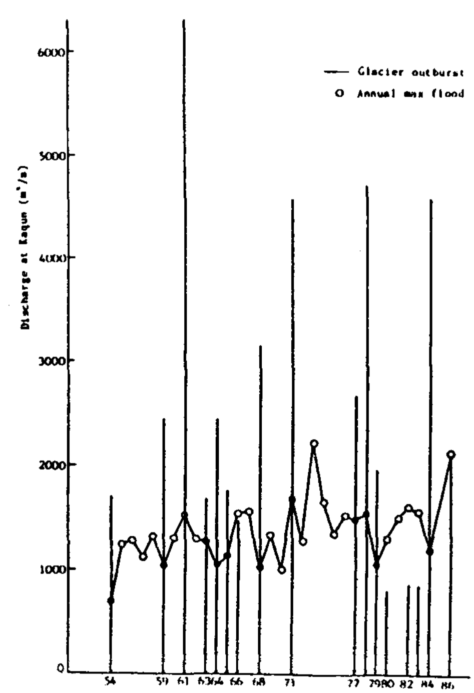


Fig 4 Annual max. melt peak discharge and outburst flood peak



Date	Peak discharge Qp (m^3/s)	Rising rate (m/hr)	Total flood volume (10^8 m^3)	Percentage in annual total volume (%)	Rising duration (hr.)	Flood duration (hr.)	Type of the flood flood
4 Sep. 1961	6270	5.84	1.5	1.8	0.5	7.3	Glacier outburst floot
21 Jul. 1973	2220	0.004	14.1	14.1	236	544	meltwater floot

Tab 4 Contrast of two typical floods at Kagun

frequency of their appearance can be distinguished. All of the floods occurred from June to November, 64% of them took place from late August to November. Usually 84.8% of the yearly maximum floods appeared in July and August. After ice and snow melted intensively in summer, due to accumulation of water and rise of water temperature, channels were formed both below and inside the ice which belongs to temperate glaciers. Warm water opened the channel after the melting period as water pressure increased in ice and, therefore, it resulted in subglacial outburst or lateral drainage. The occurrence time of the glacier outburst flood in this area is similar to that in other places in the world.

2. Glacier outburst floods which happen from June to September are generally the maximum floods of the year (Fig 4), their peak discharges are usually 2–4.5 times of that of meltwater floods. The floods which happened from late autumn to early winter (October to November) could still cause heavy catastrophes in the lower reach of the valley, although their peak discharges are not very high.

3. Contrast of a glacier outburst flood and a meltwater flood

(I) The peak discharge of the glacier outburst flood is often much higher than that of the meltwater flood, but the relationship of the total flood volume is just the opposite. Tab 4 shows the contrast of a typical glacier outburst flood and a typical meltwater flood.

(II) The glacier outburst flood rises and falls steeply. Its rising duration is usually from one to three hours, but sometimes is as short as 20 minutes. The total flood duration is usually from

20 to 40 hours. In contrast, the meltwater flood rises and falls slowly, its rising duration is usually longer than one day, its total flood duration gets to tens of days.

(III) A clear daily variation of the meltwater flood is observed (Fig 1). On the gauge observed at Kagun the daily cycle of rise and fall could be seen, the peak usually appeared in 2 to 6 p.m. every day. Nevertheless, the appearance of the glacier outburst flood peak is irregular and, moreover, its appearance often spoils the regularity of the melt flood peak.

(IV) While the glacier outburst floods appear in the ablation period, they often overlap the meltwater floods. The discharge when rising is relatively big (over 1000 m^3/s), the peak discharge is only one to two times more and the flood duration is a little longer than that of a pure glacier outburst flood.

(V) Statistical analyses of the floods at Kagun are shown in Tab 5. The statistical analyses are made for the contrast. As the glacier outburst flood adds to the statistical analysis of the annual maximum peak discharge, not only the mean value but also the coefficient of variation (Cv) and the coefficient of skew (Cs) greatly increases.

4. Contrast of glacier outburst floods with rainstorm floods. At middle-lower altitude (1300–3800 m asl), 75% of the annual precipitation falls from May to September, and rainstorms happen mainly from June to August, just in the ablation period, thus rainstorm floods often overlap the meltwater floods. The rainstorms are limited in the area,

Tab 5 Statistical characteristics of floods and runoff at Kagun

Item	Mean value (m^3/s)	Coefficient of (Cv)	Coefficient of (Cs)	Statistical time
Annual mean discharge	205	0.17	3 Cv	1984–1986
Annual max. peak discharge	2010	0.60	5 Cv	1954–1986
Annual max peak discharge of meltwater flood	1388	0.17	3 Cv	1954–1986

Name of the glacier dams	Glacier area (km²)	lenth (km)	Distance from Kaqun (km)	Altitude of the dam (m, asl)	Height of the dam (m)	Width of the dam (m)	Historical maximum capacity (10^8 m³)	Condition of the lake	From of drainage
Kyagar	105.6	20.8	517.2	4760	90	1500	3.23	perennial storage and drainage	subglacial drainage
Iram Kangri	124.5	28.0	499.2	4520	60	300	1.92	transitory stroage and drainage	marginal and sub-glacial drainage

Tab 6 Characters of glacier dammed lake at the headwater of the Shaksgam river

this is why their peak discharges can't be very high. Although one can see clearly the overlap of rainstorm flood on the gauge at Kagun, it is very difficult to separate the rainstorm flood from the other type of flood.

5. Contrast of the glacier dammed lake outburst floods to the moraine lake outburst floods. Moraine lake is surrounded by moraine dams which are left behind after quick retreat of glacier tongue. The flood process of moraine lake is similar to that of a common rockfall dam. The hydrography of moraine lake outburst flood exhibits more characteristics of "outburst", that is, its flood duration is shorter, the rise and fall are steeper.

6. Contrast of supraglacial drainage and subglacial drainage in glacier dammed lakes.

The Meicibahei glacier dammed lake (in the USSR) at the headwaters of Kunmalike river in Xinjiang is a typical glacier dammed lake with subglacial drainage. The maximum length of the lake is 4 km, the width is 1 km and the volume is 2 x 10^8 m³. The lake bursts in early September nearly every year. The length of subglacial drainage channel is 14 km (Golubev, G.N. 1976). The most important hydrographic characteristics is that the flood duration is very long, usually several days or several weeks, and, furthermore, the fall is steeper than the rise. The hydrography of the upper reach and the lower reach are quite similar. Field investigation revealed that the drainage was caused by floating up of the damming glacier. The location of subglacial drainage channels can be established by the shape of the dam, distribution of faults and crevasses. As summer approaches, water temperature rises (especially while water from the ambient barren slope flows in), the deformation of ice increases, the lake begins to leak through the englacial crevasses or channels, whereby the channels are further enlarged by heat energy and potential energy of the lake water. Even if floating up of the glacier dam is not continued, it can,t dam up water from draining downstream through the channel. Such drainage mechanism determines characteristics of the

Tab 7 Development of the outburst flood in August 1986 in the Yarkand river

Location	Distance from river source (km)	Altitude (m asl)	Peak discharge (m³/s)	Time of peak	Rise to peak (hr.)	Duration of flood (hr.)	Rate of travel (km/h)	Heigth of water level rise (m)	note
Kyagar tongue	31.2	4670							
Tram Kangri tongue	46.7	4520	2150*						*after Heab-erli (1983)
21 km downstream from Suhong shoal	119	3840	3100*						*flood survey
langran	430	1980	2130	17:24, 14 Aug.	1.3	18.0		2.01	
Kaqun	546	1320	1980	2:42, 15 Aug.	4.7	22.5	12.5	1.13	

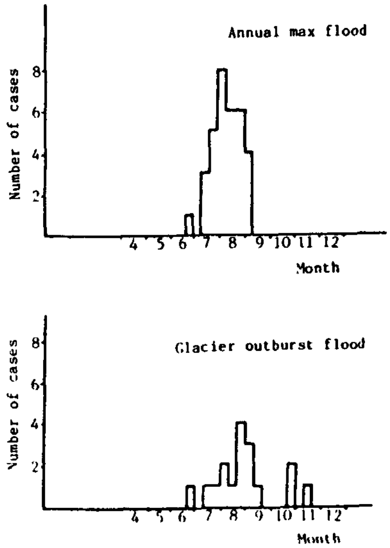


Fig 5 Seasonal distribution of glacier outburst flood and annual max flood at Kagun

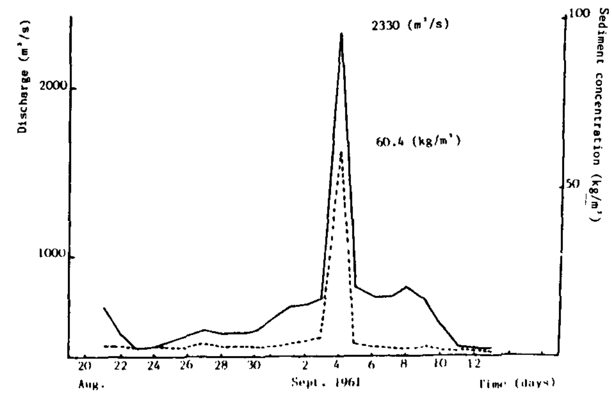


Fig 6 Exceptional sediment concentration and corresponding flood hydrograph at Kagun

flood hydrography. Generally speaking, during the subglacial drainage, channels are enlarged gradually, thus the flood rise is slow (the flood duration is usually several days to several weeks). After the flood peak passage, the flood falls quickly as a result of abrupt closing up of channels or other causes.

Glacier outburst floods caused by supraglacial drainage usually start by overflowing the ice dam. Water above 0 °C can swiftly cut out a channel with its heat energy and potential energy (thermal erosion), until the dam collapses. For instance, the lake on Axel Heiberg Island, Canada, overflowed on July 23, 1973, and 40 hours later a 14 m deep gorge was cut through the ice dam (Maag, H. U. 1969). Another case of supraglacial drainage is the outburst flood in August 1929 by Chong Khumdan glacier dam of the Shyok river at headwaters of the Indus river, S slope of Karakorum mts. The flood began through subglacial tunnels, then carried away the entire ice roof. According to the estimations made, the drain flow amounted for 13.5×10^8 m3. Some 3×10^5 m^3 of ice were also carried away by the flood. The average discharge in 48 h 200 km downstream of the dam was 7100 m^3/s, and gorge was about 120 m wide and 150 m deep (Gunn, J. P. 1930; Mason, K. et al. 1930).

The characteristics of the flood pattern depend on the drainage forms and features of the glacier dammed lake. There are hydrographic differences between the subglacial drainage and the supraglacial drainage. Therefore, the drainage form of the glacier dammed lake at the headwaters of the Shaksgam river might be the same as that in the upper reach of the Indus river.

At present the Shaksgam valley is dammed by two glaciers (Tab 7). Records show that the storage and drainage of Kyagar glacier dammed lake had happened several times (Hewitt, K. 1982). From this it follows that the glacier outburst flood on September 6, 1978, resulted from this lake. Expeditions since 1926, especially in the past three years, verified that the drainage from the lake is subglacial. Considering the great height of the dam, one can conclude that the drainage was caused by floating up the glacier dam. The Tram Kangri glacier dam lies at 18 km down the Kyagar glacier dam, the terminus of the glacier is 4 km wide, with only 300 m of discontinuous sections blocking the valley. From the expeditions in August 1971 and May 1985 we know these were ice blocks left by outburst floods in 1971 and 1984. A wider valley floor had been scoured out at the terminus after a small flood in the summer of 1987.

In conclusion, the water storage in Kyagar glacier dammed lake plays an important role for the glacier outburst floods at the Yarkant river, while the characteristics and drainage pattern of the Tram Kangri glacier dammed lake determine the hydrographical features of glacier outburst floods at Kagun.

7. The relationship of peak discharge and total volume may be well expressed by the following equation,

$$Q_m = 1.7 \, W_m^{0.97} \quad (r = 0.92)$$

where Q_m is the peak discharge (m^3/s), W_m is the total volume (10^6 m^3). The total volume of a big flood approximately equals the maximum volume of the present dammed lake. This is another evidence that the glacier outburst floods in the Yarkant river source from the glacier dammed lakes at the headwaters of the Shaksgam river.

8. Periodicity of the floods. According to the data at Kagun since 1954, a period of about 10 years is observed

Stream (station)	Drainage area (km²)	Annual mean discharge (m³/s)	Annual mean sediment discharge (10^8)	Annual mean sediment concent-ration (kg/m³)	Max. sediment concent-ration (kg/m³)	Erosion modulus (T/km². Yr)	Data source and time
Yellow river (Shan Xian)	687,869	426	15.7	36.9	590	2280	annual mean, Chinese water conservancy society 1983
Indus (Kalaqag)	305,000	34878	6.8	6.18		2230	annual mean, Chinese water conservancy society 1983
Yarkand (Kaqun)	50,248	266	0,61	7.22	60.4	1260	1961 mean, hydrologic yearbook

Tab 8 Multiyear mean sediments in the Yellow river, the Indus river and the Yarkand river in 1961

(Fig 4). That is, the glacier outburst floods were very frequent from 1959 to 1971 and from 1977 to 1986, about once within one to two years, whereas the glacier outburst floods ceased from 1954 to 1958 and from 1972 to 1976. Since 1954, a period of 6 to 10 years in the occurrence of large scale floods (with discharge of over 4500 m³/s) is observed. The glacier outburst floods in the Yarkant river are closely related to the formation, storage and drainage of the glacier dammed lakes at its headwaters, and formation of the glacier dammed lakes is closely related to the advance of glaciers. Therefore, formation of glacier dams and lakes are related to the Little Ice Age. Water storage in the Kyagar glacier dammed lake was recorded in 1920s (Mason, K. 1929; Desio, A. 1930). But no water was stored in the intervals since 1930s, which might result from the regional general retreat of the glacier (Hewitt, K. 1982). Since the 1960s, glacier outburst floods happened frequently, corresponding to the low temperatures in the 1950s that caused a stop in glaciers retreat, and the lower temperatures that led to the advance of the glaciers (Shi Yafeng et al. 1980).

Both the Kyagar and the Tram Kangri glacier dammed lakes are large lakes. Once the dammed lakes were formed, the drainage depends on the amount of water supply and water temperature. The annual water supply of the lakes varies greatly, and so does water temperature; for example, icebergs in the lake can lower the water temperature significantly. Apart from this, clear traces of the lake shoreline could be observed, which can be formed only while water level lingered at a certain level for a long time. Therefore, it may be convincing that large scale drainage does not happen every year in the Kyagar glacier dammed lake. Water drainage of the Kyagar glacier dammed lake flows into the Tram Kangri glacier dammed lake, water temperature increases during the flow process and, in addition, the ice dam (i e glacier tongue) belongs to the temperate glacier type, its subglacial channels are well developed. Therefore, the Tram Kangri glacier dammed lake drains easily. Meanwhile, the lake terrace of the ice dammed lake at the Tram Kangri is not developed so well as compared to that at Kyagar. This implies that the Tram Kangri lake is a transitory one. The Kyagar glacier dammed lake plays a very important role in large scale floods in the Yarkant river.

In conclusion, the formation and height of the glacier dams reflect the advance or retreat of the glaciers and local climate variations during a long period, while the storage of the glacier dams reflects regional heat and weather conditions. Therefore, we understand the glacier and climate conditions through the formation provided by glacier dammed lakes.

Influence of Glacier Outburst Floods

Influences of glacier outburst floods on both sides of the Karakorum mts. are far beyond that of floods caused by extreme weather conditions. The floods usually reach the regions of hundreds and even thousands of kilometers away. Several reservoirs are located at the lower reach of the Yarkant river. Peak discharge of glacier outburst floods is usually 4 to 30 times of a normal discharge, or more. The floods often bring large quantities of sediments. All these bring about great menace and losses to engineering, traffic installations and human property.

Since 1961 many investigations have been carried out after each of the large scale glacier outburst floods. Tab 7 shows a record of glacier outburst floods happened in August 1986.

In addition, attention should be paid to the geological and geomorphological processes of erosion, transportation and sedimentation. The outburst flood, with great height and unique dynamic properties, is able to transport much more sediments than a common flood. Glacier outburst floods are often accompanied by unusual sediment load. Fig 6 shows the variation of sediment content and corresponding discharge in the Yarkant river. Its maximum daily sediment flow (September 4, 1961) is about 160 times bigger than the annual mean value.

Owing to the tremendous scale of the glacier outburst flood in 1961, the annual sediment discharge of the Yarkant river that year was over two times of the annual mean value and its erosional module was half as big as that of the Yellow river (in Shaan Xian). Tab 9 shows the contrast of the sediments in the Yarkant river, the Indus river and the Yellow river. Sediment discharge of a river is very important for construction of reservoirs and channels, for irrigation and hydro-power stations. Sediment deposit diminishes the capacity of reservoirs or even lead to abandonment of the reservoirs. Meanwhile, the flood from reservoirs, with next to no load, downcuts the river bed so seriously that it makes irrigation channels ineffective. Therefore, the sediment concentration, size and their variations should be considered when constructing reservoirs and channels.

Conclusions

1. The drainage of the Kyagar glacier dammed lake and the Tram Kangri glacier dammed lake at the upper Shaksgam is the main reason for glacier outburst floods in the Yarkant river. The Kyagar glacier dammed lake is characterized by subglacial drainage, while the Tram Kangri glacier dammed lake by mainly lateral drainage and, secondly, by subglacial drainage.

2. The drainage mechanism of the Tram Kangri ice dam determines the main characteristics of flood hydrography of the Kagun station, while the Kyagar glacier dammed lake plays an important role in the formation of floods.

3. Glacier outburst floods in the Yarkant river are characterized mainly by high peak discharge, big rising rate, small total volume and short duration. The floods happen mostly from late summer to early autumn. A period of 6 to 10 years in occurrence of large scale glacier outburst floods exist. The periodicity depends mainly on large scale drainage in the Kyagar ice-dammed lake.

4. Formation and dimensions of glacier dams at the upper Shaksgam were determined by long-term variations of the regional climate, whereas the changes of storage capacity in the lake reflect cold and warm changes of alpine region.

Therefore, frequent glacier outburst floods indicate glacier advance and climatic variations.

References

Desio, A.: Geological work of the Italian Expedition to the Karakorum. Geogr. J. 75, 5, 402-411 (1930)

Desio, A.: The Ascent of K2. Geogr. J. 121, 261-273 (1955)

Golubev, G. N.: Hydrology of Glaciers Gidrometeoisdat 247 (1976) (in Russian)

Gunn, J. P.: Report on the Kumdan Dam and Shyok Flood of 1929. Government of Punjab Publication, Lahore (1930)

Hewitt, K.: Natural Dams and Outburst Floods of the Karakorum Himalaya. IAHS 138, 259-269 (1982)

Hewitt, K.: Pakistan Case Study: Catastrophic Floods. IAHS 149, 131-135 (1985)

Kalabagh Consultants: Floods due to the Failure of Natural Dams in the Indus Basin. Tech. Memo No.6, WAPDA, Pakistan 1983.

Lai Zuming: Some Features of the Glacier Flood. Journal of Glaciology and Geocryology 6, 2, 45-52 (1984) (in Chinese)

Liu Guangyuan: The Climate of the Batura Glacier and its Adjacent Areas. The Glaciclogical Survey and Study on the Batura Glacier in the Karakorum Mountains, 99-110, Science Press, Beijing 1980 (in Chinese)

Lu Ruren et al.: The Glacial Lake Outburst Debris Flow in Tangbulong Gully. Tibet, Gongbu Jiangda. Journal of Glaciology and Cryopedology 8, 1, 61-69 (1986) (in Chinese)

Maag, M.U.: Ice Dammed Lakes and Marginal Glacier Drainage on Axel Heiberg Island, Canadian Arctic Archipelago. McGill University Montreal. Axel Heiberg Island Research Report. Jacobson-McGill Arctic Research Expedition 1959-1962, 147 p., 1969.

Mason, K.: The Shaksgam Valley and Aghil Range. Geogr. J. 69, 4, 289-311 (1927)

Mason, K.; Gunn, J. P.; Todd, H. J.: The Shyok Flood in 1929. Himalayan J. 2, 35-47 (1930)

Rabot, Ch.: Glacial Reservoirs and Their Outburst. Geogr. J. 25, 5, 534-547 (1905)

Richardson, D: Glacier Outburst Floods in the Pacific North-West. U.S. Geological Survey Professional Paper 600-d, 79-86 (1968)

Shi Yafeng et al.: Forecasting the Change of the Batura Glacier in This and the Next Centuries. The Glaciological Survey and Study on the Batura Glacier in the Karakorum Mountains 191-207, Science Press, Beijing 1980. (In Chinese)

Spoleto, H. R. H.: The Italian Expedition to the Karakorum in 1929. Geogr. J. 75, 5, 385-401 (1930)

Vinogradov, Yu. B.: Glacial Floods and Sel Flows 1977. (In Russian)

Water and Energy Commission Secretariat, His Majesty's Government of Nepal (WEC HMGN): Study of Glacier Lake Outburst Floods in the Nepal Himalaya, Phase I, Interim Report, Chapter 5, 1987.

Xu Daoming: Characteristics of Debris Flow Caused by Outburst of Glacial Lakes on the Boqu River in Xizang, China. Journal of Glaciology and Geocryology 9, 1, 23-33 (1987) (in Chinese)

Young, J., ed.: Techniques for Prediction of Runoff from Glacierized Areas. IAHS 149, 109-143 (1985)

Younghusband, F. E.: The Heart of a Continent. London (1896)