CHINESE GEOGRAPHICAL SCIENCE
Volume 6, Number 3, pp. 282—288, 1996
Science Press, Beijing, China

THE ORIGIN AND CHARACTERISTICS OF THE GLACIAL DEBRIS FLOW IN THE DUKU HIGHWAY OF TIANSHAN MOUNTAINS, CHINA

Xiong Heigang (熊黑钢)
Department of Geography, Xinjiang University, Urumqi 830046, *PRC*
Liu Gengnian (刘耕年)　Cui Zhijiu (崔之久)
Department of Geography, Peking University, Beijing 100871, *PRC*
Song Changqing (宋长青)
Institute of Botany, the Chinese Academy of Sciences, Beijing 100039, *PRC*
(Manuscript was received in October 1995)

ABSTRACT: Debris flow is one of the most serious natural hazards in the Tianshan Mountains. According to trigger agent, the debris flow can be divided into storm type which is caused by flood, and glacial type which is caused by flood from melting of snow and glacier in hot weather. At present, debris flow causes damage mainly to transportation, sometimes to mining and residents in mountainous area. The catastrophic process and the forming condition of the debris flow show regional regularity, therefore, the research of its distribution, processes, and environmental condition is useful in mitigating the natural hazard.
KEY WORDS: debris flow, natural hazard, Tianshan Mountains

I. INTRODUCTION

Debris flow is one of the most serious natural hazards in the Tianshan Mountains, which causes damage to transportation, mining and pasture. The catastrophic process of debris flow has regional regularity, therefore, the research of its distribution and forming condition is useful in mitigating the natural hazard. The debris flow can be divided into two types by triggering agents, one is storm debris flow, which is caused by storm flood, the other is glacial debris flow, which is caused by snow and glacier melting flood in high temperature weather. Debris flows often appear in alpine Tianshan areas, for example, in Eren Habirga Range, Karawuchen Range, Narat Range and Bogda Range. Generally speaking, in alpine area and part of middle mountain areas debris flows are mainly caused by flood from high temperature weather when snow and glacier (ice) melt intensively. While in middle and lower mountain areas the debris flows are mainly caused by storm flood. The Duku Highway, which stretches across the Tianshan Mountains, suffers from frequent and intense debris flow hazards, which causes great costs to highway and transportation.

This paper takes the northern part of the Duku Highway, which starts from Dushanzi to Narat, as an example to discuss the debris flow hazards in Tianshan areas. Glacial debris flow occurs at gullies almost every year at milestone 85—86 km section in Haxilegen (Fig. 1), and causes traffic held up and accident. When

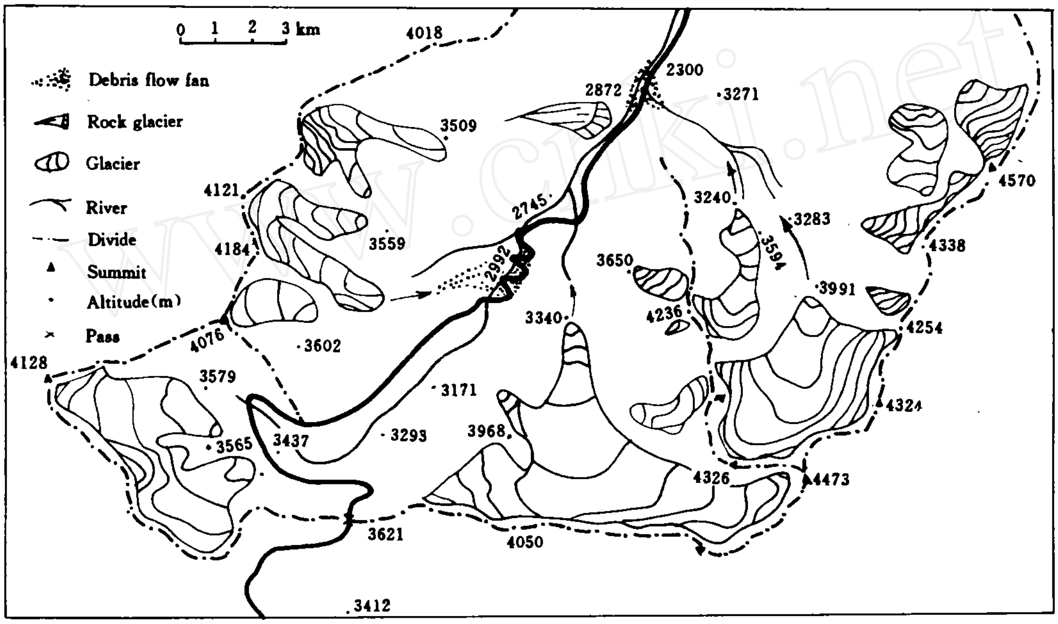

Fig. 1 Landscape and distribution of debris flow in Haxilegen along the Duku Highway

surveying the highway to be constructed, the engineers treated the gullies as inactive debris flow, and designed two culverts with 4 m span over the gullies to drain water. At the first year as the highway started to build in 1977, the culverts and road were buried by debris flow. Since then, debris flow occurs every year. As the highway began its public service in 1983, there were over 10,000 m^3 of debris cleaned at 85—86 km section and a 200-meter road was made to allow transportation. Unfortunately, one debris flow buried the cutting and held up traffic again in 1984. Based on incomplete data, there were 15 debris flows at 85 km+600 m, they deposited over 20×10^4 m^3 debris on the valley, and 2×10^4 m^3 debris on the highway (Table 1). Each debris flow hazard caused traffic suspense 3 to 5 days.

Table 1 Debris flows at 85 km+600 m in Haxilegen area along the Duku Highway

Time				Debris volume (m^3)	Debris deposits on highway (m^3)	Trigger agent
17:00—19.00	1	June	1984	—	3500	Storm
18:00—21:00	24	June	1984	—	2500	High temperature
16:00—2:00	25	June	1984	110000	3200	High temperature
16:00—2:00	26	June	1984	10000	1000	High temperature
18:00—24:00	13	July	1984	50000	1000	High temperature
17:00—20:00	13	June	1985	10000	1500	High temperature
18:00—22:00	1	July	1985	—	2000	High temperature
17:00—22:00	2	July	1985	—	4000	High temperature
20:00—21:00	13	July	1986	—	500	High temperature
16:00—22:00	11	July	1987	30000	2500	High temperature
P. m.	23	June	1991	—	·	Storm
P. m.	15	July	1992	8000	--	High temperature
19:23—22:25	28	June	1993	39000	500	High temperature
17:21—21:40	29	June	1993	26000	300	High temperature
19:23—21:45	1	July	1993	6000	300	High temperature

sometimes as long as 15 days.

This example shows the seriousness of debris flow hazards in Tianshan area. There were 22 debris flows appeared along the northern 110 km section of the Duku Highway from May 1987 to July 1988, among which there were 12 debris flows occurred in gullies that had been silence for debris flow since 1970. This suggests that extreme weather and climate may trigger extensive debris flow in large area simultaneously.

II. LANDFORM AND DEBRIS CONDITION

There are 48 debris flow gullies, among which 9 gullies are of snow and glacier melting flood triggered in the northern part of the Duku Highway, which is 172 km from Dushanzi to Yuximolegai pass. The length of the highway affected by debris is 2,870 m. The Haxilegen area is the most serious debris flow hazard region (Fig. 1) in the northern part of the Duku Highway, especially at 85 km+600 m, where there exists large dimension and high frequency debris flows from a gully that develops debris flow from glacier and snow patch area as high as 3,200—4,000 m. The other two locations with debris flow activity are at 97 km and 26—

27 km section along the highway. The altitude of the divide is 4,000—4,500 m at Haxilegen. The altitude of valley bottom varies from 2,300 m at 85 km+600 m to 3,500 m at Haxilegen pass. The glaciers are distributed above 3,250—3,350 m, and snowline is distributed at 3,900—4,000 m. Most of the glaciers are cirque glacier and tongue glacier with rather small size. It is clear from Table 1 that most of the debris flows are triggered by melting water flood from snow patches and glaciers during high temperature weather. The debris flow gully at 85 km+60 m is called Sanchahe Gully. The area of glacier is 1.7 km^2, the drainage area is 5 km^2, and deposit area is less than 0.5 km^2 in the Sanchahe Gully. The altitude of the gully mouth is 2,300 m and the glacier tongue is 3400 m. The slope gradient in the area of snow and ice (glacier) accumulation varies 40°—60°, the slope in debris transportation area varies 16°—33°, with mean gradient 28°, and the slope in deposit area is 6°—9°, six debris flows occurred at 96 km+900 m in 1984 to 1987, among which, four of them were caused by high temperature and two caused by storm.

The solid fragments in glacial debris flow are made up of tills and frost shattered debris. The till is important for the formation of debris flow in the Tianshan Mountains. Most of the debris come from the moraines developed in Little Ice Age. There are 2 to 6 Little Ice Age moraines that closely surround the glacier torque. Debris flow coming from moraines is very common in other areas of the Tianshan Mountains, also it is reported that snow and ice (glacier) melting water flood triggering debris flow during high temperature weather is common in Alps, Andes and Rocky mountains[1-3]. In addition, till of Neo-glaciation moraines and Last Glaciation moraines are important solid fragment supply to debris flow.

Another important solid fragment supply comes from frost weathering. Intense freeze and thaw fluctuation produce a quantity of frost shattering debris in the alpine area of the Tianshan Mountains. According to data from Daxigou Meteorological Station (3,580 m) at the source area of the Urumqi River, there are 130 days per year the air temperature fluctuating around 0℃. The bedrock at Haxilegen area is shale, sandstone and slate of Devonian and Carboniferous periods with intense fractures. Data of gelifraction denudation in 1981—1990 show that the mean denudation rate on the south slope is 0.006—0.0084 $m^3/(m^2.a)$ and on the north slope is 0.00059—0.0055 $m^3/(m^2.a)$ between 3,300 and 3,500 m at Haxilegen area, which is greater than that of most other areas all over the world[4]. In the alpine area, strong frost action leads to many large talus, which become important supply to debris flow.

The debris flow in middle mountain area (1,500—2,500 m) is mainly triggered by storm flood along the Duku Highway. For example, there were tow storm flood debris flows occurred at 2:00—3:00 a.m. July 8, 1993 and 17:00—

18:00 p.m. July 10, 1993 at 26—27 km section. The solid fragments come from gravels in gully and slope residua. The debris flow was small in size and shorter in time.

Another glacial debris flow location was at 95 km in Haxilegen (Fig. 1), the debris here was triggered from high temperature of June 28, 1993.

III. CLIMATIC CONDITION

Climatic condition of debris flow includes not only precipitation but also temperature, especially prolonged high temperature weather, because high temperature weather can produce intense melting of snow and ice (glacier)in alpine area and release melting water flood that triggers debris flow. Shown in Table 1, among the 15 debris flows at 85 km+600 m from 1984 to 1993, 13 debris flows were triggered by high temperature melting and only 2 debris flows were triggered by storm flood. This shows that in alpine area the main type of debris flow is triggered by snow and ice (glacier) melting. The debris flow of 1984 happened in late June, while the debris flow of 1985 happened in early July. According meteorological data from Dushanzi (730 m a. s. l.), the extreme high air temperature was 39℃ on June 26, 1984, and 37.8℃ on July 3, 1985. The two recorded extreme high temperatures at Dushanzi fit in with the two debris flows at 85 km+600 m in 1984 and 1985 (Table 1). From the climatic observation at the gully mouth (2,300 m a. s. l.) of 85 km+600 m, it is found when air temperature at the gully mouth reaches 25℃, there will be debris flow rush down. Measurement at 3,700 m a. s. l., where is the source area of snow, ice and debris, shows the critical temperature for strong melting to produce debris flow is 4℃—8℃. High temperature usually appears in afternoon of late June and early July, which is in accordance with the strong melting season of snow and ice (glacier) in alpine area. The catchment of melting water is located between 3,400 m to 3,900 m a. s. l., while catastrophic area is usually distributed between 2,000 m to 3,000 m.

The debris flows in middle and low mountain area are mainly caused by storm flood. For example, the storms at 2:00—3:00 a.m. July 8 and 17:00—18:00 p.m. July 10, 1993 triggered debris flows at 26 km to 27 km, respectively. The fragment volume of each debris flow was nearly 500 m^3, among which 50—100 m^3 was on the highway. The debris flows held up traffic for several days[5]. The hazards of storm debris flow were reported at many places in the Tianshan Mountains, such as Houxia in the Urumqi River drainage, Ala valley at northwest Turpan[6], Botu valley in Gonglu County[7]. The storm debris flows in Ala valley harmed the enterprises, roads and people and caused huge damage in the 1970s and 1980s. The debris flow occurring at Botu valley in Gonglu County is a typical example.

First storm triggered landslide, then landslide became debris flow to rush down the valley in the early morning of June 7, 1991. Along the main active faults in the Tianshan Mountains there exist many potential sites for landslide and many old landslides. The forming and damaging area of storm debris flow is mainly located from 1,000 m to 2,500 m a. s. l. , occurs during June, July and August.

IV. CATASTROPHIC CHARACTERISTICS AND MITIGATING APPROACHES

Debris flow in cryosphere is mainly caused by melting flood from snow and ice (glacier) during high temperature weather in the Tianshan Mountains. The solid fragments of the debris flow are composed of tills and frost weathering debris. The high temperature weather is strongly influenced by the upper-air anticyclone in summer, especially as the Tianshan Mountains is controlled by strong South Asian High. The duration for developing glacial debris flow is late June and early July. The time for debris flow rushing down is after 16:00 p. m. Volume density of debris flow ranges from 1. 9 t/m^3 to 2. 3 t/m^3, the highest density may reaches 2. 46 t/m^3[5]. The processes of debris flow at 85 km+600 m on the Duku Highway was to interrupt flows with one surge passing time 0. 5—3 minutes and intermit 1—2 minutes. The total active time is as long as 2—10 hours. The volume of debris flow can reach 6,000—40,000 m^3. More than 50% of debris was gravel, clay content was only 2%—3%. The composition mainly reflects the debris source. In the damage area, intense erosion and deposit happen. Erosion happens as lower density debris flow rush down, while deposit happens as higher density debris flow rush down.

According to the forming condition and processes of debris flows in the Tianshan Mountains, suggestions and approaches to protect traffic are as follows. 1) To build weather monitor and forecast systems at selected location which suffer from debris flow. The main task is to obtain critical temperature and precipitation parameters for forecasting debris flow. 2) To construct protective devices to deflect and dam debris flow. 3) To build long span high bridge over the valley of debris flow. 4) For new land use area, identification of potential debris flow site and location is very important, including mapping of dangerous area, forming condition and process analysis.

REFERENCES

[1] Deng Yangxing. Glacial debris flow in Bogda area, Tianshan. Journal of Glaciology and Cryopedology, 1983, 5(3): 235—241. (in Chinese)

[2] Deng Yangxing, Zhu Mingdi, Zhao Degang et al. Debris flow disasters and characters in 1993 along

Duku Highway of Tianshan Mountains, Xinjiang. In: Proceedings of the 4th National Symposium on Debris Flow. Lanzhou: Gansu Culture Press, 1994. 132—138. (in Chinese)

[3] Costa J E. Flood from dam failures. Flood Geomorphology, ed. Baker V R et al. 1988, 451—453.

[4] Liu Gengnian, Xiong Heigang, Cui Zhijiu. The denudation by gelifraction and its influential factors in the periglacial environment of Tianshan Mountains, China. In: Permafrost VI International Conference, Proceedings, Vol. 1, South China University of Technology Press, 1992. 397 — 402. (in Chinese)

[5] Deng Yangxing. Study on the debris flow at the northern section of Dushanzi—Kuqa Highway through Tianshan Mountains. Arid Land Geography, 1994, 17(1): 30-37 (in Chinese)

[6] Chen Yaning, Mu Guijing. Investigation of debris flow in Alagou Basin, Tianshan Mountains. Arid Land Geography, 1991, 14 (Special): 1—5. (in Chinese)

[7] Hu Ruji. An Investigation on debris flow in Buotu Valley, Gonglu County, Xinjiang. Arid Land Geography, 1992,15(1): 25—28. (in Chinese)