Editor-in-Chief: Shi Yafeng

CONCISE GLACIER INVENTORY OF CHINA

Shanghai Popular Science Press
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A Brief Introduction to Contents

This book is a concise and synthetic monograph of *Glacier Inventory of China*, which consists of 12 volumes and 22 books. For convenience, we predigest the detailed data in *Glacier Inventory of China*, and add some new information about glaciers and environmental changes in each glaciered region, and new knowledge about glacier changes and their influence on water resources. This book consists of nine chapters, including the distribution of glaciers in each drainage system in China, glacier changes and its meltwater runoff. Especially is given an in-depth discourse by drainage basin, the amount of glaciers in statistics tables and maps of glacier distribution, classic glacier images and photos supplemented newly.

This book is a systematic, all-round work in glacier resources and environmental changes, with abundant and original data and a mass of beautiful pictures. This book has offered a scientific support to natural strategy of water resources and management in Development of the West Regions of China. It is a useful reference book for those who do research in geography, water conservancy, disaster prevention and environment, and also for educational and productive purpose.

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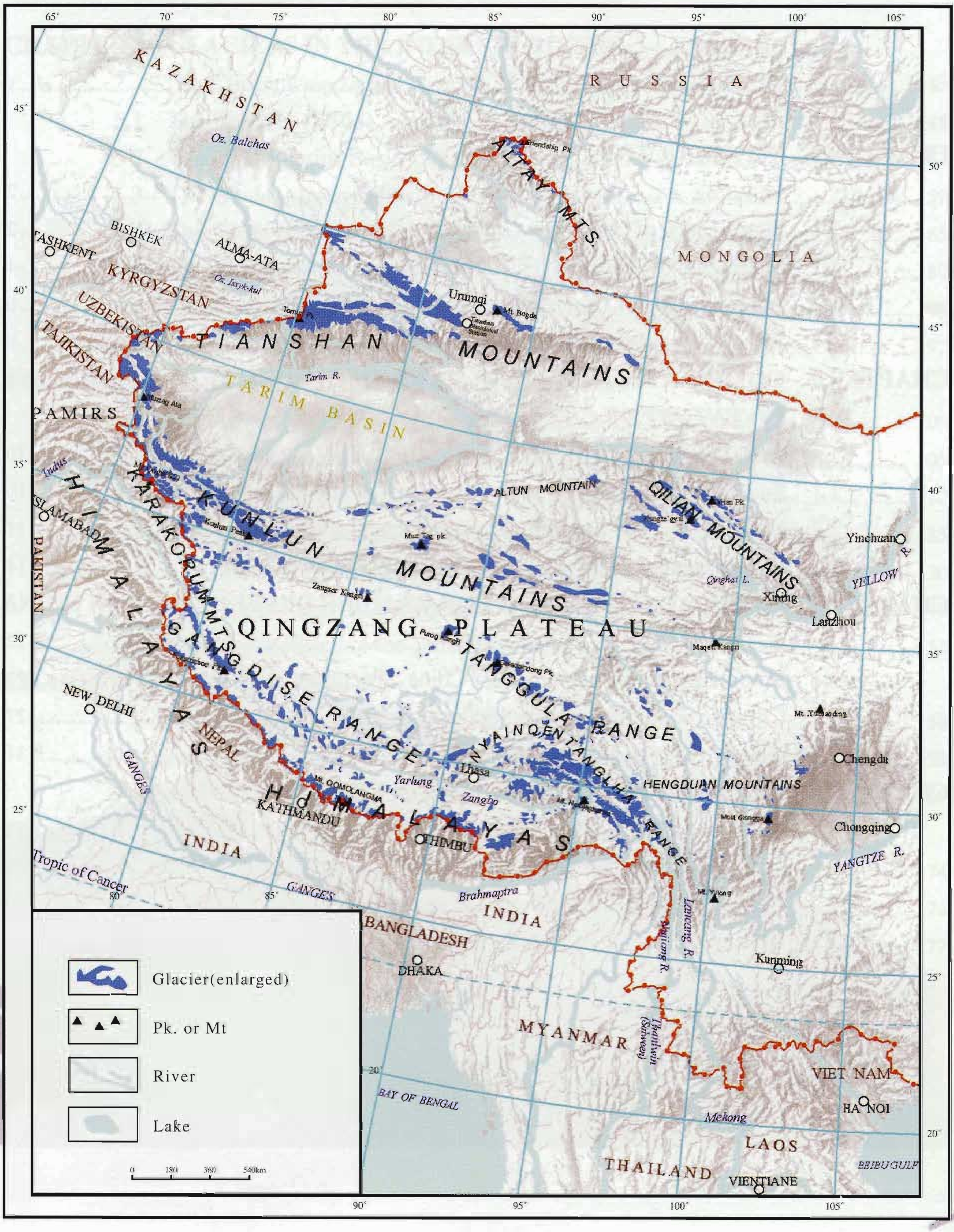
Concise Glacier Inventory of China (CGIC) is an integrated and simplified introduction to glaciers in China, based on individual volumes of *Glacier Inventory of China* (GIC) for a series of mountains in West China contributed by many researchers from the Lanzhou Institute of Glaciology and Geocryology, the Chinese Academy of Sciences (LIGG, CAS), now re-organized into the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), CAS. The authors of the present book would like to give their thanks to those not included in the book for their zealous, though exhausting, dedication to compile glacier inventories for all mountains in West China during the last 24 years. We are grateful to the continuous support from LIGG for compilation of GIC, also to CAREERI for funding the publication of this book. The working group of CGIC also received the support of projects from the National Natural Science Foundation of China (NNSFC) (90202013), the Chinese Academy of Sciences (KZCX3-SW-339). All the color figures and maps were prepared by Mi Desheng and Wu Lizong. The following colleagues provided precious photos that make this book interesting and vivid. They are Ding Liangfu, Pu Jianchen, Wang Zongtai, Yao Tandong, Qi Long, Deng Xiaofeng, Su Zhen, Ma Qiuhua, Shen Yongping, Zheng Benxing, Lu Anxin and Liu Chaohai. Julia Taylor Broussard arranged the language editing; Liu Shiyin, Liu Chaohai and Ye Baisheng made the final editing both in language and science. Shanghai Popular Science Press covers expenses in editing and printing this book.

Glacier distribution in West China



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PREFACE

Shi Yafeng

For the wide interests in glaciers in China and convenient application of *Glacier Inventory of China*, we compile this book. This book is a brief introduction to *Glacier Inventory of China* which consists of 22 books in 12 volumes. To this aim, we analyze and summarize all findings in the 22 books of *Glacier Inventory of China*; in addition, we complemented new information about changes of glaciers and environment in each glacierized area after compilation of glacier inventory in the region. This book consists of nine chapters, introducing the distribution of glaciers, glacier changes and glacier meltwater runoff in every mountain range or water system in West China. The most obvious advance in this book is the complete information about glaciers in different water systems, statistic tables, maps, photos or figures of typical glaciers in the individual basins, which is thought to be helpful to readers related to studies and planning performance on water resources and environment.

This book is a systematic, all-round work concerning glacier resources and environmental changes. It composes of abundant and original data and a mass of beautiful pictures. It offers the background information in connection with large-scale management of water resources, mitigation and prevention of glacial disasters, planning of glacier parks and so on, especially, with such activities during Development of West Regions of China. It is a useful reference book for graduate students, policy makers working in the field of geography, water conservancy, disaster prevention, and environment.

November 2005

CHAPTER 1 INTRODUCTION

Shi Yafeng

1.1 Significance of compiling *Glacier Inventory of China*

Glacier is a natural ice body formed by accumulation and deformation of perennially precipitated snow in cryogenic areas. Glaciers slowly flow from the higher accumulation areas above the equilibrium line altitude (ELA) to the lower ablation areas where the melted glacier ice forms the sources of many rivers. Interactions between glaciers, the atmosphere and the lithosphere produce a sequence of changes in water and heat budgets, forming complex glacial systems.

Most global glaciers can be found on the Antarctic continent and Greenland Island near the Arctic Pole. Alpine glaciers also cover the mid- and-low-latitude mountain areas. Glaciers roughly cover 11% of the total landmass and hold 80% of global fresh water. The population explosion and increasing demand for clear and fresh water require a thorough investigation of the quantities and characteristics of glacier resources. Compiling a global glacier inventory can be of great help to this end.

Geologic history recovered from paleoclimatological research provides another reason for such a glacier inventory. During the Last Glacial Maximum (LGM) approximately 20,000 years ago, 30% of the total global landmass was covered with glaciers and ice sheets, transferring a large body of water from the oceans to the land and lowering the sea level by about 130 m relative to the modern sea level. The ancient coastline in China during that time was 600 km east of the current Yangtze River estuary. The Bohai Sea and the Huanghai Sea were totally converted to land, as well as most parts of the East and South China Seas. Roughly 6000 years ago the global temperature was 2~3℃ higher and the sea level was 1~3 m above the present levels (Shi Yafeng *et al.*, 1992). Accelerated anthropogenic emissions of greenhouse gases, such as carbon dioxide, have contributed to the irrepressible trend of climate warming, subsequently increasing glacial melting and causing the sea level to rise, threatening the safety of island countries and coastal lowlands. An evaluation report issued by the Intergovernmental Panel on Climate Change (IPCC) in 2001 proposed that 1.4~5.8℃ rise in global mean air temperature and 0.1~0.9m rise in sea level can be expected in the 21st century despite the large uncertainties in numerical modeling and significant differences between regions. In order to calculate the impact of glacial melting on the sea level accurately and precisely, we are in great need of a detailed compilation of glacier inventory that provides essential information about surviving glaciers.

China is in more urgent need than many other countries for such a compilation of glacier inventory because most of the meltwater from alpine glaciers flow into Chinese giant arid inland basins such as the Tarim, the Junggar, the Qaidam, as well as the Hexi Corridor. These regions have been relying heavily on the glacial meltwater as the key source of oasis irrigation for a long time. With the rapid development of agriculture and industry and continuous population growth, the supply of and demand for water has become an urgent problem. Glaciers, acting as alpine solid reservoir of water that regulates seasonally and annually stream flows, are a reliable water source for sustainable development in arid regions. Glaciers and their meltwater not only become the basis upon which an oasis can stably form and develop, but also become an indispensable and lively part of the environment. In the 1980s a national leader of China once said: "Alpine glaciers are a reliable and relatively stable water resource in solid form. We should cherish this precious resource, allowing it to create more wealth and benefit the people." China also has quite a number of glaciers that contribute to major seaward rivers with an important role in regulating yearly runoff, producing hydropower, and preventing floods.

In the early years before the establishment of the People's Republic of China, little is known about glaciers in China until a milestone investigation of glaciers in the Qilian Mountains was carried out in 1958 initiating formal glacier research in the nation. The Investigation Team on Utilization of Snow and Ice Resources in Mountain Regions, the Chinese Academy of Sciences (1959), a body of 120 personnel from the Chinese Academy of Sciences headed by Professor Shi Yafeng, was divided into seven groups with the goal of finding out the distribution and features of glaciers in the Qilian Mountains. After a long expedition of more than four months, traversing 2500 km on foot and climbing more than 60 glaciers, combined with the visual interpretation of aerial photographs of some areas, the scientific expedition has documented roughly 941 glaciers with a total area of about 1149 km^2 equivalent to 33.2×10^9 m^3 of water. However, the exact number of glaciers was greatly underestimated. Although several subsequent investigations have expanded, to some extent, our knowledge on glaciology, they still could not meet the need for a detailed calculation of nationwide glacier resources. In 1978, in response to the international project of compilation of glacier inventories, the Chinese scientists began to offer a systematic effort to compile *Glacier Inventory of China*, finally leading studies on glacier resources in China to regular, reasonable and effective tracks.

1.2 International Glacier Inventory and Glacier Inventory of China

In 1955, a working group of the International Geophysical Year (1957~1959) first proposed all member countries to register the position, altitude, area, volume and activity of glaciers. The coordinating council of the International Hydrological Decade (IHD) during 1965~1974, further called on the participating countries to map the distribution of perennial ice and snow and to record relevant data in detail. Sponsored and supported by the Secretariat of the IHD, a work group guided by Swiss Professor F. Müller published in 1970 *A Guide for Compilation and Assemblage of Data for a World Glacier Inventory*, which provides rules for the standard measurements of 40 glacier parameters. After years of practice, this book was modified for reprinting in 1977 and was widely accepted as the criterion for compilation of glacier inventory worldwide. In 1973 the Temporary Technical Secretariat (TTS) of the World Glacier Inventory was set up at the Department of Geography of the Switzerland Federal Institute of Technology (SFIT), directed by Professor F. Müller who was responsible for promoting and coordinating the compilation of glacier inventory. In September 1978 the International Commission on Snow and Ice (ICSI) organised a workshop, participated by scientists from 19 countries, on the World Glacier Inventory in Switzerland. Before the opening of the workshop, Professor F. Müller delivered an official letter in the name of TTS to the Chinese Academy of Sciences (CAS) in which he invited delegates from China to attend this meeting and to initiate the glacier inventory task over China. CAS and the Ministry of Foreign Affairs of China jointly submitted an application to the State Council of China. In this application Shi Yafeng, head of the Lanzhou Institute of Glaciology and Geocryology (LIGG), CAS of the time, was officially appointed chief of the delegation to participate in the meeting in Switzerland and undertake the glacier inventory on behalf of China. Professor F. Müller pointed out in the report of the meeting that the compilation of World Glacier Inventory would be of great significance in three aspects: 1) to enrich knowledge on local, regional and global hydrological cycles and water budgets; 2) to provide basic data for freshwater resource planning, hydropower generation, irrigation, disaster prevention, relaxation and tourism; 3) to obtain the necessary background data for studying climatic processes and monitoring climatic change. By the time the workshop was convened, five nations (the USSR, Norway, Austria, Switzerland and Sweden) had already finished compiling their glacier inventories, and most of the countries were carrying out the compilation of their own glacier inventories.

After LIGG undertook the compilation of the glacier inventory in China in 1978, the group coordinated by Prof. Shi Yafeng chose the Qilian Mountains as the first prototype of the Chinese glacier inventory. Then a working team was sent to investigate the glaciers in the Altay Mountains and began working on the difficult task of compilation of glacier inventories in the Altay and Tianshan Mountains. The project group estimated that the national glacier inventory could be finished within ten years. While the inventory was smoothly progressing, the unfortunate news came that Professor F. Müller died of a heart attack in the field work on the Rhone Glacier in Switzerland. His death was a great loss to the course of glacier inventory compilation. In the autumn of 1981, K. Scherler, an assistant of Professor F. Müller, presided over a glacier inventory inspection symposium at Zurich, which Shi Yafeng attended and reported the progress of the Chinese glacier inventory. At that time the atmosphere of the symposium changed greatly. Some speakers thought the originally conceived glacier inventory was too difficult to be completed. They in turn proposed that simple methods, such as using satellite imagery, should be adopted and quickly put into practice. In response to such suggestions, researchers from some countries simplified the former glacier inventory procedures according to their own conceptions. Only a few researchers, including those from China, adhered to TTS criterion of 1977. Since then, TTS and the Permanent Service on the Fluctuation of Glaciers (PSFG), formerly directed by F. Müller, merged with the Institute of Hydro-Engineering, Hydrology and Glaciology. In 1986 the World Glacier Monitoring Service (WGMS) headed by Dr. Haeberli founded and ran into operation. In 1989 WGMS published its world glacier inventory, in which the global glacier coverage area was estimated to be 15,861,766 km^2. In this publication, the glacier area in China was estimated by Shi Yafeng to be 56,482 km^2, including three fully inventoried mountainous regions and nine mountainous regions where the inventories were based on satellite imageries. Thereafter the glacier inventory of China continued with more than 50 participants in total, who made a great effort to overcome difficulties such as low fund, shifts in the research paradigm, manpower alteration, and problems within the collection of aerial photographs and topographic maps. However, the project of compiling glacier inventory in China was finally completed and the 12 volumes of *Glacier Inventory of China* with additional maps were all published in 2002. Meanwhile the Chinese team established a large-scale, unified glacier inventory database with the Geographical Information System technology. In September 2004 an expert team including academician Li Jijun and Chen Zhikai unanimously issued positive comments on the inventory and suggested to publish *Concise Glacier Inventory of China* for the general public's convenience.

1.3 Achievements of *Glacier Inventory of China*

The main achievements of the compilation of *Glacier Inventory of China* include the Glacier Inventory in detail, glacier information system databases and application of the glacier inventory.

1. Publication of *Glacier Inventory of China* in 12 volumes and 22 issues (Table 1-1). The inventory for the first time accurately determined the number of glaciers in all drainage areas, mountains and provinces across the nation, providing basic scientific information for the reasonable utilization of water resources and implementation of global climate change research. Among the four major nations with glaciers, *i.e.* China, U.S.A, Canada and Russia. China has the maximum distribution of Alpine glaciers in mid-and-low latitudes and is the only country that has finished its glacier inventory in accordance with the glacier inventory criteria.

2. Establishment of a digital database for *Glacier Inventory of China*. This database was the first attempt to vectorize glacier coverage with attributes of *Glacier Inventory of China*. This has greatly promoted the practical and illustrative applications of glacier inventory data, bringing great convenience to use the inventory.

3. Promotion of widespread applications of the glacier inventory (Photo 1-1). While compiling *Glacier Inventory of China*, glaciological researches in China were activated with the applications of the glacier inventory data in the fields of glaciology, hydrology, paleoclimatology and so on, for example, estimations of glacier runoff and changes of glaciers since the Little Ice Age and during recent decades, as well as on projections of future changes in glaciers and their impact on river runoff. This research had great theoretical and practical significance and important impact

Table 1-1 List of *Glacier Inventory of China**

Volume	Issue	Authors	Publishing Year
Ⅰ Qilian Mountains	Qilian Mountains	Wang Zongtai and Liu Chaohai *et al.*	1981
Ⅱ Altay Mountains	Altay Mountains in China	Liu Chaohai *et al.*	1982
Ⅲ Tianshan Mountains	Interior Drainage Area of Scattered Flows in East	WangYinsheng and Liu Chaohai *et al.*	1986
	Interior Drainage Area of Junggar Basin in Northwest	Lai Zuming and Liu Chaohai *et al.*	1986
	Interior Drainage Area of Tarim Basin in Southwest	Xie Weirong and Ding Liangfu *et al.*	1987
	The Ili River Drainage Basin	Ding Liangfu and Xie Weirong *et al.*	1987
Ⅳ Pamirs	Pamirs	Luo Xiangrui and Mi Desheng *et al.*	1988
	Drainage Basins of the Kaxgar River and Others (Revised Edition)	Liu Chaohai and Wang Zongtai *et al.*	2001
Ⅴ Karakorum Mountains	Drainage Basin of the Yarkant River	Yang Hui'an and An Ruizhen	1989
Ⅵ Kunlun Mountains	Drainage Area of Southern Qaidam Basin and Upper Reaches of the Yellow River	Yang Hui'an and An Ruizhen	1992
	Interior Drainage Area of the Hotan River	Yang Hui'an and An Ruizhen	1992
	Interior Drainage Area of the Karamiran-Keriya River	Yang Hui'an and An Ruizhen	1994
	Interior Drainage Area of the Miran-Qarqan River	Yang Hui'an and An Ruizhen	1994
	Drainage Basins of the Ayakkum Lake and the Hoh Xil Lake	Yang Hui'an and An Ruizhen	1988
Ⅶ Qinghai-Xizang (Tibetan) Plateau Inteiror Area	Drainage Basins of the Bangong Lake	Jiao Keqin and Zhang Zhenshuan	1988
	Drainage Basins of the Dogaicoring and Yibuchaka Lakes	Jiao Keqin and Zhang Zhenshuan	1988
	Drainage Basins of the Siling Lake	Jiao Keqin and Zhang Zhenshuan	1988
	Drainage Basins of the Zharinam Lake	Jiao Keqin and Zhang Zhenshuan	1988
Ⅷ The Changjiang (Yangtze) River	The Changjiang (Yangtze) River	Pu Jianchen	1994
Ⅸ The Mekong River	The Lancang River	Pu Jianchen	2001
Ⅹ The Salween River	The Nujiang River	Pu Jianchen	2001
Ⅺ The Ganges Drainage Basin	The Ganges Drainage Basin in China	Mi Desheng and Xie Zichu *et al.*	2002
Ⅻ The Indus River	The upper reaches of Indus River in China	Mi Desheng and Xie Zichu *et al.*	2002

* "Pamirs" and "Drainage Basins of the Kaxgar River and Others" in Ⅳ Volume are considered as one because the latter is a revised edition of "Pamirs".

Photo 1-1 A meeting on compiling *Concise Glacier Inventory of China* under sponsorship of Prof. Shi Yafeng

in both China and international academic communities. More than 200 papers and monographs resulting from this systematic research were published in journals such as *Journal of Geophysical Research, Annals of Glaciology, Science in China, Chinese Science Bulletin, Acta Geographica Sinica, Journal of Glaciology and Geocryology. Glacier Inventory of China* has been cited for 2330 times in the database of Chinese Scientific Citation (1989~2001). And it has been regarded as the only authority that can provide full-scale information to research organizations, government and production industries.

1.4 Aims of *Concise Glacier Inventory of China*

Those involved in water resource management, disaster prevention, tourism planning and those with special scientific purpose can refer to the detailed *Glacier Inventory of China* and the database (Photo 1-2, Photo 1-3). In comparison, *Concise Glacier Inventory of China* is for the Chinese and overseas readers ranging from scientists to teachers and technicians who are generally interested in glaciers and their changes in China. Its contents are consistent with the detailed general inventory, while replacing the immense amount of information with readable, clearly defined statistical summarization for the readers' convenience. Another advantage of this *Concise*

Photo 1-2 Snow flower in Tianshan

Glacier Inventory of China is that the reliable, up-to-date information about changes in glaciers and their environments is frequently revised and supplemented after each investigation. Glacier changes and their impacts on water resources are documented. All these make this book a trailblazing scientific work in this field. In brief, *Concise Glacier Inventory of China* is markedly different from its published predecessor in the way information is reorganized and descriptions of drainage systems vary with the economic and scientific value of those glaciers.

Photo 1-3 Teram Kangri glacier terminal and lake

CHAPTER 2 COMPILATION CRITERIA AND INTRODUCTION OF *GLACIER INVENTORY OF CHINA*

Wang Zongtai and Zhu Guocai

2.1 Sources of data in *Glacier Inventory of China*

The compilation of *Glacier Inventory of China* required systematic, full-scope measurements and the careful documentation of all geometrical parameters and essential features of glaciers that were investigated. Geometrical parameters was obtained from high-precision, large-scale topographic maps. Essential features must be determined from field investigation. Compilation of *Glacier Inventory of China* has lasted more than 20 years, resulting in wide time spans between data. Geometrical features are measured on 1 : 50,000 or 1 : 100,000 high-precision topographic maps based on photogrammetry. The Volume of the Qilian Mountains (Volume I) used such aerial photographs taken between 1956 and 1973. While topographic maps used for compilation of the upper reaches of the Indus and Ganges Rivers were made around 1984. More than 2000 maps are used in this book.

To determine the exact quantity of glaciers and their geometrical features, glacier extent on the maps were reexamined by using aerial photographs with large scale so that the boundaries between glaciers and seasonal snow cover, and between the debris-covered portion of glaciers and moraines, could be correctly distinguished and documented. The fact that some aerial photographs of mountainous regions were taken between September and November when the ground was largely snow-covered made field verification necessary, as the nine specific field investigations have been carried out and the additional data collected by more than 20 field expeditions have been used. On the basis of such efforts, topographic maps were corrected and updated. Over 342,000 aerial photographs during the 1950s~1970s together with over 200 MSS satellite images between the 1980s and 1990s have been applied in the compilation of *Glacier Inventory of China*.

2.2 Measurements of geometrical parameters of a glacier

The compilation of *Glacier Inventory of China* strictly followed the guidelines of *World Glacier Inventory*. To facilitate a computer-based database, all water system codes and all geometrical parameters are digitalized. 34 geometrical parameters are registered in this book. The specifications for measurement and documentation are stated as follows:

1. Globally unified coding system for water systems. *World Glacier Inventory* is built on the basic unit of the water system, which is encoded into four parts: state code, continent code, water system code and glacier code. Take CN5Y123A4 for example. "CN" stands for "China", "5" for "Asia", "Y" for the first-order drainage system, and "1~3" for the second-, third- and fourth-order drainage basins respectively. "A" represents the lowest-level basins code number, and "4" stands for the code of the glacier. 10 codes for the first-order drainage systems are endowed to China in the international glacier cataloguing specifications (for detailed descriptions and code map of river systems, please refer to Chapter 4).

2. The data marker is denoted by combination of English abbreviations and Arabic numerals. An aerial photograph taken in 1956 with a scale of 1 : 50,000 is recorded as AM · 5 · 56, while a photogrammetric topographic map is abbreviated as "AP", an on-the-spot surveyed map as "TM", and satellite images as "SP".

3. The names of glaciers use the traditional names on the map, or names cited in scientific literature given by researchers, for instance, "Qiyi Glacier". Most of the glaciers are actually nameless, represented only by corresponding codes.

4. Geographic coordinates use longitude and latitude of glacier location. For larger glaciers, the coordinates were measured at the center of the firn basin. For smaller ones, their coordinates are read at the geometric center of the glaciers. All measurements of geographic coordinates have an error of 1% of a minute.

5. Glacier areas: three kinds of area of a glacier were measured, total area, area of exposed ice, and area of ablation area. The unit of area is square kilometer (km^2). The exposed ice area refers to the portion of the glacier that is not covered by the surface debris or moraines. The portion of glacier covered by spare surface debris was treated as exposed ice. Those glaciers with an area of less than 0.02 km^2 are not documented, only recording the total number of such glaciers.

The glacier area covered by rock piles and the surface area with bedrock outcrops were subtracted from the total glacier area if their area exceeding 0.02 km^2.

6. Length of glacier: four kinds of length of a glacier were measured, maximum length, length of the exposed ice, length of the ablation area, and the average length. All measurements were in kilometers (km) and rounded to the nearest tenth. The maximum length refers to the length of central line of a glacier. The average length refers to the average value of each branch maximum length or the average length from each firn basin to the glacier terminus.

7. The average width of a glacier was commonly calculated by dividing the total glacier area by its average length. This parameter was in kilometers (km) and rounded to the nearest tenth.

8. The exposure of a glacier for both the accumulation and ablation areas was denoted by eight orientations (N, NE, E, SE, S, SW, W, NW). In general, most glaciers either in accumulation or ablation areas expose to the same orientation.

9. Four specific altitudes for a glacier were measured as: the highest elevation, defined by the highest elevation of the glacier's back wall; the medial elevation represented by the height of the contour that equally divides the glacier area into two parts; the elevation of the terminus; and the lowest elevation of the exposed ice. These were in meters (m), too. Where there is no surface debris cover, the elevation of the glacier terminus should be the same as the lowest elevation of the exposed ice.

10. The geomorphological classification of a glacier was denoted by a 6-digit code. For example in the code "520102", "5" represents the type of valley glacier, "2" means there are two or more firn basins, "0" means the normal or miscellaneous shape in the glacier front, "1" stands for longitudinal profile that are even and regular, "0" stands for uncertain or miscellaneous of major sources of nourishment, and "2" means the glacier tongue is slight retreat. All glacier geomorphological classification and their corresponding codes are listed in Table 2-1.

11. Glacier activity refers to the advance or retreat of glaciers at the time of measurement. It is in the unit of $\pm$ m · a^{-1}. Where there is no on-the-spot measurement, the corresponding items are left blank.

12. Moraine is represented by a two-digit code. The tens digit stands for modern moraine while the single digit for ancient moraine. Moraines are then divided into nine types, *i.e.* end moraine, lateral moraine, medial moraine, no moraine and other corresponding combinations (Table 2-2).

Table 2-1 Glacier classification's descriptions and code

Code	Digit 1 Primary classification	Digit 2 Form	Digit 3 Frontal Characteristics	Digit 4 Longitudinal profile	Digit 5 Major source of nourishment	Digit 6 Activity of tongue
0	Uncertain or Misc.	Uncertain or Misc.	Normal or Misc.	Uncertain or Misc.	Uncertain or Misc.	Uncertain
1	Continental ice sheet	Compound basins	Piedmont	Even; regular	Snow and/ or drift snow	Marked retreat
2	Ice-field	Compound basin	Expanded foot	Hanging	Avalanche ice and/or avalanche snow	Slight retreat
3	Ice cap	Simple basin	Lobed	Cascading	Superimposed ice	Stationary
4	Outlet glacier	Cirque	Calving	Ice-fall	—	Slight advance
5	Valley glacier	Niche	Coalescing, non-contributing	Interrupted	—	Marked advance
6	Mountain glacier	Crater	—	—	—	Possible surge
7	Glacieret	Ice aprons	—	—	—	Known surge
8	Ice shelf	Groups of small units	—	—	—	Oscillating
9	Rock glacier	Remnant	—	—	—	—

Table 2-2 Types of moraines and code

Code	0	1	2	3	4	5	6	7	8	9
Moraine types	No moraine	End moraine	Lateral and/or medial moraine	Push moraine	Combination of 1 and 2	Combination of 1 and 3	Combination of 2 and 3	Combination of types 1, 2 and 3	Debris, uncertain if moraine	Moraines, type uncertain or not listed

13. The glacier snowline altitude (SLA) refers to a specific firn line altitude (FLA) rather than the glacier equilibrium line altitude (ELA). Since direct observational data on the SLA for most glaciers are lacking (otherwise they are documented according to the altitude of the snowline), this parameter is measured indirectly through interpretation of aerial photos or topographic maps. The Hess method is adopted during map interpretation to identify contours in relatively smooth sectors between the convex in the accumulation area and the concave in the ablation area. The so-called Lieyd approach is used to interpret aerial photos, calculating the average height of crevices on the margin of the firn basin and the height on the maximum surface till in the ablation area. The maximum height of medial or lateral moraines is occasionally chosen as the approximation for the height of the firn line. These indirect methods have a margin of error of 50~100m.

14. Glacier volume is calculated by multiplying the glacier area by its average thickness. This indicator is in the unit of km^3 and is rounded to four digits after the decimal point.

2.3 Measurements of ice thickness and estimation of ice volume

Measurements of glacier thickness: Ice penetrating radar (radio echo sounding method) was first used to measure ice thickness of the Antarctic Ice Sheet several decade years ago. In May 1979, the Chinese glaciologists also succeeded for the first time in measuring ice thickness of the glacier tongue of the Yanglong River Glacier in the Qilian Mountains using the KDL-A model of geological radar for mining. After that, to meet the need of compilation of *Glacier Inventory of China*, another measurement was carried out on the Glacier No.1 at the source of the Urumqi River (Glacier U-1) in the Tianshan Mountains in October 1980 by using a newly-designed radar module by the Lanzhou Institute of Glaciology and Geocryology, CAS. This model was improved into the B-1 model radar for ice thickness measurements during 1981~1982. This radar was widely used between 1981 and 1987 on 23 glaciers in the Tianshan Mountains, the Qilian Mountains and the West Kunlun Mountains, for more than 2000 sounding sites, along 95 cross-sections of 104 km long. In early 1983 a new model of low-frequency single-pulse radar came into use on four temperate type glaciers in the Mount Gongga of the Hengduan Mountains, where 54 sounding sites were measured along 13 cross-sections with 6 km.

Ice penetrating radar, a type of radar designed to penetrate specific media such as ice and snow, identifies the distance and orientation of the target through the reflected electromagnetic waves from motionless ice-bed rock, icebound holes and inner tills.

According to the known characteristics of low absorbent loss of the electromagnetic waves below 500MHz, the nearly dielectric constant of the ice mass in different temperatures, and given the sharp contrast between the dielectric constant of the ice mass and the ice-bed rock, the glacier thickness can be calculated with this method of radar measurement. The following equation is valid when the distance between the sending and receiving antenna is far less than the reflecting distance:

$$H=v_i\,(\tau_B-\tau_A+\tau_C)\div 2 \tag{2-1}$$

where: H = the distance from the reflector to the antenna, in meters (m)

v_i = the propagating velocity of electromagnetic waves in ice, v_i = 169m/μs

τ_B = the time delay of reflected waves, in μs

τ_A = the time delay of through waves, in μs

$\tau_B-\tau_A$ = the time slice between the reflected wave and the through wave displayed on the radar screen

τ_C = the additional time delay of the radar system when the space between the sending and receiving antennas equals 7m, τ_C = 0.04μs

Table 2-3 lists ice thickness measured by radar sounding in comparison with that of borehole measurement. The overall error of radar-surveyed thickness relative to borehole data is no more than 5%.

Table 2-3 Comparison of radar-surveyed thickness with that of borehole measurement

Name of glaciers	Surveying sites	Ice-radar thickness measurement		Borehole thickness measurement		Precision
		Thickness (m)	Date	Thickness (m)	Drilling date	(m)
Glacier U-1	East branch between C3-D3 sticks	110	1981.8	109.91	1982.08	+0.09
Glacier U-1	East branch B3 stick	74	1981.8	70.00	1983.08	+4.00
Glacier U-1	East branch H stick east offset 20m	90	1981.8	90.00	1990.11	0.00
Glacier U-1	East branch between B2-C3 sticks	75	1981.8	72.40	2001.01	+2.60
Hailuogou	Ⅰ horizon-3 to Ⅱ horizon-3	126	1983.8	125.00	1992.07	+1.00
Hailuogou	Ⅱ horizon-3	147	1983.8	147.00	1994.05	0.00

Table 2-4 gives the final results of thickness measurements on 27 glaciers, of which 16 are in the Tianshan Mountains, 6 in the Qilian Mountains, 4 in the Mount Gongga and one in the West Kunlun Mountains. Key sites for surveying include Glacier U-1, Qiyi Glacier and Laohugou No.12 Glaciers in the Qilian Mountains, and Hailuogou Glacier in the Mount Gongga and Chongce Glacier in the West Kunlun Mountains. Table 2-4 lists surveyed glacier sections, the number of sites, cross-sectional length, maximum thickness and altitude. Among the surveyed glaciers, the maximum ice thickness of the maritime-type glaciers in China is 263 m in Da Gongba Glacier in the Mount Gongga. It is located 4.47 km away from the glacier terminus with an altitude of 4380 m a.s.l. The maximum thickness of the continental-type glaciers is 192 m found from the Heigou No.8 Glacier in the Mount Bogda of the Tianshan Mountains at the altitude of 3840 m a.s.l., right below a place where two firn basins converged.

Figure 2-1 illustrates the sounding profiles and the isopleth of ice thickness on the Qiyi Glacier in the Qilian Mountains. The longitudinal profile and a typical cross section of the glacier are shown in Figures 2-2 and 2-3. The ice thickness distribution in the Qiyi Glacier demonstrates the following features: 1) The maximum ice thickness typically appears above the outlet of the firn basin, where the maximum thickness of 117 m occurred at an altitude of 4536 m a.s.l. and 4710 m a.s.l.; 2) Based on surface velocity measurements, the cross-section with maximum ice thickness is consistent with areas of maximum surface velocity; 3) The pattern of glacier surface flow is closely linked to ice-bed form. The mainstream line of ice flow is obtained by connecting the maximum thickness points in each section. Comparing the Ⅱ, Ⅲ, Ⅳ and Ⅴ cross-sectional forms, it was concluded that the topography of the glacier bed at terminus is determined by the upstream ice flow direction, and that the left-side slope is rather steep in response to the erosive force of the mainstream ice flow; 4) The altitude of ice bed in the terminus is obviously lower than the height of the conterminous riverbed. It can be inferred from Figure 2-2 that the riverbed exceeds the height of the glacier bed by several meters to more than 30 meters. This implies that the buried ice should exist under the riverbed bellow the glacier terminus. Glacier area with sounding measurement in Figure 2-1 account for 48% of the total glacier area, with the remainder being the back cliff of the firn basin and the mountain peak. It is estimated that the average ice thickness in the sounding region is 66.4 m and the ice volume is estimated to be 0.0885 km^3. For the non-surveyed areas, these two figures are 53.5 m and 0.0776 km^3, respectively. The

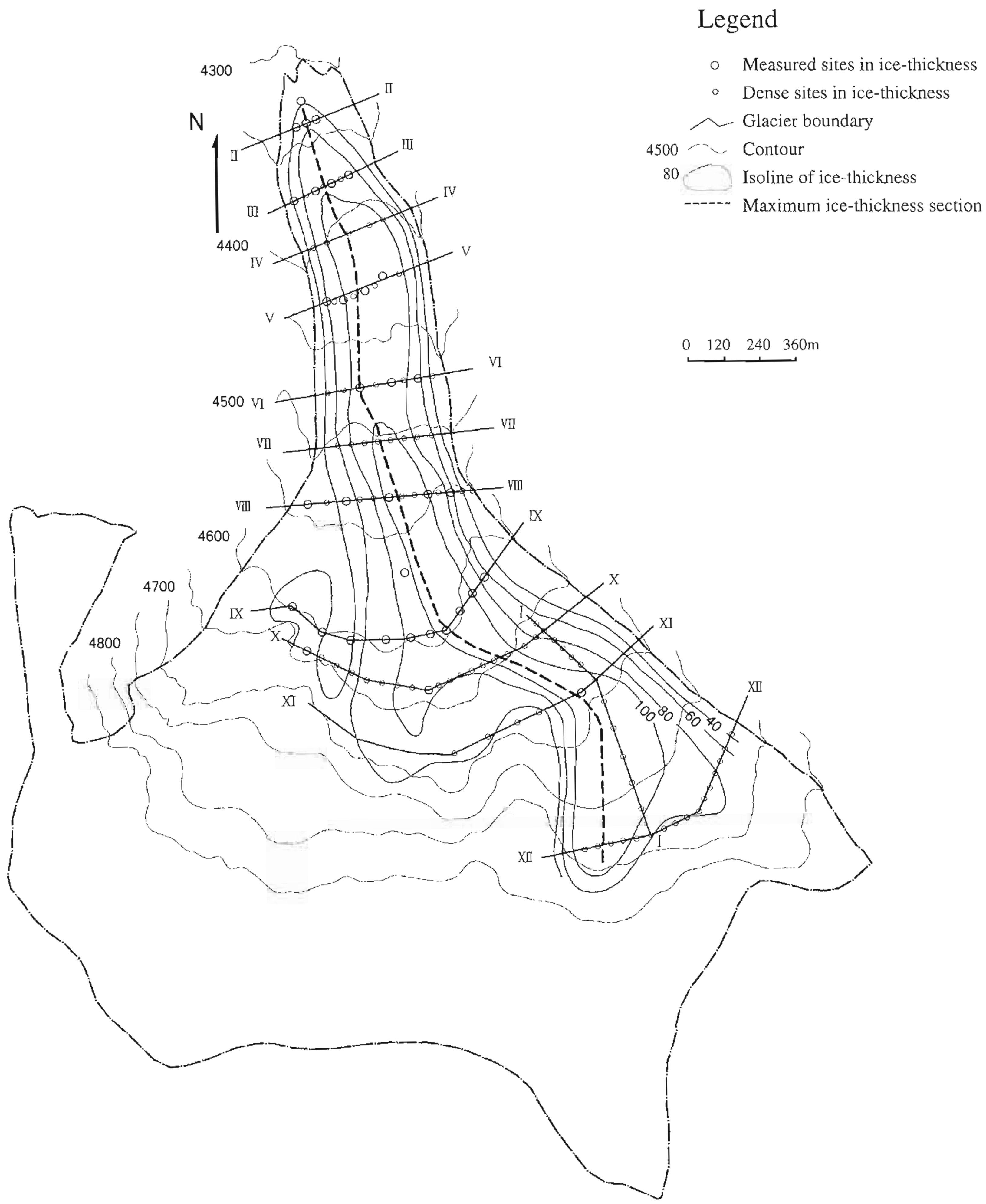


Figure 2-1 Thickness measurements points and the isopleth of ice-thickness distribution of the Qiyi Glacier

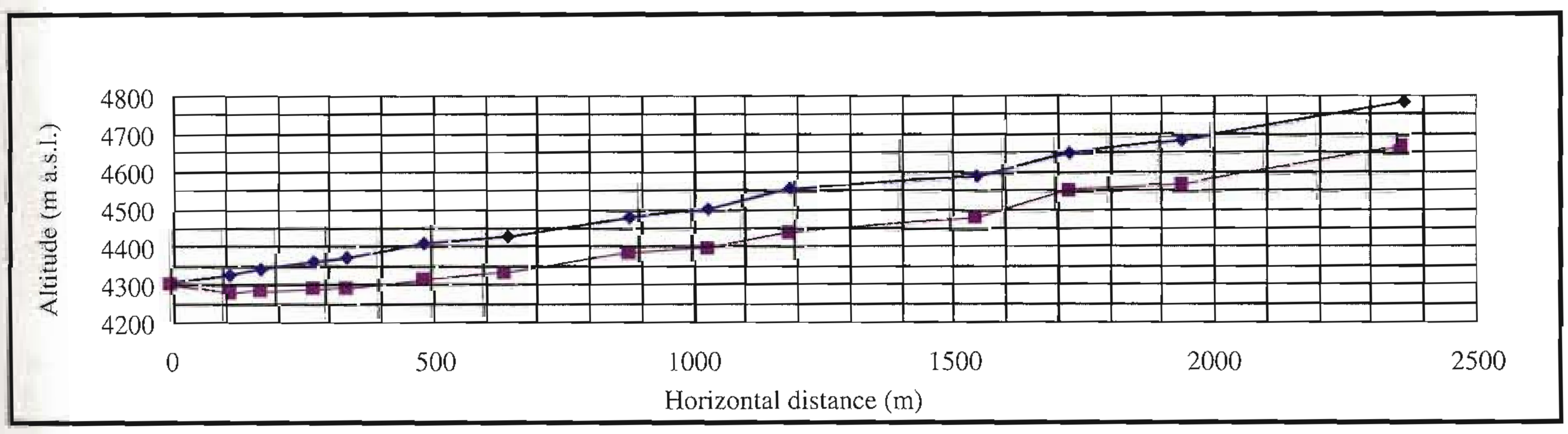


Figure 2-2 Longitudinal profile of maximum ice thickness between glacier surface (upper line) and bed (below line) in the Qiyi Glacier

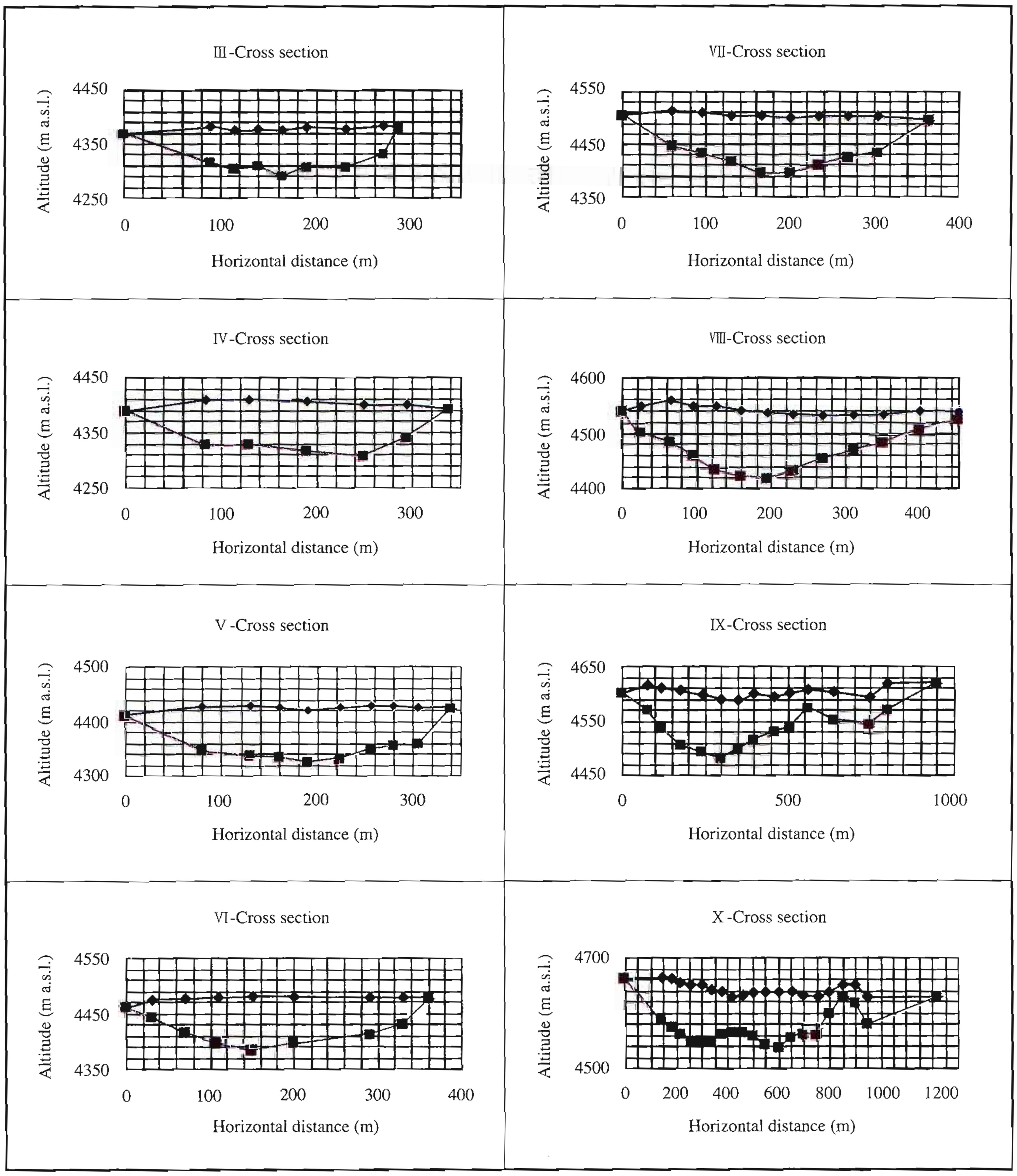


Figure 2-3 Typical cross-sectional profiles in the Qiyi Glacier

average thickness of the Qiyi Glacier is 59.7 m and the ice volume is 0.166 km^3.

Estimation of ice volume: The measured ice thickness data from 27 glaciers show that the thickness of glaciers increases with glacier area increase (Figure2-4). The relationship between the average thickness ($\bar{H}$,m) and area (F_g, km^2) of a glacier has been established as follows:

$$\bar{H} = -11.32 + 53.21 F_g^{0.3} \qquad (2\text{-}2)$$

Equation 2-2 is applicable only for cirque glaciers, cirque-valley glaciers, valley glaciers and mountain ice caps. Because the most observed glacier areas are smaller than 8.0 km^2, the

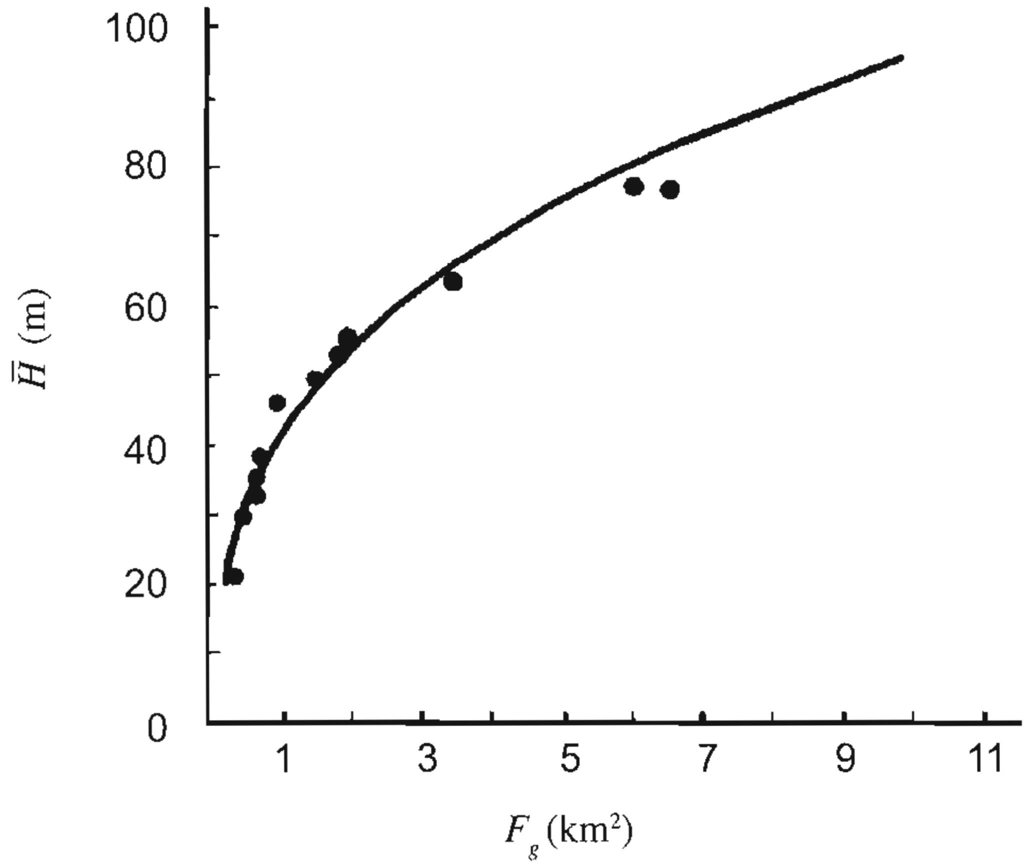


Figure 2-4 Relationship between average thickness ($\bar{H}$) and glacier area (F_g)

errors for the thickness estimation are acceptably low, ranging from 5% to 10% with glacier area less than 8.0 km^2. This error grows relatively larger for large glaciers with an area more than 8.0 km^2 that are only sparsely surveyed. For hanging glaciers and mountain slope glaciers that have a smaller average thickness than other types of glaciers with the same size, we take the formula used in the Qilian Mountains:

$$\bar{H} = 34.4F_g^{0.45} \tag{2-3}$$

Ice volume in km^3 for each glacier can be obtained by multiplying the average thickness of each type of glacier calculated from the above mentioned equations by the corresponding glacier area. Total ice volume in each watershed and/or mountain area is the sum of the ice volume of each glacier.

The nonlinear relationship indicates that ice volume of basins or mountainous regions not only depends on the total glacier area, but also on the average glacier area ($\bar{F}_g$). Therefore the average glacier area in a glacierized watershed is divided into 3 levels: $\bar{F}_g$<1.0 km^2, 1.0 km^2 to 3.0 km^2, and $\geqslant$ 3.0 km^2. We obtained equations for ice volume estimations (V_g) for glaciers in different average sizes (F_t), as shown below:

$$V_g = 0.0305F_t^{1.11} \qquad \bar{F}_g < 1.0 \text{ km}^2 \tag{2-4}$$

$$V_g = 0.5420F_t^{1.06} \qquad 1.0 \text{ km}^2 \leqslant \bar{F}_g \leqslant 3.0 \text{ km}^2 \tag{2-5}$$

$$V_g = 0.0674F_t^{1.16} \qquad \bar{F}_g > 3.0 \text{ km}^2 \tag{2-6}$$

The correlation coefficients for each equation are greater than 0.96 and therefore can be used to estimate the ice volume of glaciers in a glacierized basin. Furthermore, these equations are also applicable to derive the approximate ice volume of a glacier during the Ice Age.

CHAPTER 3 PHYSICAL CONDITIONS FOR GLACIER DEVELOPMENT IN CHINA

Liu Chaohai

3.1 Mountains and glaciers in West China

Since the late Tertiary, the mountain systems in West China, from the Himalayas and the Qinghai-Xizang (Tibet) Plateau in the south to the Tianshan Mountains and the Altay Mountains

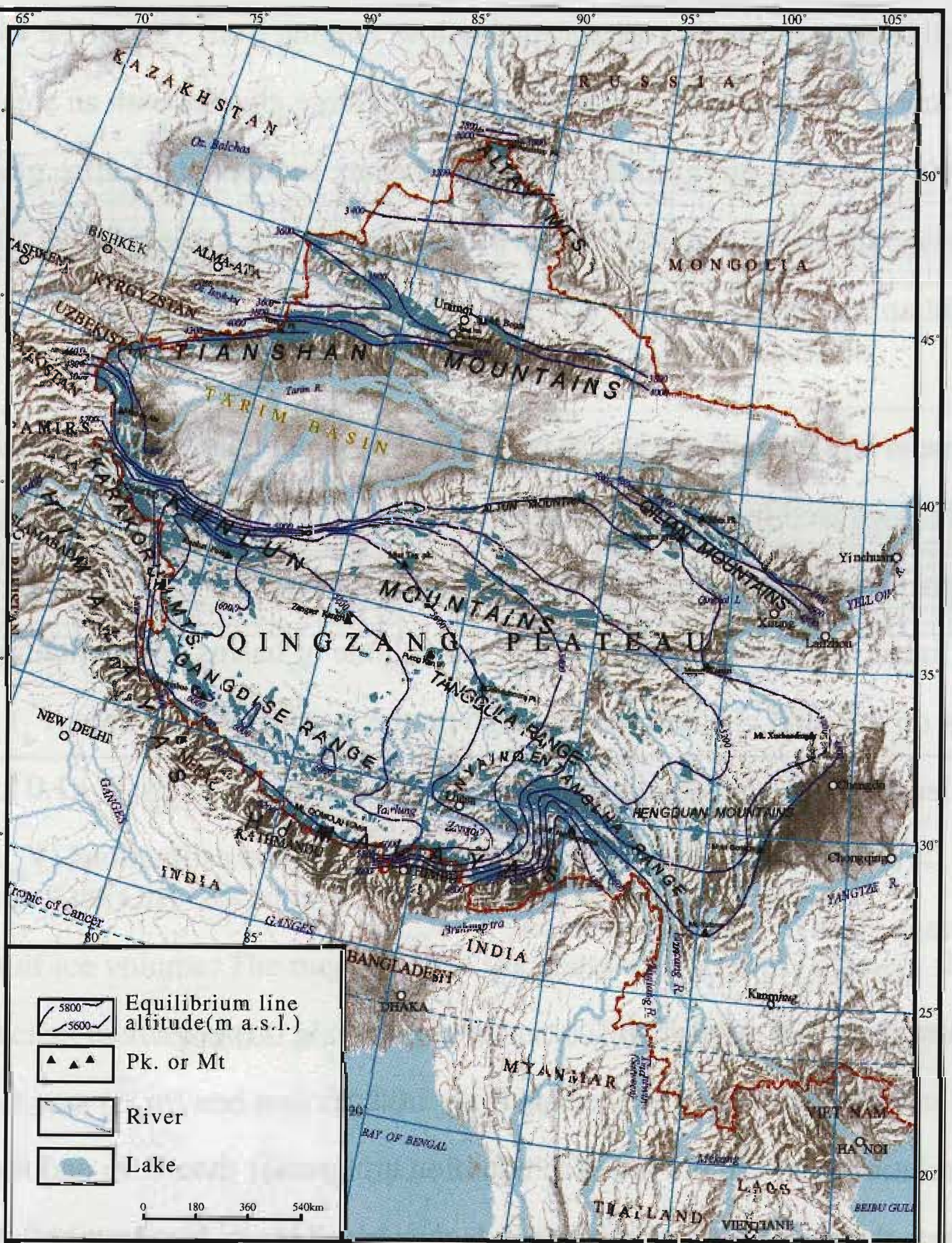


Figure 3-1 Mountains and the snowline altitude distribution in West China

Photo 3-1 The Kunlun Mountains and their glaciers (Cited from *Chinese Glaciers*, 1980)

Photo 3-2 The Himalayas and their glaciers from the northern slope (Shen Yongping)

in the north, have been rapidly uplifting, giving the birth of the world's largest and highest mountains and plateaus (Figure 3-1). The tectonic thrust that lifted the mountains above the snowline altitude (SLA) led to the formation of many large alpine glaciers, making China a country with the most alpine glaciers in the middle and low latitudes.

The altitude of a mountain above the equilibrium line or snowline altitude is the key factor that determines the formation of glaciers. The difference of altitudes between the peak and the equilibrium line altitude (ELA) determines the number and sizes of glaciers formed around the mountain (Photo 3-1, Photo 3-2). The climate factor in a region can be represented by equilibrium line altitude (Z_s, m), and the topographical condition can be represented by the accumulation area above the ELA (ΔF_g, km^2) and the highest altitude in the accumulation area (Z_{max}, m). Glacier number (N_g), area (F_g, km^2) and volume (V_g, km^3), developed in the mountain are related to the ΔF and the altitudinal difference above ELA or SLA ($\Delta Z=Z_{max} - Z_s$). In the Tianshan

Mountains, such relations are shown quantitatively as given by Ye Baisheng and Lai Zuming (1992), as follows:

$$F_g = 1.35\ \Delta F^{0.82} / \Delta Z^{0.55} \qquad (R=0.97) \qquad (3\text{-}1)$$

$$N_g = 1.01\ \Delta F^{0.93} / \Delta Z^{0.50} \qquad (R=0.95) \qquad (3\text{-}2)$$

$$V_g = 0.036 F_g^{1.73} / N_g^{0.62} \qquad (R=0.99) \qquad (3\text{-}3)$$

Table 3-1 Distribution of glaciers on mountains in China

Mountain system	Mountain area (km²)	Highest elevation (m)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)	Glacier coverage (%)
			Number	(%)	(km²)	(%)	(km³)	(%)		
Altay	28,800	4374	403	0.87	280	0.47	16	0.29	0.69	0.97
Sawir	4400	3835	21	0.05	17	0.03	1	0.02	0.81	0.38
Tianshan	211,900	7435	9035	19.48	9225	15.52	1011	18.05	1.02	4.35
Pamirs	23,800	7649	1289	2.78	2696	4.54	249	4.45	2.09	11.33
Karakorum	26,600	8611	3563	7.68	6262	10.54	692	12.36	1.76	23.54
Kunlun	478,100	7167	7697	16.60	12,267	20.64	1283	22.91	1.59	2.57
Altun	56,300	6295	235	0.51	275	0.46	16	0.29	1.17	0.49
Qilian	132,500	5827	2815	6.07	1931	3.25	93	1.66	0.69	1.46
Qiangtan	441,900	6822	958	2.06	1802	3.03	162	2.89	1.88	0.41
Tanggula	141,300	6621	1530	3.30	2213	3.72	184	3.28	1.45	1.57
Gangdise	158,300	7095	3554	7.66	1760	2.96	81	1.45	0.50	1.11
Nyainqentanglha	110,600	7162	7080	15.27	10,700	18.01	1003	17.91	1.51	9.67
Hengduan	356,300	7556	1725	3.72	1579	2.66	97	1.73	0.92	0.44
Himalayas	202,500	8844	6472	13.95	8418	14.17	712	12.71	1.30	4.16
Total	2,373,300	8844	46,377	100.00	59,425	100.00	5600	100.00	1.28	2.50

14 mountain systems in West China are distributed in parallel one after the other from the north to the south, including the Altay Mountains, the Tianshan Mountains, the Pamirs, the Karakorum Mountains, the Kunlun Mountains and the Himalayas. As shown in Table 3-1, the total glacier area and ice volume in the Tianshan Mountains, the Karakorum Mountains, the Kunlun Mountains, the Nyainqentanglha Range and the Himalayas account for 78.9% and 84.0%, respectively, of the corresponding totals in China.

We define an index, the ratio of the glacier area to the mountains area, to indicate the degree of glacier coverage in a mountain system. The Tianshan Mountains, the Pamirs, the Karakorum Mountains, the Kunlun Mountains, the Nyainqentanglha Range and the Himalaya have a higher degree of glacier coverage than the average of 2.5%, among all the mountains in West China. Around the peaks of the above mountain systems there are huge radially distributed valley glaciers and glacierized centers such as the Mount Qogir in the Karakorum Mountains, the Hantengri (Khan Tengri)-Tomur Knot in the Tianshan Mountains, the Kunlun Peak in the West Kunlun Mountains, peaks in the east Nyainqentanglha Range and the Mount Qomolangma in the Himalayas. All 33 of the glaciers with more than100 km^2 in area are located in these glacierized centers with a glacier coverage ranging from 20% to 46% in China, called half-covered glaciated regions (Wang Zongtai and Liu Chaohai, 2001). Most notably, the West Kunlun, bounded by the Keriya River to the east, form the largest glacierized center in China, covering an area of 10,844 km^2 by 6580 glaciers, among which nine glaciers with more than 100 km^2 in area are centered around the Kunlun Peak (Figure 3-2). At the highest peak in the world, the Mount Qomolangma, the largest glacier is the Rongbuk Glacier, 85.4 km^2 in area. There is no glacier with more than 100 km^2 in area in the Mount Qomolangma. Although the Mount Qomolangma is the highest in the world, the steep and narrow ridges of the mountain are not a beneficial condition for the development of large glaciers.

The different combinations of water and heat conditions with topographical factors result in different patterns of glacier distribution on both the southern and northern slopes of every mountain. Generally speaking, the glacier, the glacier area and ice volume should be larger

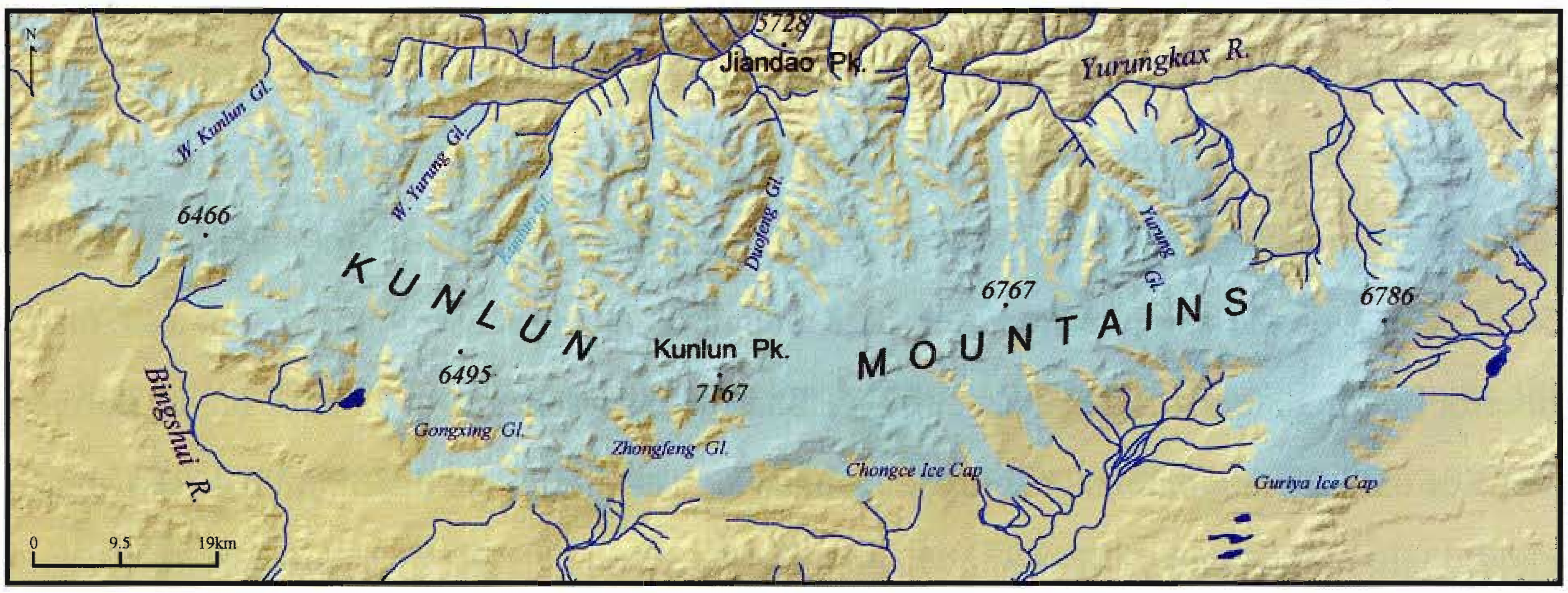


Figure 3-2 Distribution of glaciers around the Kunlun Peak in the West Kunlun Mountains

on the northern slope with low temperature. However, the average area of an individual glacier tends to be larger on the southern slopes than on the northern slopes in West China. The asymmetric distribution on the northern and southern slopes of each mountain is of the following characteristics: 1) Mountains with large glacier number and area on the northern slopes than those on the southern slopes include seven mountains, the Karakorum Mountains, the Pamirs, the Qilian Mountains and so on; 2) Mountains with more glacier number on the northern slopes than those on the southern slopes, but larger mean glacier area on the southern slopes than that on the northern slopes, including the east and west Kunlun Mountains, the Tanggula Range and the Himalayas; 3) The Nyainqentanglha Range is the only mountains with more glacier number, area and volume on the southern slopes than those on the northern slopes. The southern slopes of the east part of the range are in the main pathway of the northward warm and humid moisture from the Indian Ocean monsoons, resulting in an annual precipitation ranging from 2500 mm to 3000 mm at the snowline altitude in the region. The abundant rainfall offsets the effect of higher temperatures on glacier development on the southern slopes and creates more and larger glaciers there than on the northern slopes; 4) The Tianshan Mountains are a special case. Although glaciers on the northern slopes outnumber those on the south, the glacier area and ice volume are both larger on the southern slope. This is because the northward situation of the main ridges of the Hantengri-Tomur Knot, densely populated by glaciers, leaves broad space for the development of huge valley glaciers on the southern slopes.

The distribution of SLA in West China is illustrated in Figure 3-1. The lowest snowline altitude exists at an altitude of about 2800 m a.s.l. in the Haba River basin in the Altay Mountains (49°06′ N). The snowline altitude is generally higher in mountains with lower latitudes. The snowline altitude ranges from 4000 m a.s.l. in the northern Tianshan Mountains at 44° N, to 5400 m a.s.l. on the northern slopes of the Kunlun Mountains at 37° N, to 5800 m a.s.l. on the interior of Qinghai-Xizang Plateau at 34° N, and finally reaches 6000 m a.s.l. on the northern slope of the Mount Qomolangma in the Himalayas. The altitudinal distribution of snowline is clearly latitude-dependent. The snowline altitude rises on average by 152.4 m with 1 degree southward in latitude.

The Qinghai-Xizang Plateau is the highest plateau in the world. The Plateau's tremendous influence on heat budgets and precipitation creates the anomaly of an asymmetric ring-shaped pattern of snowlines between the Plateau heartland and its peripheral mountains. Precipitation decreases dramatically from the peripheral mountains in the Plateau's east and southeast to the west and northwest, reaching the minimum in the Plateau's western region. Total solar radiation is also maximized on the western part of the Plateau, where a heat anomaly creates a temperature 4~6℃ higher than that of the free atmosphere at the same altitude in the eastern part. These water and heat conditions make the snowline altitude (SLA) higher in the west and northwest than that in the east or southeast. The maximum altitude of snowlines (5800~6000 m a.s.l.) occurs on the western and southern sides of the Plateau. Snowline altitudes in the eastern part are at least 1000 m lower than those at the same latitude in the western part. In the southeast Tibetan region, there is a track of the Indian Ocean monsoon where precipitation is quite abundant and, therefore, a low-SLA area extends northwards in a tongue-like manner. The snowline altitude on the southern slopes of the Himalayas from 28°N ~ 29°N, is about 600 m lower than the average snowline altitude on the northern slopes in response to the greatly increased precipitation. This contributes to the anomaly of the snowline altitude being higher on the northern slopes than that on the southern slopes. This snowline altitude distribution is only a generalization, however. For specific mountain regions, the snowline altitude may differ by hundreds of meters even within a short distance owing to glaciers' slopes, exposures, and their mass balance.

3.2 Climatic conditions for glacier development

Water (precipitation), heat (temperature), and their combination are the major climatic factors that influence the development of glaciers. Precipitation determines glacial accumulation, while temperature controls glacial ablation. They together determine the features, growth, and evolution of glaciers.

Precipitation is closely related to atmospheric circulation. In respect of moist air sources, the south Asian monsoon circulation and the westerly circulation are dominant in the alpine regions in West China. The large extension of the Qinghai-Xizang (Tibet) Plateau and its high altitudes in the interior of the Asian continent originate the special plateau monsoon circulation, together with the local circulation in certain mountain regions, both greatly influencing the mountain precipitation.

The south Asian monsoon circulation nurtures mountain glaciers on the major part of the Qinghai-Xizang (Tibet) Plateau. After the beginning of the rainy season in the Zayu Qu region of southeast Tibet in March, the onset of the monsoons in late May and early June forces humid air from the Indian Ocean northward through the gateway of the great hairpin bend of the Yarlung Zangbo onto the Plateau, into the upstream of the Yangtze River and the Yellow River, finally reaching the Qilian Mountains. The East Nyainqentanglha Range in Southeast Tibet and the Hengduan Mountains enjoy the longest and most abundant rainy season, with an annual precipitation of 1000~3000 mm at the equilibrium line altitudes, creating a typical region of maritime type or monsoonal temperate glaciers in China.

In winter, the north and south branches of the westerly circulation control the whole Qinghai-Xizang (Tibet) Plateau by creating cold high-pressure zones dominated by blue skies and sparse rainfall. However, in winter and spring the mountains on the western margin of the Plateau, such as western section of the Himalayas, the Karakorum Mountains, the West Pamirs, the West Tianshan and the Altay Mountains, receive relatively more precipitation. In the summertime the westerly circulation migrates northward on the Plateau. The topographical uplift of moisture creates an annual precipitation greater than 1000 mm at the western edge of the Pamirs and the West Karakorum Mountains where snowlines are somewhat lowered. Eastward in the East Pamirs and the West Kunlun Mountains, precipitation drops to only 300~500 mm, and snowline altitudes are elevated much higher than that in the West Pamirs. Glaciers there depend on the cold climate provided by the body of mountains.

Seasonal thermodynamic differentiation between the huge mass of the Qinghai-Xizang (Tibet) Plateau and the surrounding free atmosphere creates a plateau monsoon. In winter, the atmosphere over the Plateau is a source of coldness relative to the free atmosphere at the same altitude, creating anti-cyclones. In summer, however, the atmosphere over the Plateau produces heat, which in turn forms strong, warm low-pressure zones. Water vapor in this cyclonic circulation condenses and precipitates as rainfall when lifted over the surrounding high mountains, creating rainy belts. Precipitation decreases considerably from the peripheral areas into the Plateau heartland. Valley wind circulation in mountainous regions also plays an important role in alpine precipitation. Intense upward moving air currents coming out of the valleys in the daytime form cumulus clouds at vapor condensing height and relatively rich precipitation. In the alpine zones of the Tianshan Mountains, the Pamirs, the Karakorum Mountains and the Himalayas the higher maximum rainfall belt exists, second only to the maximum rainfall belt existing at roughly 1000~2000 m a.s.l. in the mid-mountain ranges. However, in the West Qilian Mountains, the West Kunlun Mountains and on the western Qinghai-Xizang (Tibet) Plateau where water vapor content decreases with the rise in aridity no second maximum rainfall belt exists (Shi Yafeng and Bai Chongyuan, 1988).

As a result of these air circulation conditions, precipitation in the mountains in West China is considerably greater than that in the valleys or basins. Belts of rich rainfalls are the most abundant on the peripheral mountains of the Plateau. Away from sources of water vapor in the northwest, northeast and southeast, the precipitation decreases gradually when moving into the interior of the Plateau. On the Qiangtan Plateau where the eastern part of the West Kunlun Mountains and the West Qilian Mountains are located, the continental climate is especially cold and dry, making it the coldest and most arid poles of the Northern Hemisphere (Zheng Du *et al.*, 1996).

The pattern of yearly precipitation distribution and the timing of high precipitation have more influence on glaciers than the total amount of solid precipitation on their surfaces. Due to the influence of the Atlantic and the Arctic Ocean air currents, the winter and spring precipitation makes up a large percentage of the annual total, while the summer precipitation accounts for 40% or less, the maximum precipitation occurs between May and June in the Altay Mountains, the West Tianshan Mountains, the West Pamirs and the West Karakorum Mountains (Yang Zhenniang,1991). The precipitation sources tends to concentrate in the summer months with distance from the water vapor. Rainfalls from May to September account for over 80% of the total annual precipitation. In many regions, for example the East Tianshan Mountains, the middle and eastern part of the West Kunlun Mountains, the West Qilian Mountains and the west fringe of the Qaidam Basin, there are summer precipitation centers, where the summer precipitation accounts for 90% or more of the annual precipitation, the maximum precipitation period is delayed until July or August. As a result, glacier accumulation and ablation in most mountains of West

China are almost simultaneous in summer. As compared with glaciers in the Alps of Europe and elsewhere, which are nourished by heavy westerly precipitation, glacier accumulation and ablation in West China are low, the level of mass balance is lower and glacier stability is higher. The altitude of the glacier terminus and the equilibrium line altitude are higher by 700~1000 m than those on the European and North American mountains at the same latitude. The highest snowline altitude (6200 m a.s.l.) in the Northern Hemisphere occurs on the north slopes of the Himalayas and the West Qinghai-Xizang Plateau (Shi Yafeng and Bai Chongyuan, 1988).

Air temperature generally decreases with increasing altitudes, but the relationship between air temperature and altitude is non-linear. The temperature lapse rate actually escalates during the transition from a non-glacier area onto the glacier surface, called the temperature jump, commonly being 0.2~3.5℃ as observed in the field investigations. Calculating from the lapse rate of air temperature and considering the air temperature jump, Yang Zhenniang (1991) found that the annual mean air temperature may drop to −15 ~ −4℃ at the ELAs of glaciers in West China. The summer mean air temperature during May to August varies between −2.5~4.2℃ with the maximum temperature of 3.9~4.2℃ in the mountainous region with maximum precipitation in the southeast Tibet and the minimum temperature of −2.5~ −2.0℃ in the mountainous region with minimum precipitation in the West Kunlun Mountains and Muztag Ata in the East Pamirs. On mountain peaks where glaciers develop, the temperature is significantly lower. A former USSR mountaineer recorded a −38℃ record in September on the Hantengri (Khan Tengri) Peak at 6995 m a.s.l. (Рацек, 1954). The average summer temperature can be as low as −21℃ there (Liu Chaohai and Ding Liangfu, 1988). According to the temperature lapse rate, the annual average temperature on the Mount Qomolangma is estimated as low as −27℃. This indicates that the high mountains in West China become the regions of perennial negative temperatures nestled above the river valleys or basins, providing essential atmospheric conditions for glacier development.

Under stable conditions, glacial accumulation at the equilibrium line altitude (ELA), represented by annual precipitation (P_a,mm) at this altitude, is balanced by glacial ablation, related to the mean summer temperature ($T_{6\text{-}8}$,℃) from June to August. Consequently, combinations of P_a and $T_{6\text{-}8}$ reflect the glacier state in a given region, and also are indicators of the features, type and activity of a glacier. Based on an indirect calculation, a regress equation can be established between $T_{6\text{-}8}$ and P_a at the ELAs based on measurements on 16 glaciers in West China and the Batura Glacier in Kashmir, as shown in Figure 3-3 and equation (3-4), with a correlation coefficient r=0.936, at the significance test of a =0.01.

$$T_{6\text{-}8} = -15.4 + 2.48 l_n P_a \quad (3\text{-}4)$$

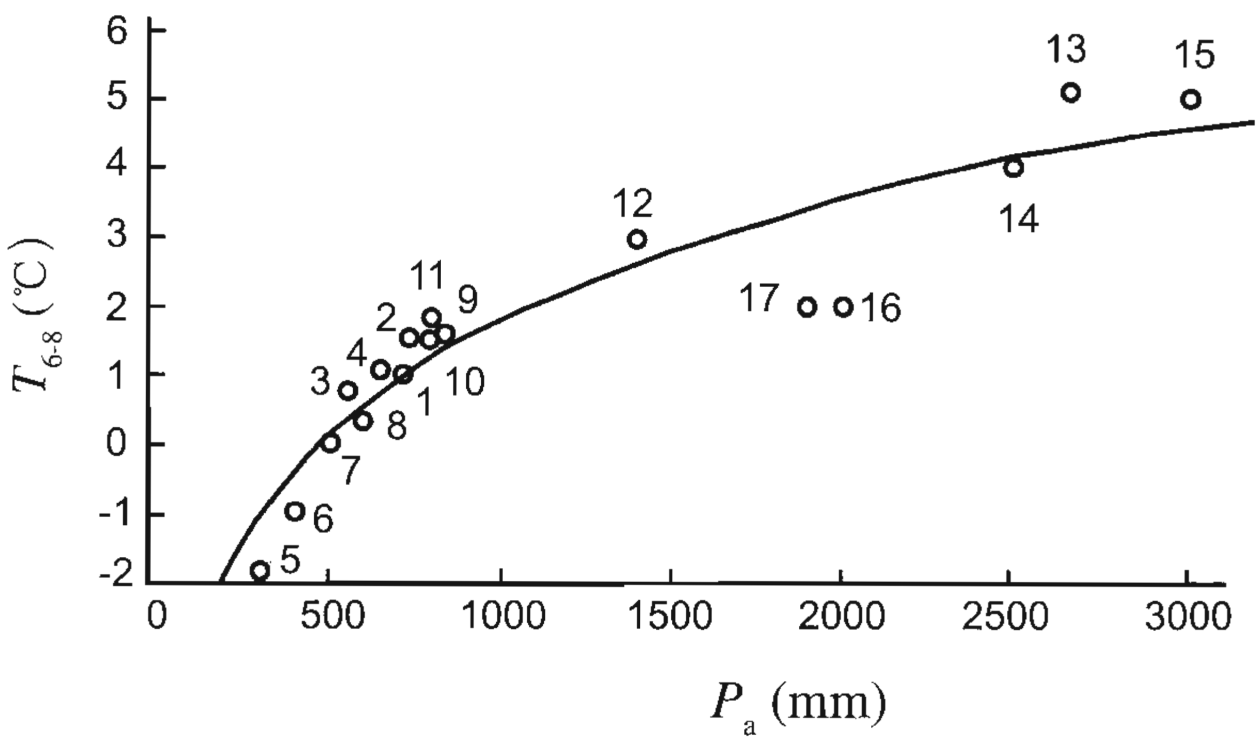


Figure 3-3 Relationship between summer mean air temperature ($T_{6\text{-}8}$) and annual precipitation (P_a) at ELAs of 16 Chinese glaciers and the Batura Glacier in the Kashmir actually controlled by Pakistan (By courtesy of Lai Zuming)

1. Kanas Glacier in the Altay Mountains; 2. West Qong Terang Glacier in the Tianshan Mountains; 3. Glacier U-1 in the Tianshan Mountains; 4. Sigonghe Glacier No.5 in the Tianshan Mountains; 5. Kaltamak Glacier in the Pamirs; 6. Laohugou Glacier No.12 in the Qilian Mountains; 7. Qiyi Glacier in the Qilian Mountains; 8. Yanglonghe Glacier No.5 in the Qilian Mountains; 9. Shuiguanhe Glacier No.4 in the Qilian Mountains; 10. Dasuopu (Yebokangjiale) Glacier in the Himalayas; 11.Rongbuk Glacier in the Himalayas; 12. Batura Glacier in the Karakorum Mountains (in Kashmir area actually by Pakistan); 13. Rogoi Glacier in the Nyainqentanglha Range; 14. Guxiang Glacier in the Nyainqentanglha Range; 15. Azha Glacier in the Kangri Garpo Range; 16. Baishuihe Glacier.No.1 in the Hengduan Mountains; 17. Hailuogou Glacier in the Hengduan Mountains.

As shown in Figure 3-3, the summer mean air temperature increases with increase of annual precipitation or accumulation at the ELA, creating more ablation that balances the high accumulation. Therefore, we can deduce the annual precipitation if we know the summer mean air temperature at the ELA, and vice versa. For example, the ELA on the northwest Qinghai-Xizang (Tibet) Plateau is as high as 5600~6000 m a.s.l. with an annual precipitation of 200~300 mm, and the corresponding summer mean air temperature of less than −1℃.

3.3 Glacier types and their distribution

Glaciers in China have been divided into three types according to the climatic and topographical conditions, as well as physical properties of glaciers (Shi Yafeng and Liu Shiyin, 2000). The distribution of these three glacier types in China is illustrated in Figure 3-4. The boundaries between these three types are not strictly defined and may overlap. Further improvement is needed.

Maritime type or monsoonal temperate type glaciers: On such kind of glaciers, the annual

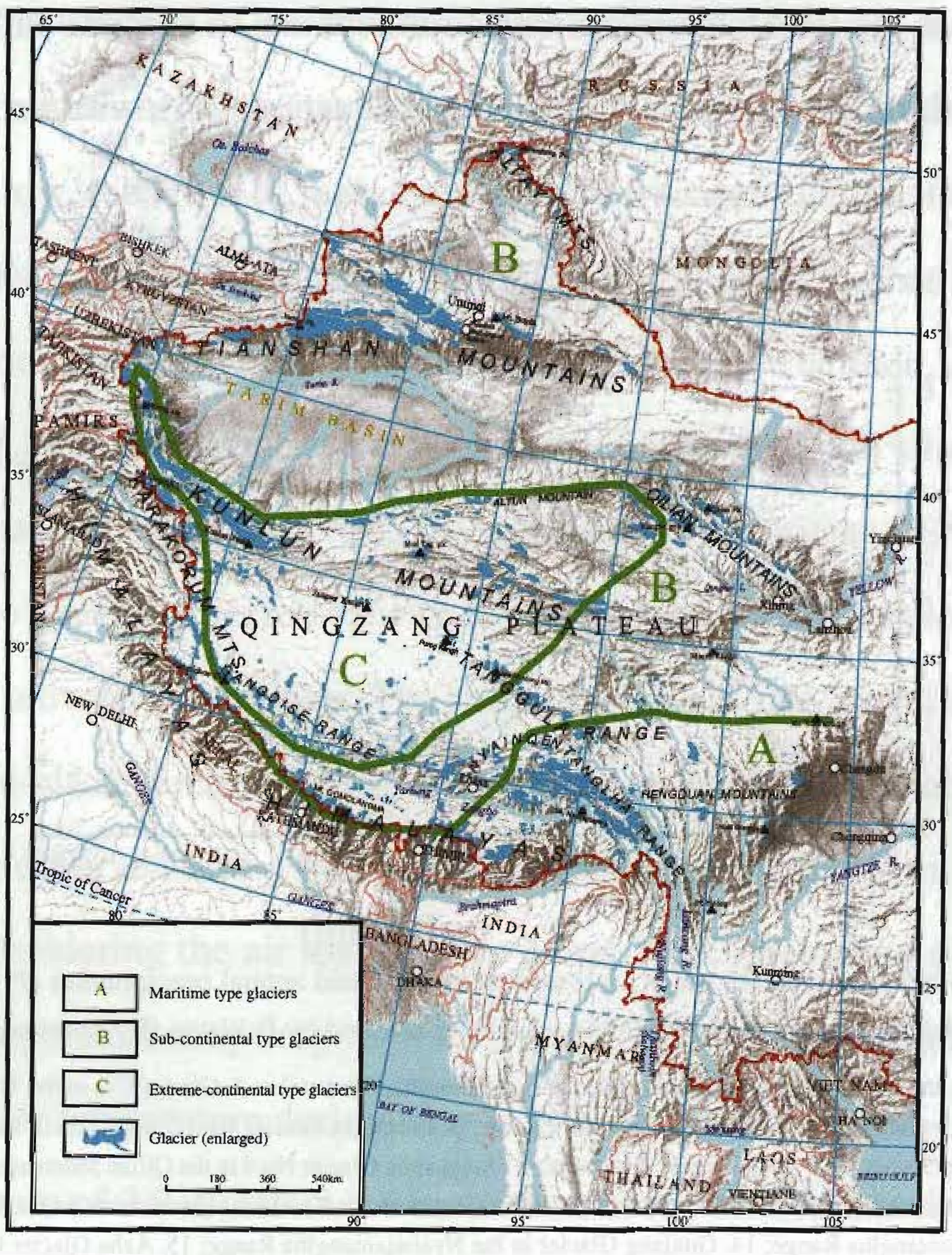


Figure 3-4 Distribution of the three types of glaciers in China

precipitation is up to 1000~3000 mm at the ELA, summer mean air temperature ranges from 1~5℃, and an ice temperature is between −1~0℃. This type of glacier is mainly located in the southeast Tibet and the Hengduan Mountains, accounting for about 22% of total glacier area in China.

Sub-continental type or sub-polar type glaciers: The annual precipitation is between 500mm and 1000 mm at the ELA. Annual mean air temperature ranges from −12~−6℃, with summer mean air temperature of 0~3℃. And ice temperature in the active layers less than 20 m in depth is −10~−1℃. Sub-continental type glaciers constitute 46% of the total glacier area in China and are mainly distributed in the Altay Mountains, the Tianshan Mountains, north slopes of the middle and western part of the Himalayas and the north slopes of the Karakorum Mountains.

Extremely continental type or polar type glaciers: The annual precipitation is within a range of 200~500 mm at the ELA, annual mean air temperature is lower than −10℃ with summer mean air temperature below −1℃. This type of glacier accounts for 32% of the total area of glaciers in China and is mainly distributed in the Middle and West Kunlun Mountains, the Qiangtan

Plateau, the East Pamirs, the West Tanggula Range and the West Qilian Mountains.

Glaciers may be also classified into different morphological types. World Glacier Inventory uses a 6-digit code for such a classification with each digit standing for classification, primary classification, form, frontal characteristic, longitudinal profile, major source of nourishment, as well as activity of tongue of a glacier. Each main category includes a certain number of sub-categories. The major morphological types of glaciers in China include hanging glaciers, cirque glaciers, valley glaciers, flat-topped glaciers, ice caps and ice fields. According to their longitudinal profile and frontal characteristic, the hanging glaciers and cirque glacier categories can be further divided into cirque-hanging glaciers, cirque-valley glaciers and mountain slope glaciers. According to the situation of the firn basis, the valley glaciers can be subdivided into single valley glaciers, complex valley glaciers and dendritic valley glaciers.

The fact that hanging glaciers and cirque-hanging glaciers dominate most types of glaciers means that the 77.3% glaciers are less than 1.0 km^2 (Table 3-2). As the classes of glacier length and glacier area become greater, glacier numbers decrease, but their total area and ice volume become larger. The distribution of glacier area ranked in an exponential expression 2^n is generally the same in various mountains, basically conforming to a normal distribution (Figure 3-5). The

Table 3-2 Glacier distribution in various area classes in China*

Area classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier
(km^2)	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
≤ 0.50	28,129	60.65	6062.56	10.20	128.80	2.30	0.22
0.51~1.00	7719	16.65	5534.81	9.31	199.64	3.57	0.72
1.01~5.00	8614	18.57	17,937.95	30.19	1025.18	18.31	2.08
5.01~10.00	1100	2.37	7553.53	12.71	635.44	11.35	6.87
10.01~30.00	629	1.36	9734.58	16.38	1086.13	19.39	15.48
30.01~50.00	109	0.24	4068.02	6.85	601.65	10.74	37.32
50.01~80.00	34	0.07	2136.65	3.59	365.54	6.52	62.84
80.01~100.00	16	0.03	1437.45	2.42	278.74	4.98	89.84
100.01~300.00	23	0.05	3535.28	5.95	824.60	14.72	153.71
≥ 300.00	4	0.01	1424.35	2.40	454.53	8.12	356.09
Total	46,377	100.00	59,425.18	100.00	5600.25	100.00	1.27

* Another six huge compound ice caps are not included in the glacier area larger than 100 km^2 in area.

correlation between the cumulated percentage of glacier resources (glacier number, glacier area and ice volume) and area (Figure 3-6) shows that the curves for the cumulated percentages of glacier area and ice volume become more steep when those of the cumulated percentage of glacier number become flat. This indicates that the glacier resource in a mountain system depends primarily on glaciers with large area and ice volume, not their total number. Hanging glaciers and cirque-hanging glaciers are usually less than 1.0 km² in area, while cirque glaciers and cirque-

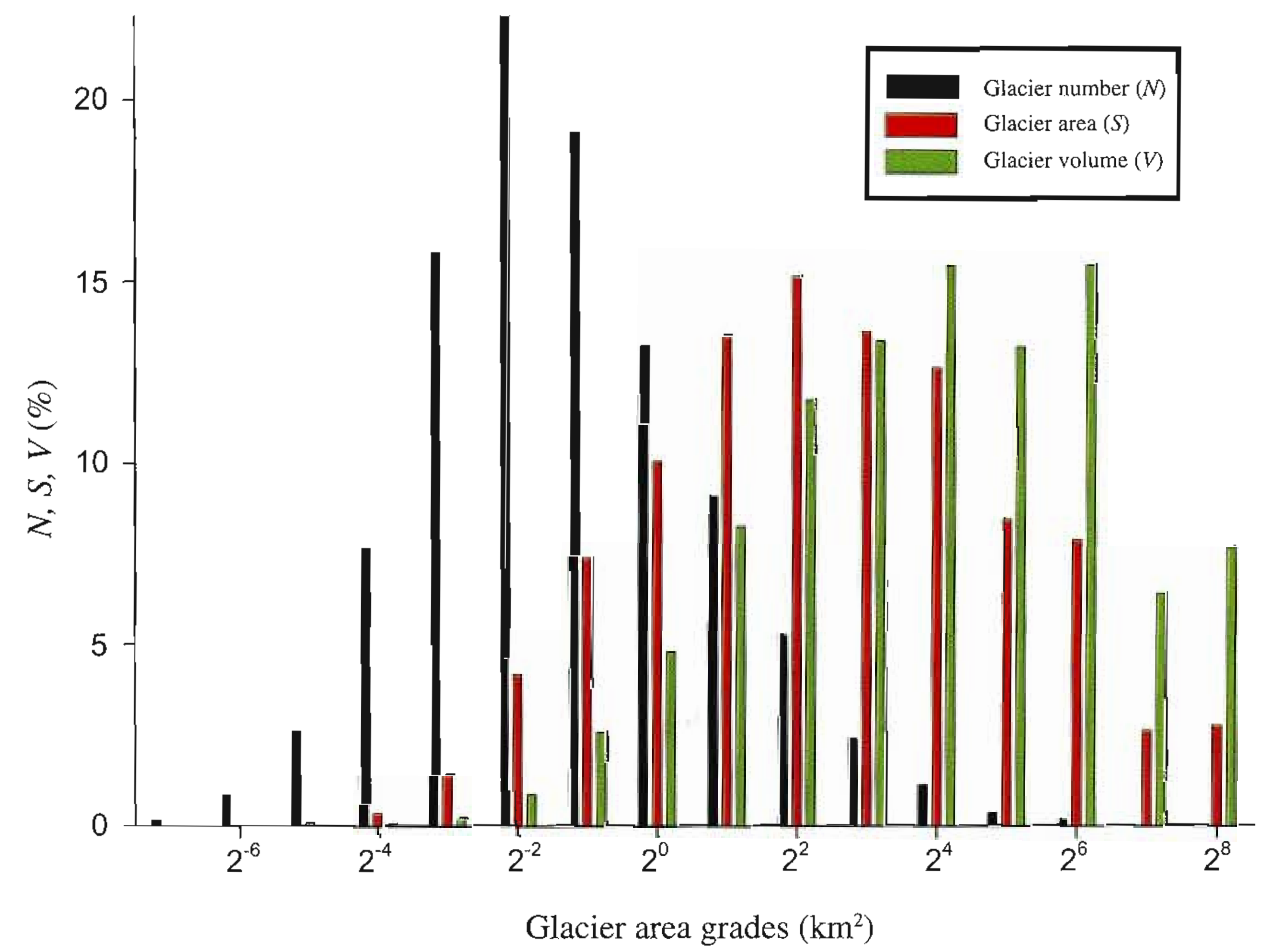


Figure 3-5 Distribution of glacier resources (*N,S,V*) versus area grades in Chinese

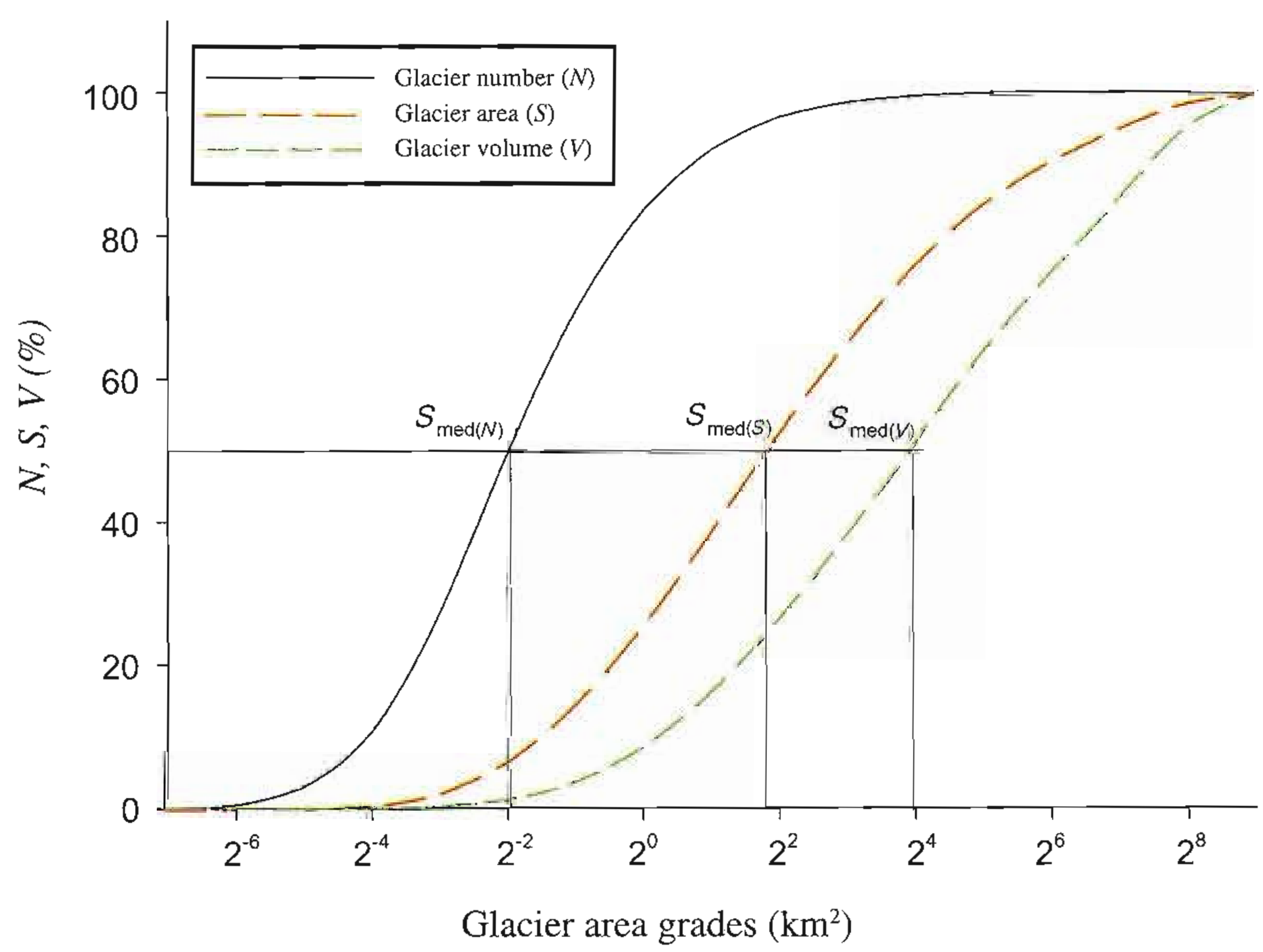


Figure 3-6 Cumulated curve of glacier resources (*N,S,V*) versus area grades in Chinese

valley glaciers usually rank between 1.01 km^2 and 5.00 km^2. Glaciers with an area of more than 5 km^2 are mostly valley glaciers, among which complex valley glaciers or dendritic valley glaciers are the largest with more than 50 km^2 in area.

There are 815 glaciers with individual area larger than 10 km^2, accounting for 1.8% of total number of glaciers over China. However, the total area and ice volume of these glaciers account for 37.6% and 64.5% of corresponding totals, respectively, in China. The 33 largest glaciers with an area greater than 100 km^2 in China possess a total area of 6167.38 km^2 and total ice volumes of 1429.16 km^3, accounting for 10.4% and 25.5% of corresponding totals, respectively (Table 3-3).

Obviously these huge glaciers have an important influence on the amount of water resources and water cycles. These largest glaciers are distributed in the Tianshan Mountains (6 glaciers), the Karakorum Mountains (5 glaciers), the Kunlun Mountains (11 glaciers), the Nyainqentanglha Range (4 glaciers), Pamirs (2 glaciers), the Tanggula Range (1 glacier) and the Qiangtan Plateau (4 glaciers). The three largest valley glaciers in China, each with an area greater than 300 km^2, are Yengisogat Glacier in the Karakorum Mountains (Figure 3-7), and Tomur Glacier and Tugaibieliqi Glacier in the Tianshan Mountains. The largest ice field is Purog Kangri Glacier with an area of 422.85 km^2 (Figure 3-8), and the largest ice cap is Chongce Glacier covering an area of 163.06 km^2 (Figure

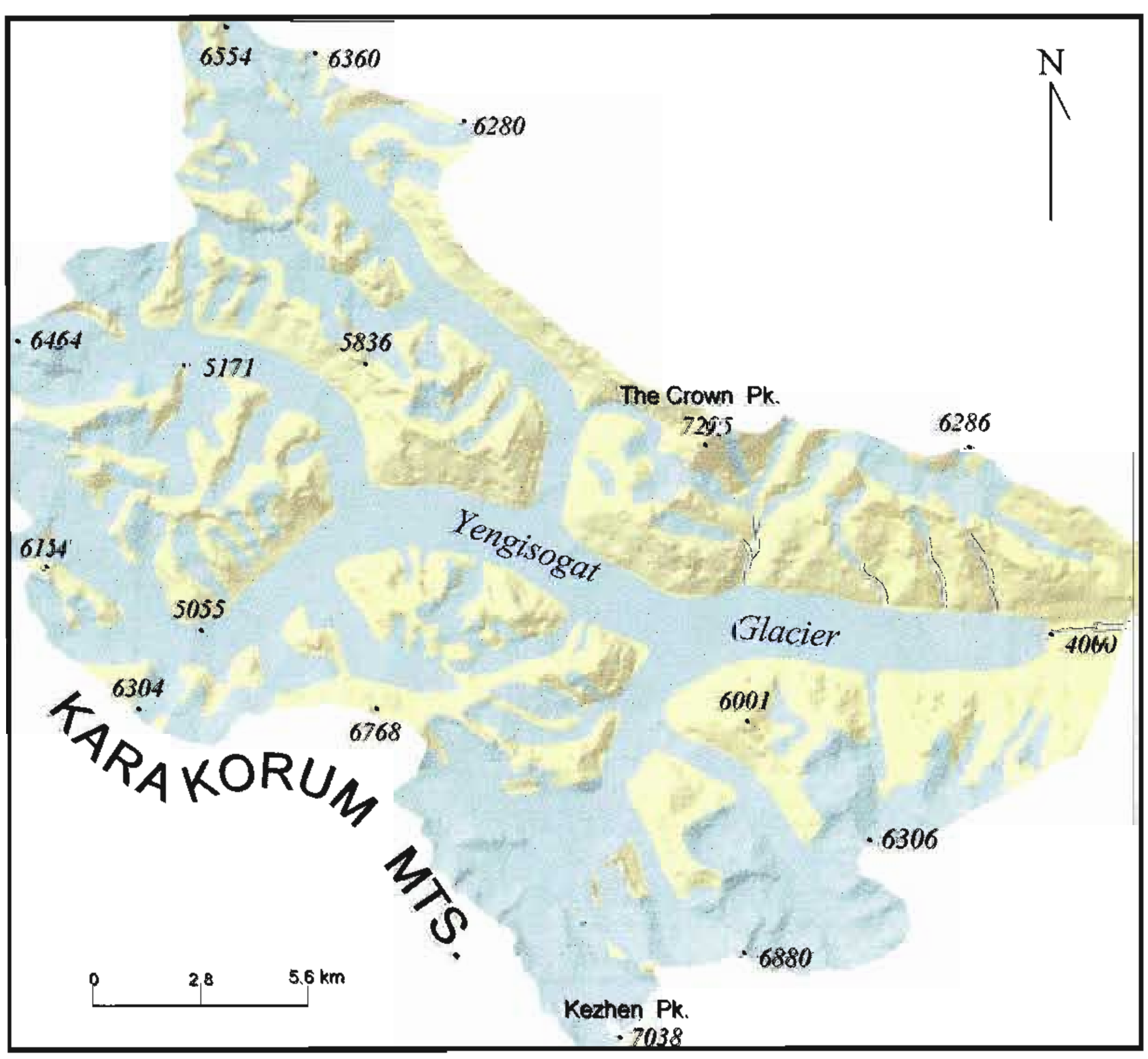


Figure 3-7 The largest valley glacier in China —— Yengisogat Glacier

Table 3-3 List of glaciers larger than 100 km² in China

Glacier name	Mountain system	Summit elevation (m)	Glacier length (km)	Glacier area (km^2)	Glacier volume (km^3)	SLA* (m)	Terminus altitude (m)	Glacier types
Tomur	Tianshan	7435	41.5	337.85	99.33	4350	2780	Dendritic valley
Qong Terang	Tianshan	7435	23.8	165.38	38.86	4300	3038	Dendritic valley
Tugaibieliqi	Tianshan	7435	36.1	313.69	90.03	4200	2680	Dendritic valley
Ukur	Tianshan	6995	32.4	184.95	44.93	4240	2790	Dendritic valley
Muzart	Tianshan	6627	33.0	137.70	30.57	4220	2950	Dendritic valley
South Inylchek *	Tianshan	7435	63.5	392.84	149.28	4450	2800	Dendritic valley
Qimgan	Pamirs	7649	22.2	103.71	21.04	4420	3140	Dendritic valley
Karayaylak	Pamirs	7649	18.4	128.15	27.79	4290	2980	Dendritic valley
Yengisogat	Karakorum	7295	42.0	379.97	115.89	5420	4000	Dendritic valley
Muzta	Karakorum	7410	29.4	196.76	48.80	5230	4100	Dendritic valley
Teram Kangri	Karakorum	7441	28.0	124.53	26.77	5390	4520	Dendritic valley
Gasherbrum	Karakorum	8501	26.0	119.80	25.40	5540	4250	Dendritic valley
Kyagar	Karakorum	7243	20.8	105.60	21.54	5420	4760	Dendritic valley
Duofeng	Kunlun	6957	31.0	251.70	67.46	5760	4590	Dendritic valley
Yurung	Kunlun	6778	30.9	139.07	31.02	6020	5140	Complex valley
Zhongfeng	Kunlun	7167	23.4	241.00	63.87	5965	5400	Dendritic valley
Gongxing	Kunlun	6721	20.5	113.80	23.78	5940	5360	Dendritic valley
Kunlun	Kunlun	6785	23.6	200.02	49.81	5920	4882	Dendritic valley
West Kunlun	Kunlun	6522	18.5	131.78	28.86	5900	5 120	Dendritic valley
West Yurung	Kunlun	6532	21.9	125.86	27.19	5900	5140	Dendritic valley
Yulinchuan	Kunlun	6925	14.0	103.53	21.02	5640	5160	Dendritic valley
Chongce	Kunlun	6903	28.7	163.06	38.16	6120	5320	Ice cap
Guriya	Kunlun	6667	12.4	119.33	25.30	6100	5500	Ice cap
Purog Kangri	Qangtan	6482	30.0	422.85	52.52	5780	5550	Ice field
Zangser Kangri	Qangtan	6508	29.0	191.60	23.81	5840	5600	Compound Ice cap
Tuze Kangri	Qangtan	6356	21.0	127.20	15.81	5840	5670	Compound Ice cap
Jinyang Kangri	Qangtan	6136	12.0	105.30	13.09	5440	5540	Compound Ice cap
Malan	Kunlun	6056	25.0	172.80	21.47	5490	5090	Compound Ice cap
Tanggula	Tanggula	6099	17.0	188.00	23.36	5730	5400	Compound Ice cap
Kyagqen	Nyainqentanglha	6356	35.3	206.70	52.10	4890	2900	Dendritic valley
Xiaqu	Nyainqentanglha	6692	21.0	163.60	38.32	4740	3160	Complex valley
Nalung	Nyainqentanglha	6204	19.0	117.80	24.87	4500	4400	Complex valley
Lago	Nyainqentanglha	6606	32.5	191.45	47.11	5040	3960	Dendritic valley
Total	—	—	—	6167.38	1429.16	—	—	—

* SLA is snow line altitude.

* The South Inylchek Glacier spans the border between China and Kyrgyzstan. The glacier's area will be measured after determining national boundaries. The current figure is a provisional measurement.

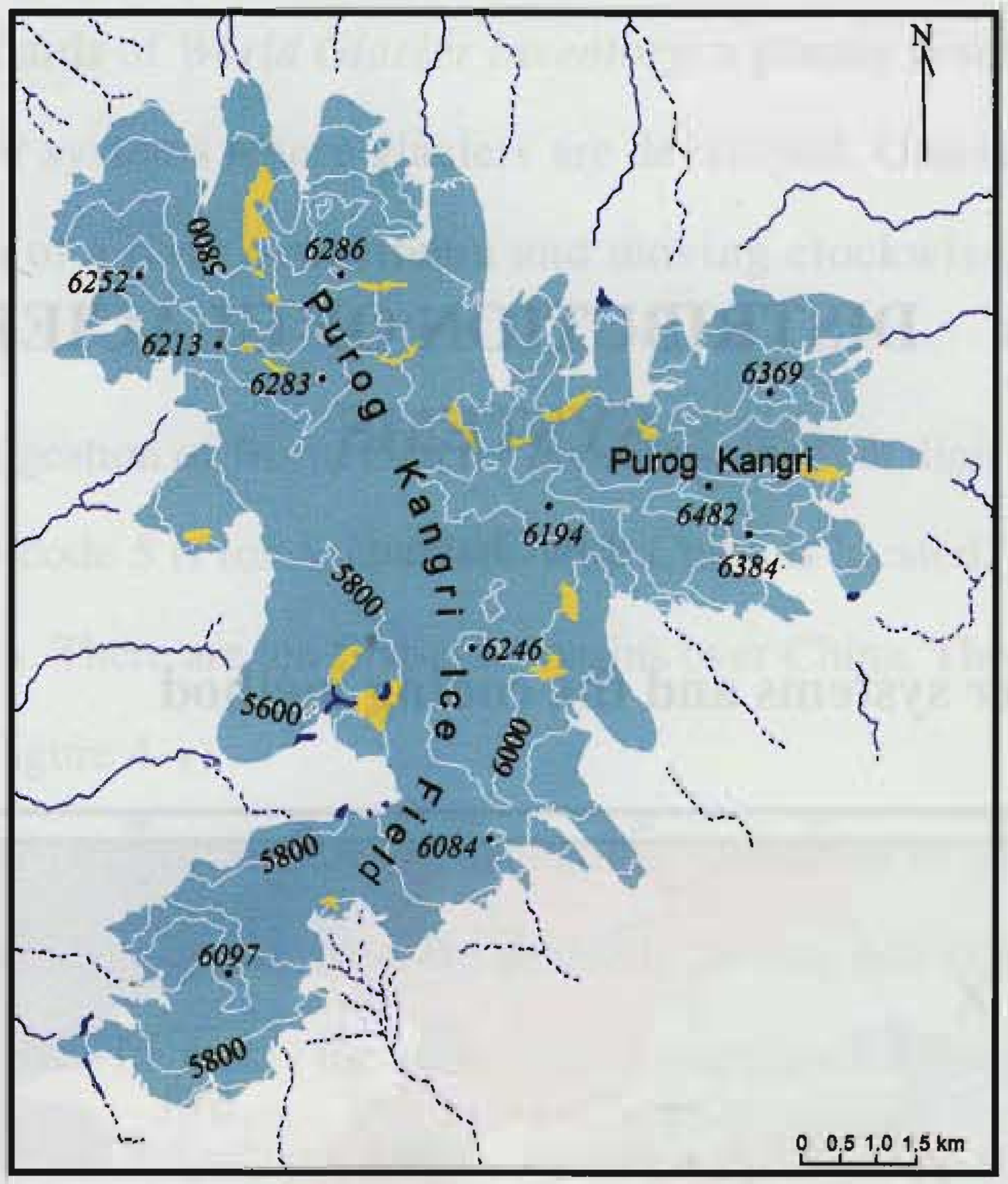


Figure 3-8 The largest ice field in China —— Purog Kangri Glacier

3-9). Many ice caps belonging to different drainage basins develop on the gentle mountain tops of the Zangser Kangri, Tuze Kangri, Jinyang Kangri, Purog Kangri in the Qangtan Plateau, the Tanggula Peak in the Tanggula Range and the Mount Malan in the central Kunlun. These ice caps join together to form six huge compound ice caps, quite spectacular in their grandness.

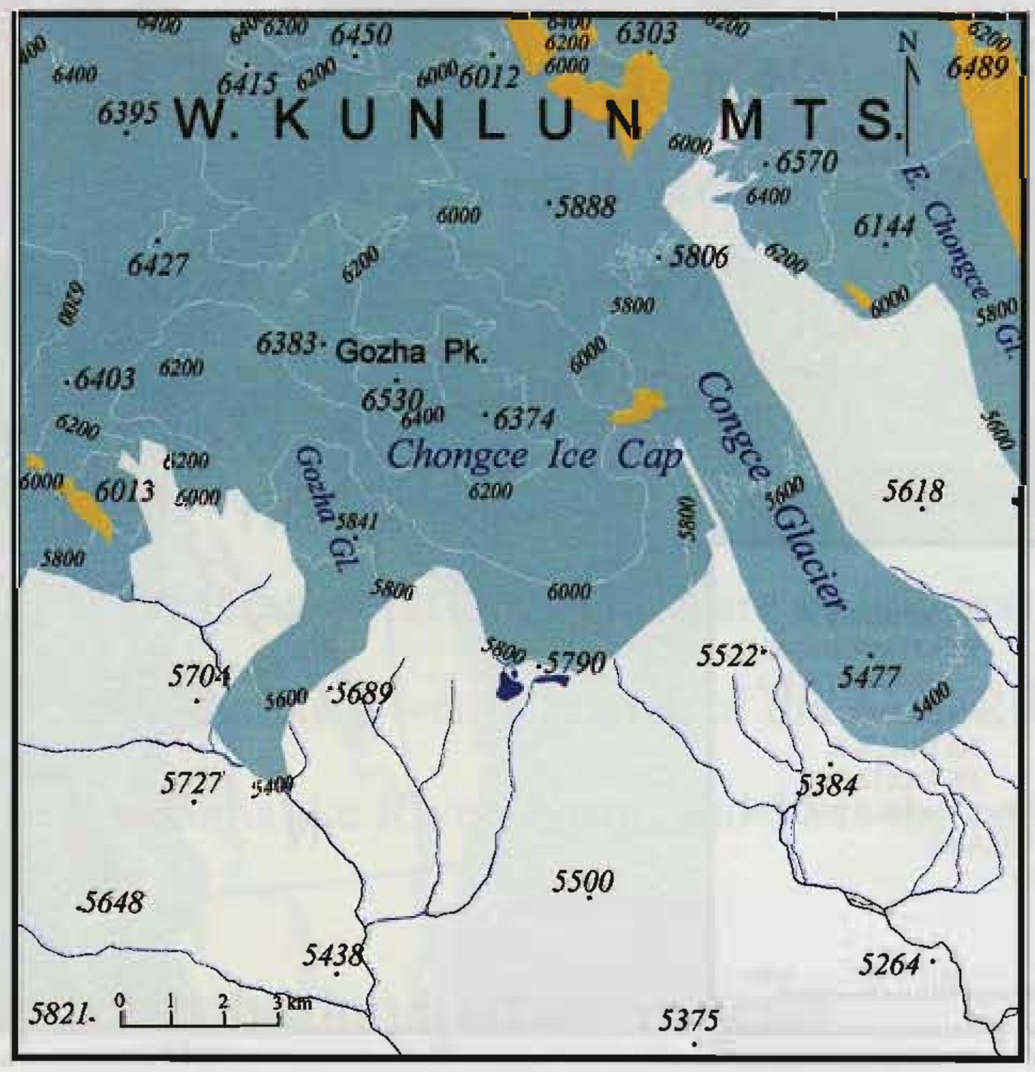


Figure 3-9 The largest ice cap in China —— Chongce Glacier

CHAPTER 4 DISTRIBUTION OF GLACIERS IN RIVER SYSTEMS

Liu Chaohai

4.1 Division of river systems and the coding method

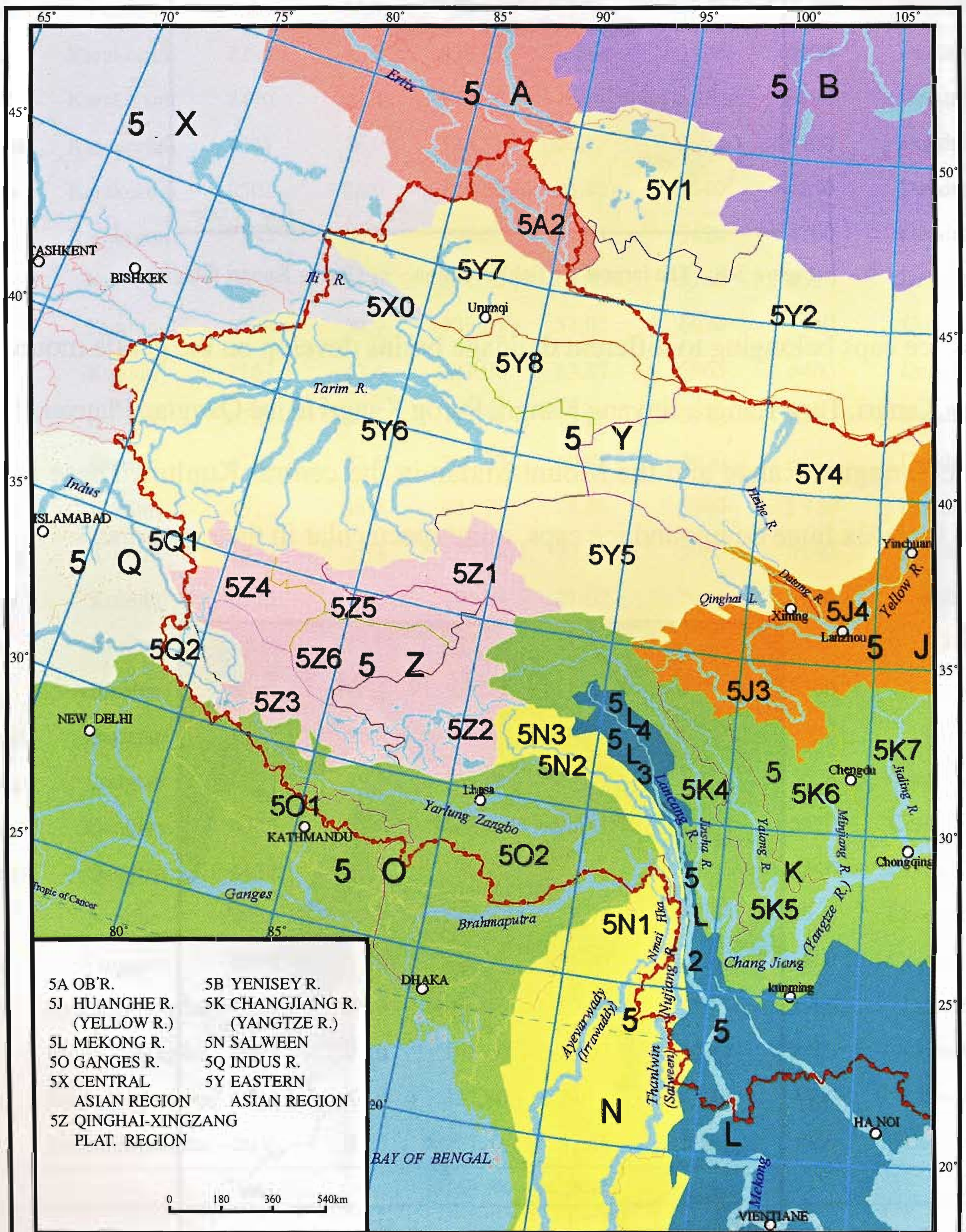


Figure 4-1 A code map of river systems in China and their adjacent areas

Following the standards of *World Glacier Inventory*, a glacier inventory is strictly coded in accordance with river systems where glaciers are developed. Glaciers are coded in order starting at the entrance of a river mainstream and moving clockwise around the drainage area.

According to the suggestion of *World Glacier Inventory*, the first digit of the river code is for region or continent. The code 5 is for Asia where West China is located. Then, river basins are classified into five grades. There are ten first-class basins over China. Those basins are coded in capital English letters (Figure 4-1).

In order to reflect the large differences in the natural conditions of tributaries and maintain the integrity of small river basins, great rivers are generally divided into different sub-class basins, while small tributary basins with nearly the same natural conditions are merged. Following these principles, we have delimited the second-, third-, fourth- and fifth-class sub-basins in China for this inventory compilation. There are 30 second-class basins with the development of glaciers. The second-, third- and fourth- classes basins are coded in sequential Arabic numerals, respectively, and the fifth-class is coded in sequential English letters.

The following examples explain the use of *Glacier Inventory of China*. The Eastern Asia Interior Region (EAIR) is a first-class water system in *World Glacier Inventory* and coded as "Y". Moving clockwise around this basin, the Tarim River basin is the sixth second-class basin in the EAIR, represented by the numeral 6. The third-class basins of the Tarim River, the Aksu River, the Ogan River and the Konqi River, are coded 5Y67, 5Y68 and 5Y69 respectively in the same way. The Aksu River has four tributaries, namely, the Toxkan River, the Qongtax River, the Kumalike River and the Tarang River, coded as 5Y671, 5Y672, 5Y673 and 5Y674, respectively. Those four tributaries include some fifth-class rivers. Take the code 5Y673P37 for example. The meaning of last four digits are as follows: 7 stands for the Aksu River basin, 3 stands for the Kumalike River (a branch of the Aksu River) basin, P is for the Tomur River (a branch of the Kumalike River) basin, and 37 is the code of a glacier, *i.e.* the Tomur Glacier.

4.2 Features of glacier distribution in river systems

This glacier inventory provides a precise information of glacier resources in river systems over China. Using field investigations with various small-scale geographical maps, the total glacier area of 44,000 km^2 in China was first estimated in the late 1950s and early 1960s (Shi Yafeng and Xie Zichu, 1964). In 1980, an initial inventory was conducted in some mountainous regions. Then, careful estimates and statistics for glaciers in twelve mountainous areas in West China were thoroughly gathered, accomplishing three detailed glacier inventories and nine approximate glacier inventories mainly obtained from Landsat images. Statistics from those regions projected the total glacier area in China to be 56,482 km^2. Shi Yafeng reported this estimate at an international glacier inventory conference in 1981. The World Glacier Monitoring Service (WGMS) adopted and published this result in *World Glacier Inventory* (World Glacier Monitoring Service, 1989). Since then, during detailed glacier inventory compilation over many years, other researchers have proposed slightly different results for the total glacier area in China based on different data. Those results remain close to Shi Yafeng's result published in *Glacier Inventory of China*, however. Although these estimates for total area of glaciers, having been calculated from glacier inventory measurements, are fairly accurate, a few mountainous systems have not yet to be fully inventoried. Therefore none represents the final and most accurate estimate.

The work of *Glacier Inventory of China*, which began in 1979, has been done mainly using aerial photographs and topographic maps taken in the 1960s and 1970s in accordance with the suggestion of *World Glacier Inventory*. All glaciers in river basins were recoded, and thirty-four glacier parameters were mainly measured and calculated manually. After 22 years of hard work, *Glacier Inventory of China* was published in 12 volumes and 22 issues by 2002. Since then, Yang Hui'an *et al.* (2003) modified the inventory of glaciers in the Bangong Co basin in the Qinghai-Xizang (Tibet) Plateau Interior Area based on new large-scale topographic maps and aerial photographs.

Glacier Inventory of China shows there are 46,377 glaciers, with a total area of 59,425.18 km^2 and a total volume of 5600.25 km^3 over China. The World Glacier Monitoring Service (WGMS, 1989) and Долгущин и Осипова(1989) reported that the total area of all global glaciers (including Antarctic and Greenland ice sheets) is 15,865,756 km^2. Thus, the glacier area in China comprises 0.4% of the global glacier area (Wang Zongtai and Su

Hongchao, 2003). The area of alpine glaciers in China, however, accounts for 14.5% of the total global alpine glacier area (410,700 km^2) and 47.6% of the corresponding area of alpine glaciers in Asia (124,900 km^2). On a global scale, glaciers in China represent a very small proportion and are relatively insignificant. However, the glaciers in China account for 30% of the area of alpine glaciers in middle and low latitude regions. There are 33 glaciers with an area over 100 km^2 in China, accounting for 39.3% of global glaciers of that size (84 glaciers) and 47.8% of corresponding Asian glaciers (69 glaciers) in the middle and low latitudes. China is not only the country with the most and best-developed glaciers in middle and low latitude regions, but also the country with the most glaciers drained to extensive desert and arid regions (Wang Zongtai and Su Hongchao, 2003). *Glacier Inventory of China* reflects the status of glaciers between the 1950s and 1980s when aerial photographs and topographic maps were taken. But these glaciers are changing and most of them are shrinking due to climate warming. Monitoring and conducting research on the changes of glaciers is an imperative.

The statistics on ten first-grade river basins in China (Table 4-1) indicate that the glaciers in the Eastern Asian Region (5Y) comprise 42% of the total numbers, 43% of total area, and 47% of total ice volume of glaciers in China, the largest proportion over China. The glaciers in the Ganges River basin (50, including the Yarlung Zangbo and other rivers) account for 30.5% of total glacier area and 29.0% of total ice volume, being the second highly glacierized river basin. As a first-grade river system, the Yellow River basin (5J) is the less glacierized, covering 0.4% of total numbers, 0.3% of total area, and 0.2% of total ice volume of glaciers in China.

The Chinese Hydraulic Engineering Society (2002) divides West China into four glacier water resource regions (Figure 4-2): the Yellow River Region, the Yangtze River Region, the Southwestern River Region and the Northwestern River Region. These classified regions are larger than those of the first-grade basins in *Glacier Inventory of China*. Glaciers in the 4 regions are listed in Table 4-2.

Among these four regions, the Yellow River Region, the Yangtze River Region and the Southwestern Rivers Region are exterior drainage areas and the Northwestern River Region is an interior drainage area except for the Ertix River, which originates in the Altay Mountains.

Table 4-1 Glaciers in river systems over China

Area	First grade		Second grade		Glacier number		Glacier area		Ice volume		Mean area per glacier (km^2)
	Code	Name	Code	Name	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Internal Drainages	5Y	Eastern Asia	5Y124	Kebuduo R.	6	0.01	3	0.01	< 1	0.00	0.50
			5Y4	Hexi	2194	4.73	1335	2.24	62	1.11	0.61
			5Y5	Qaidam	1581	3.41	1865	3.14	128	2.29	1.18
			5Y6	Tarim	11,665	25.15	19,878	33.45	2313	41.31	1.70
			5Y7	Junggar	3406	7.35	2251	3.79	137	2.45	0.66
			5Y8	Turpan-Hami	446	0.96	253	0.42	13	0.23	0.57
				sub-total	19,298	41.61	25,585	43.05	2654	47.39	1.33
	5X	Central Asia	5X0	Ili R.	2373	5.12	2023	3.41	142	2.54	0.85
			5X1	Karakul L.	12	0.02	25	0.04	2	0.03	2.08
				sub-total	2385	5.14	2048	3.45	144	2.57	0.86
	5Z	Qinghai-Tibetan interior R.	5Z1~6		5341	11.52	7836	13.19	777	13.88	1.47
	sum				27,024	58.27	35,469	59.69	3575	63.84	1.31
External Drainages	5A	Ob R.	5A2	Ertix	403	0.87	289	0.49	16	0.29	0.72
	5J	Yellow R.	5J3	Upper reach	68	0.15	132	0.22	11	0.19	1.93
			5J4	Datong R.	108	0.23	41	0.07	1	0.02	0.38
				sub-total	176	0.38	173	0.29	12	0.21	0.98
	5K	Yangtze R.	5K4	Jinsha R.	935	2.02	1427	2.40	112	2.00	1.53
			5K5	Yalong R.	150	0.32	130	0.22	7	0.13	0.87
			5K6	Minjiang R.	246	0.53	338	0.57	28	0.50	1.38
			5K7	Jialing R.	1	0.00	<1	0.00	<1	0.00	0.15
				sub-total	1332	2.87	1895	3.19	147	2.63	1.42
	5L	Mekong R.	5L2~4	Lancang R.	380	0.82	316	0.53	18	0.32	0.83
	5N	Salween	5N1~2	Nujiang R.	2021	4.36	1730	2.91	115	2.05	0.86
	5 O	Ganges	5O1	Pumqu R. etc.	2192	4.73	3609	6.07	330	5.89	1.65
			5O2	Yarlung Zangbo	10,816	23.32	14,493	24.39	1293	23.09	1.34
				sub-total	13,008	28.05	18,102	30.46	1623	28.98	1.39
	5Q	Indus R.	5Q1	Sengge Zangbo	1244	2.68	779	1.31	44	0.79	0.63
			5Q2	Langqen Zangbo	789	1.70	672	1.13	50	0.89	0.85
				sub-total	2033	4.38	1451	2.44	94	1.68	0.71
	sum				19,353	41.73	23,956	40.31	2025	36.16	1.24
	Total				46,377	100.00	59,425	100.00	5600	100.00	1.28

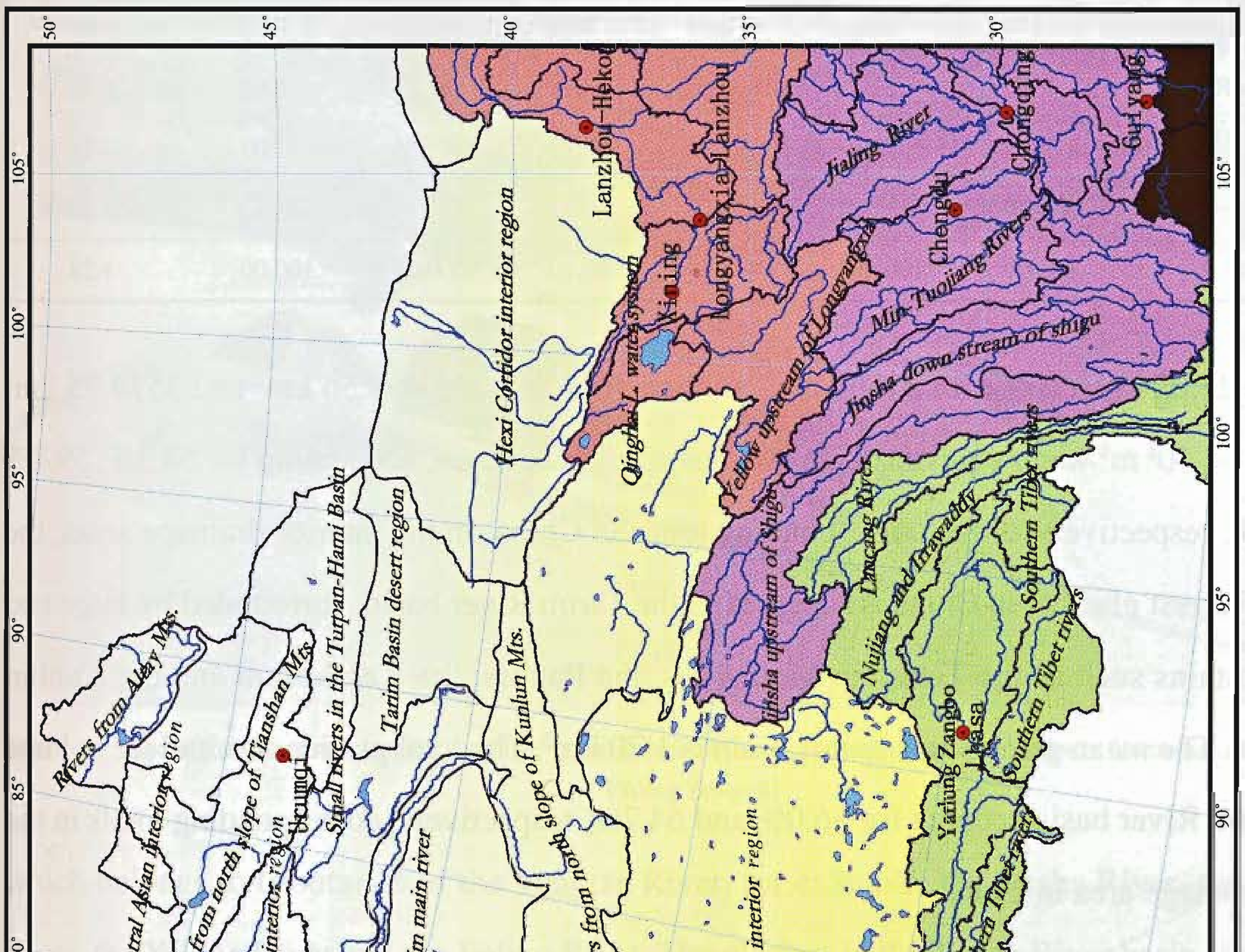


Figure 4-2 Regions of glacier water resource in West China

Table 4-2 Glaciers in the water resource regions in West China

Water resource regions	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Yellow River	176	0.38	172.41	0.29	12.29	0.22	0.98
Yangtze River	1332	2.87	1895.00	3.19	147.27	2.63	1.42
Southwestern Rivers	17,442	37.61	21,599.92	36.35	1849.55	33.03	1.24
Northwestern Rivers	27,427	59.14	35,757.85	60.17	3591.14	64.12	1.30
Total	46,377	100.00	59,425.18	100.00	5600.25	100.00	1.28

There are 27,024 glaciers with a total area and ice volume of 35,468.56 km^2 and 3574.75 km^3 (32,172.3 $\times$ 10^8 m^3 water equivalent) in the interior drainage area, accounting for 58.3%, 59.7% and 63.8%, respectively, of the corresponding totals in China. In the interior drainage areas, the most and largest glaciers in China are located in the Tarim River basin, surrounded by large and high mountains such as the Tianshan Mountains, the Pamirs, the Karakorum and the Kunlun Mountains. The mean glacier area in this basin is 1.70 km^2. The total glacier area and ice volume of the Tarim River basin account for 56.0% and 64.7%, respectively, corresponding totals in the interior drainage area in China.

Glaciers in the exterior drainage areas are the sources of large rivers such as the Yangtze River, the Yellow River and the Yarlung Zangbo and others. There are 19,353 glaciers, with an area of 23,956.62 km^2 (mean glacier area of 1.24 km^2) and ice volumes of 2025.50 km^3 (18,229.5 $\times$ $10^8 m^3$ water equivalent) in this region. The numbers, area and ice volume of glaciers in this region account for 41.7%, 40.3% and 36.2%, respectively, of the corresponding totals in China. Glaciers in the Yarlung Zangbo (Photo 4-1), which account for 60.5% of glacier area and 63.9% of ice volumes in the exterior drainage area, are the most in number and largest in area. The river basins with glaciers more than 1000 km^2 in area include source tributaries within China of the Ganges, the Yangtze, the Nujiang and the source region of the Indus River in China.

The Yangtze River originates from the Jianggudiru Glacier, riverhead of the Tuotuo River in the Tanggula Range. There are 1332 glaciers with an area of 1895.00 km^2 and volume of 147.25 km^3 in the Yangtze River basin. Glaciers are also developed in the high mountains (Photo 4-2)

Photo 4-1 The highest Lamasery in the world —— the Rongbuk Lamasery at the foot of the Mount Qomolangma (5100 a.s.l) (Wang Zongtai)

which belongs to tributaries of the Yangtze River, for example, the Jinsha River, the Minjiang River, the Yalong River and the Jialing River. The glaciers in the Jinsha River basin alone covers 75% of the total area.

Due to the abundant precipitation generated by the Indian Ocean monsoons, many glaciers, with a total area of 1730.20 km^2 and ice volumes of 114.97 km^3, develop in the Nujiang River

Photo 4-2 Overlook the Yulong Xueshan (Su Zhen)

basin in the southeast of Tibet. The Nujiang River is the mostly glacierized among rivers that originate from the Hengduan Mountains and flow from north to south.

Small glaciers with a total area of 1451.26km^2 are also developed along the upper reaches of the Indus River in China, such as the Sengge Zangbo (also named the Shiquan River), the Shyak River, and the Langqen Zangbo (also named the Xiangquan River).

4.3 Glacierization rate in mountain river basins

The ratio of the glacierized area in a basin to the drainage area is used as an index, to represent the degree of glacier cover (DGC). This index may represent not only the intensity of glacier impacts, but also an initial indicator for studying glaciers' past evolution and predicting their future changes in mountainous river basins. Тихановская и др. (1983) proposed a division of DGC in mountainous river basins into four grades: $<$0.20, 0.20 ~ 0.40, 0.41 ~ 0.70 and $>$0.70, which are respectively called scattered glacier areas, semi-scattered glacier areas, semi-covered glacier areas, and covered glacier areas. The DGE for 250 fourth-grade basins show that over 98% of the basins are scattered glacier areas with the DGC under 0.20. Some basins, like the Kulqin River in the upper reaches of the Yarkant River, the Yurungkax River in the Hotan River basin, and the Kapusilang River of the Ogan River and the Tarang River, are semi-scattered glacier areas with the DGC of 0.20 ~ 0.40. The Muzart River, a main tributary of the Ogan River, has the DGC of 0.43 and is a semi-covered glacier area.

Generally, the lower the grade of basins becomes, the higher the DGC is. For instance, the DGC of the Kax River basin is 0.05, but it increases to 0.22 for the Kaxguole River basin (5X043P), the source of the Kax River. During the Quaternary Glaciations, the DGC might have been doubled compared with the present value. Take the Tarang River basin for example, the present DGC is 0.31, but it was 0.35 during the LIA and 0.67 during the Last Glacial Maximum LGM, turning it into a semi-covered glacier area. In the Urumqi River basin with small glaciers, the DGC of present time, the LIA and the LGM are 0.04, 0.07, and 0.28, respectively.

With climate warming, glacier shrinkage accelerates and the DGC becomes smaller. Monitoring changes in the DGC is significant for predicting, estimating and understanding glacier runoff.

The DGC results from the interaction between topography, climate and glacier type. Glaciers

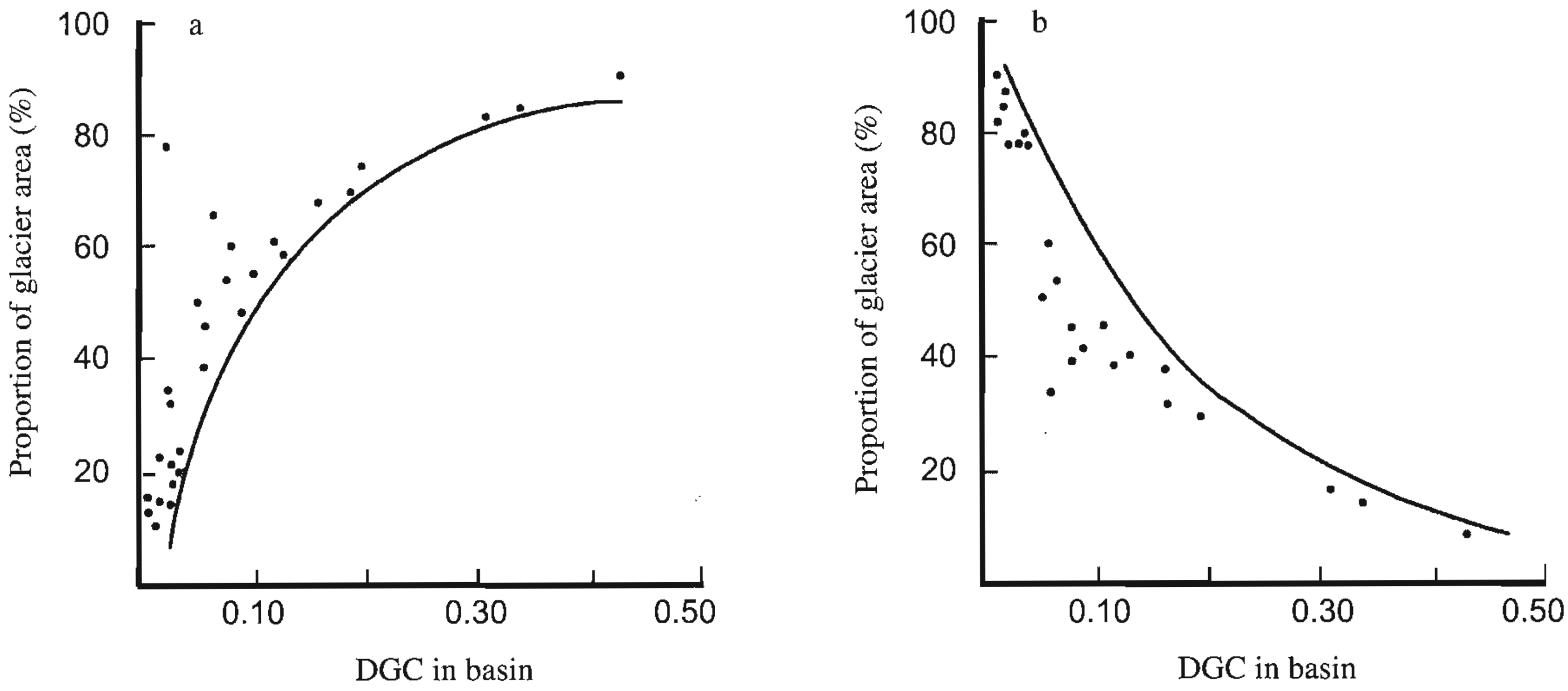


Figure 4-3 The relationship between the degree of glacier cover (DGC) and the proportion of glacier area for the first type (a) and second type (b) of glaciers

can be divided into two basic types. The first type is valley glaciers, which include dendritic-valley glaciers, complex-valley glaciers, single-valley glaciers and cirque-valley glaciers. The second type of glaciers includes hanging glaciers, cirque-hanging glaciers and cirque glaciers. As the DGC increases, the area of the first type of glaciers increases while that of the second type decreases (Figure 4-3). The DGC in mountainous areas mainly depends on the number and individual size of glaciers. In some river basins like the Kulqin River in the upper reaches of the Yarkant, and the Muzart River and the Kumalike River in the Tianshan Mountains, the existence of many large valley glaciers (accounting for over 85% of the total glacier area) results in the DGC over 0.30. For most of the 250 fourth-grade basins revealed in *Glacier Inventory of China*, the DGC is usually less than 0.10 when total area of valley glaciers in the basin is less than 50%.

CHAPTER 5 GLACIERS IN THE INTERIOR RIVERS

Ding Liangfu,Wang Zongtai,Yang Hui'an and Jiao Keqin

5.1 The Ili River (5X04)*

The Ili River, an interior river in Central Asia, coded as 5X04 in *Glacier Inventory of China*, flows through the Ili Prefecture, Xinjiang Uygur Autonomous Region of China, into the Balchas Lake, Kazakhstan (one of the tributaries, the source of the Tekes River is located in Kazakhstan).

The Ili River valley lies in the West Tianshan Mountains in China, within an area of 42°14′N ~ 44°51′ N, and 80°15′ E ~ 85°00′ E, or 381km (east to west) × 285 km (south to north). In the source region of the river, there are a series of longitudinally distributed parallel ranges, basins and valleys (Figure 5-1). The source region of the river is delimited by the North Tianshan Mountains to the north, the Halik and Nalati Ranges to the southwest, and the border with Kazakhstan to the west.

There are 2373 glaciers with the total area and ice volume of 2022.66 km^2 and 142.18 km^3, respectively, in the five tributaries of the Chinese Ili River, the Kunes, the Kax, the Korgas, the Tekes and the Kuksu (Table 5-1), with the Tekes and the Kuksu highly glacierized. The two tributaries own about 1441 in number, 1449.16km^2 in area and 108.43km^3 in ice volume, which

Table 5-1 Glaciers in the Ili River basin (5X04) in the Tianshan Mountains

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA*	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Korgas	5X042	131	5.52	55.22	2.73	2.12	1.49	0.42	3630	3.86	3.3
Kax	5X043	551	23.22	421.60	20.85	28.18	19.82	0.77	3660	35.06	11.0
Kunes	5X044	250	10.53	96.68	4.78	3.45	2.43	0.39	3710	3.34	2.2
Kuksu	5X045	625	26.34	421.58	20.84	23.08	16.23	0.67	3840	18.17	10.0
Tekes	5X046	816	34.39	1027.58	50.80	85.35	60.03	1.26	3820	48.60	13.8
Total	5X04	2373	100.00	2022.66	100.00	142.18	100.00	0.85	3730	48.60	13.8

* SLA is snow line altitude.

* This subsection is prepared by Ding Lianfu.

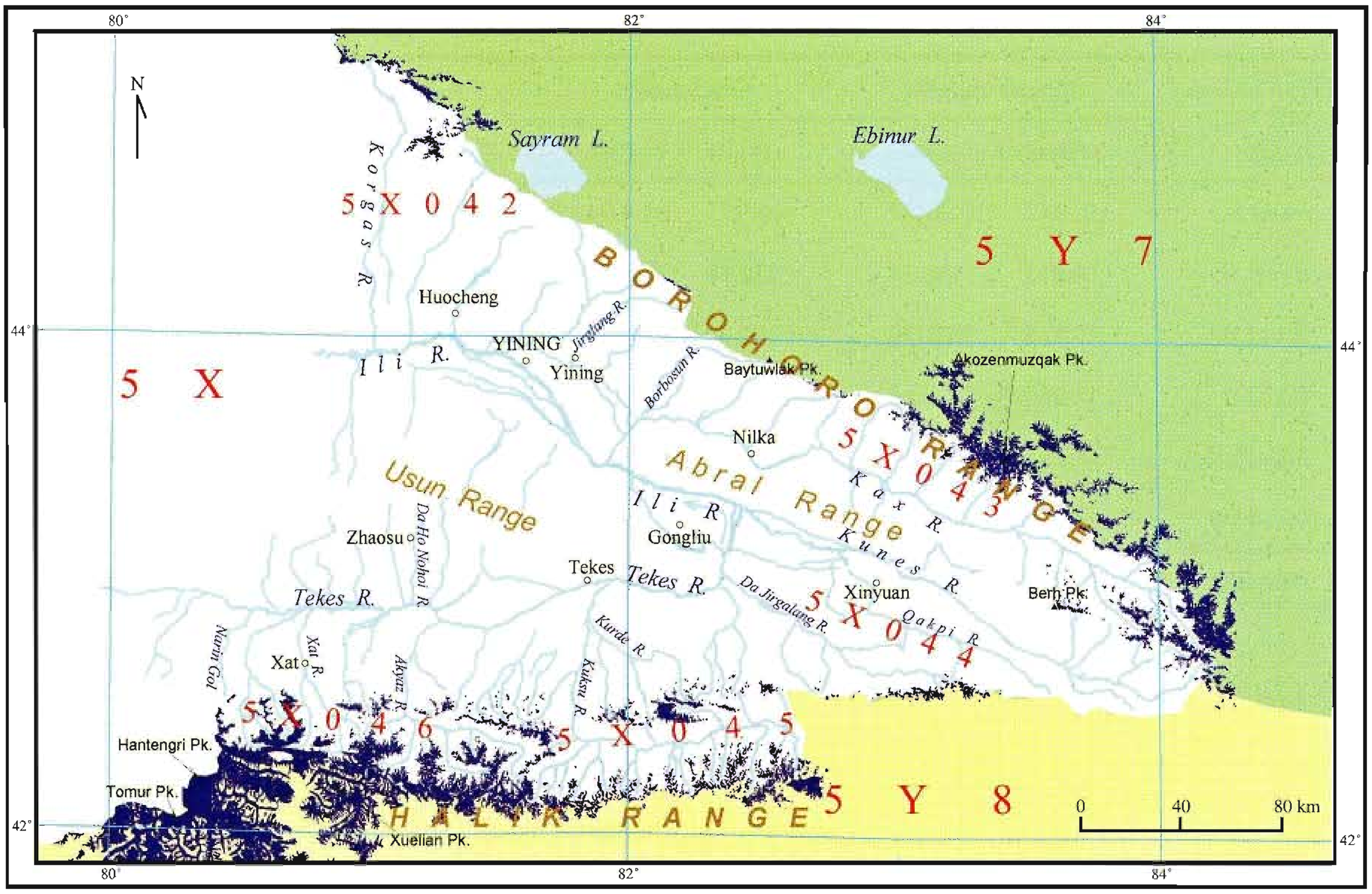


Figure 5-1 Distribution of glaciers in the Ili River basin

respectively covers 60.7%, 71.6% and 76.2% of the corresponding totals in the Ili River.

Most of the glaciers in the Ili River are smaller than 1 km^2, comprising 83.3% of the corresponding total number in the basin (Table 5-2, Table 5-3). There are six glaciers with larger than 30 km^2 in area or longer than 10 km in length in the basin. The Aerqialete Glacier (5X046K33) in the upstream of the Tekes River is the largest one, 48.6 km^2 in area, 13.8 km in length, with the tongue terminated at an altitude of 2720 m a.s.l. in the forest region. A glacier (5X045I44) in the upstream of the Kuksu River, 4.73 km^2 in area and 8.20 km in length, is the lowest glacier with its terminus extending as low as 2520 m a.s.l. in the Tianshan Mountains of China. Larger glaciers are few because of the unfavorable terrain conditions (low ridges and narrow valleys) of the Ili River. In general, glaciers in the river are characterized by sporadic distribution, low average altitude, no obvious centralized glaciation region.

Most glaciers are smaller than 1 km^2 in area and the hanging glaciers are the dominant type, comprising 66.1% of all glaciers in the Ili River basin. The number of hanging glaciers and cirque-hanging glaciers amounts to 75.9% of all glaciers. Although valley glaciers make up only 8.1% of total numbers, their area and volume account for 51.5% and 71.3% of the corresponding

Table 5-2 Glacier distribution in various length classes in the Ili River basin (5X04)

Length classes (km)	Glacier number Number	(%)	Glacier area (km^2)	(%)	Glacier volume (km^3)	(%)	Mean area per glacier (km^2)
⩽ 0.5	742	31.27	81.75	4.04	1.26	0.89	0.11
0.6~1.0	815	34.34	221.40	10.95	5.18	3.64	0.27
1.1~2.0	515	21.70	389.98	19.28	15.81	11.12	0.76
2.1~5.0	260	10.96	720.73	35.63	48.40	34.04	2.77
5.1~10.0	35	1.48	373.51	18.47	36.43	25.63	10.67
10.1~15.0	6	0.25	235.29	11.63	35.10	24.68	39.22
Total	2373	100.00	2022.66	100.00	142.18	100.00	0.85

totals (Table 5-4). Obviously the glacier resources mainly depend on the numbers and sizes of valley glaciers. The size of glaciers within a basin depends on the ratio of total area of valley glaciers (including cirque-valley glaciers) to that of hanging glaciers (including cirque-hanging glaciers and slope glaciers). In the Halik Range and on the northern slope of the Hantengri (Khan Tengri)-Tomur Knot, this ratio is as high as 3.3, and the corresponding average area of glaciers is 1.26 km^2. There are 23 glaciers larger than 10 km^2 in the whole basin and 16 of 23 glaciers are in the area of the Halik Range and the Hantengri Tomur Knot located in the Ili River basin. Glaciers in the Kunes River between the Awulale and the Nalati Ranges are the smallest in the whole basin, where this ratio is only 0.14 and the average area of glaciers is 0.39 km^2.

Water resource in the Ili River with a drainage area of 5.7×10^4 km^2, may be the most abundant river in the Xinjiang Uygur Autonomous Region, its average annual runoff is 153.7×10^8 m^3 (Zhou Yuchao *et al.*, 2004). Ice mass in the Chinese territory of the basin is 142.2 km^3, 1209×10^8 m^3 water equivalent, 7.8 times the annual runoff of the river basin. Glaciers supply about 16.5% of the total surface runoff, however, winter and spring snowfalls comprise 53% of the annual precipitation. The combination of glacier and snow meltwater with precipitation creates a relatively small variation of stream flow in the Ili River throughout the year. As a result, the region has no noticeable spring drought and little summer flooding, greatly favoring the agricultural irrigation and water carriage.

The Kax River, a tributary of the Ili River, originates from the southern slope of the Borohoro Range, with 551 glaciers of a total area of 421.60 km^2. By using aerial photogrammetry in 1962

Table 5-3 Glacier distribution in various area classes in the Ili River basin (5X04)

Area classes (km^2)	Glacier number: Number	Glacier number: (%)	Glacier area: (km^2)	Glacier area: (%)	Glacier volume: (km^3)	Glacier volume: (%)	Mean area per glacier (km^2)
≤ 0.50	1662	70.04	317.16	15.68	6.10	4.29	0.19
0.51~1.00	316	13.32	219.06	10.83	7.97	5.60	0.69
1.01~2.00	194	8.18	271.10	13.40	12.97	9.12	1.40
2.01~5.00	130	5.48	390.46	19.30	24.86	17.48	3.00
5.01~10.00	48	2.02	329.61	16.30	27.78	19.54	6.87
10.01~15.00	7	0.29	79.62	3.94	7.90	5.56	11.37
15.01~20.00	10	0.42	180.36	8.92	19.50	13.72	18.04
20.01~30.00	—	—	—	—	—	—	—
30.01~40.00	4	0.17	142.37	7.04	20.50	14.42	35.59
40.01~50.00	2	0.08	92.92	4.59	14.60	10.27	46.46
Total	2373	100.00	2022.66	100.00	142.18	100.00	0.85

and 1989, we analyzed glacier changes during the period in five selected sub-basins in the Kax River, the Aleshalang, the Tulugengqiagan, the Aersangsayi, the Tewasayi and the Mengkedesayi (Table 5-5). The all monitored 66 glaciers were retreating, with mean length retreat by 149 m (7.0% of that in 1962), and area and volume reduction by 4.81 km^2 (or −3.5%) and 99,119.8 × 10^4 m^3 (−7.5%), respectively. Ice thickness has thinned by 7.1 m in average (Liu Chaohai *et al.*, 2002).

Table 5-4 Morphological types of glaciers in the Ili River basin (5X04)

Glacier type	Glacier number: Number	Glacier number: (%)	Glacier area: (km^2)	Glacier area: (%)	Glacier volume: (km^3)	Glacier volume: (%)	Mean area per glacier (km^2)
Hanging glacier	1568	66.08	281.75	13.93	5.05	3.55	0.18
Cirque-hanging glacier	233	9.82	137.39	6.79	4.87	3.42	0.59
Cirque glacier	367	15.47	532.20	26.31	29.71	20.90	1.45
Cirque-valley glacier	109	4.59	464.76	22.98	38.79	27.28	4.26
Valley glacier	82	3.46	576.14	28.48	62.55	43.99	7.03
Canyon glacier	6	0.25	3.96	0.20	0.14	0.10	0.66
Mountain slope glacier	6	0.25	21.37	1.06	0.72	0.51	3.56
Flat-topped glacier	2	0.08	5.09	0.25	0.35	0.25	2.55
Total	2373	100.00	2022.66	100.00	142.18	100.00	0.85

Table 5-5 Recent glacier changes in five sub-basins in the Kax River

Basins	Glacier terminus			Glacier area				Glacier volume and ice surface height		
	Retreat	Average	Rate	Area (km^2)		Decrease	Rate	Volume reduction	Rate	Height decrease
	(m)	($m \cdot a^{-1}$)	(%)	1962	1989	(km^2)	(%)	($\times 10^4 m^3$)	(%)	(m)
Aleshalang	−149	−5.5	−6.5	27.43	26.33	−1.10	−4.0	−21,507.6	−8.9	−7.8
Tulugengqiagan	−166	−6.2	−6.9	25.50	24.44	−1.06	−4.1	−17,758.9	−9.3	−7.0
Aersangsayi	−150	−5.6	−6.0	40.02	39.15	−0.87	−2.2	−31,623.2	−6.3	−7.9
Tewasayi	−146	−5.4	−7.6	36.02	34.75	−1.27	−3.5	−20,964.5	−6.1	−5.8
Mengkedesayi	−131	−4.8	−7.7	9.68	9.17	−0.51	−5.3	−7265.6	−6.5	−7.5
Total	−149	−5.5	−7.0	138.65	133.84	−4.81	−3.5	−99,119.8	−7.5	−7.1

Precipitation in some parts of the Ili River basin is greater than 1000 mm, which benefits greatly to the development of glaciers, with some of them extending down into the forests. It forms a beautiful, natural landscape of blue skies, white clouds, snow-covered mountains, woodlands, glaciers, grasslands and brooks, which is even more breathtaking than some famous landscapes. The northern Muzart River is even more unique (Photo 5-1). The Muzart Valley is the main pass between northern and southern slopes in the western Tianshan Mountains. With

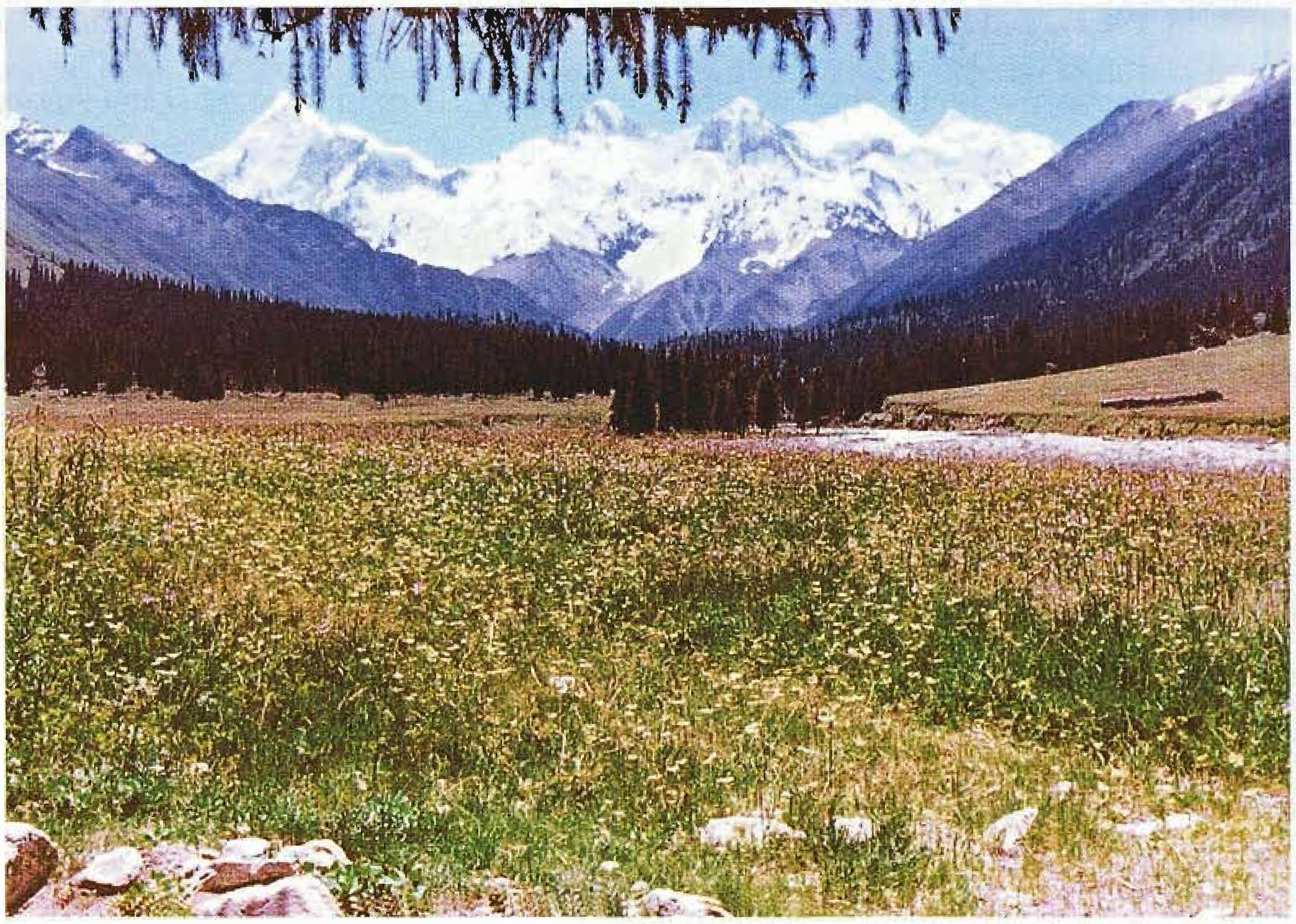


Photo 5-1 The landscape of the northern Muzart Valley (with glacier extending into the forest area) (Wang Zongtai)

the seasonal snow melting away, this valley becomes the shortest pathway between the southern and northern Xinjiang Uygur Autonomous Region. With its elegant and unique natural environment, glaciers, hot springs in the river valley, and ancient cultural remains, this place is a resort for scientific research, tourism and expedition.

In the Karakul Lake basin in the Pamirs along the border between China and Tajikistan, there exist 12 glaciers, which belong to the Central Asian region. Glaciers here occupy an area of 25.5 km^2 with ice volume of 1.5336 km^3.

5.2 The Hexi Interior Basin (5Y4)*

There are 50 rivers in the Hexi Interior Basin (HIB, also named as Hexi Corridor). According to their flowing direction and final merging place, these rivers are divided into five primary basins, including the Shiyang River (5Y41), the Heihe River (5Y42), the Beida River (5Y43), the Shule River (5Y44) and the Danghe River (5Y45) (Figure 5-2). Glacial meltwater supplies plenty water to these rivers and benefits oases along the ancient Silk Road, forming the main food supplies of Gansu Province.

There are 2194 glaciers with a total area of 1334.77 km^2 and volume of 61.54 km^3 in the Hexi Interior Basin (Table 5-6). Roughly 98% of the glacier area is located in the Qilian Mountains, with only 2% in the east end of the Altun Mountains. Glaciers in the HIB are relatively small, with the average area being only 0.61 km^2. There are only nine glaciers larger than 10 km^2 in area, accounting for 0.4% of total number and 9.9% of total area (Table 5-7). This makes it one of the basins with the smallest glacier size in the interior drainage areas.

Table 5-6 Glacier distribution in the Hexi Interior Basin(5Y4)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Shiyang	5Y41	141	6.43	64.84	4.86	2.14	3.48	0.46	4400	3.16	2.7
Heihe	5Y42	428	19.51	129.79	9.72	3.30	5.36	0.30	4440~4500	2.81	2.2
Beida	5Y43	650	29.63	290.76	21.78	10.37	16.85	0.45	4600~4700	7.02	5.5
Shule	5Y44	639	29.12	589.64	44.18	33.34	54.18	0.92	4800	21.91	10.1
Danghe	5Y45	336	15.31	259.74	19.46	12.39	20.13	0.77	4800	11.68	6.4
Total	5Y4	2194	100.00	1334.77	100.00	61.54	100.00	0.61	4400~4800	21.91	10.1

* This subsection is prepared by Wang Zongtai.

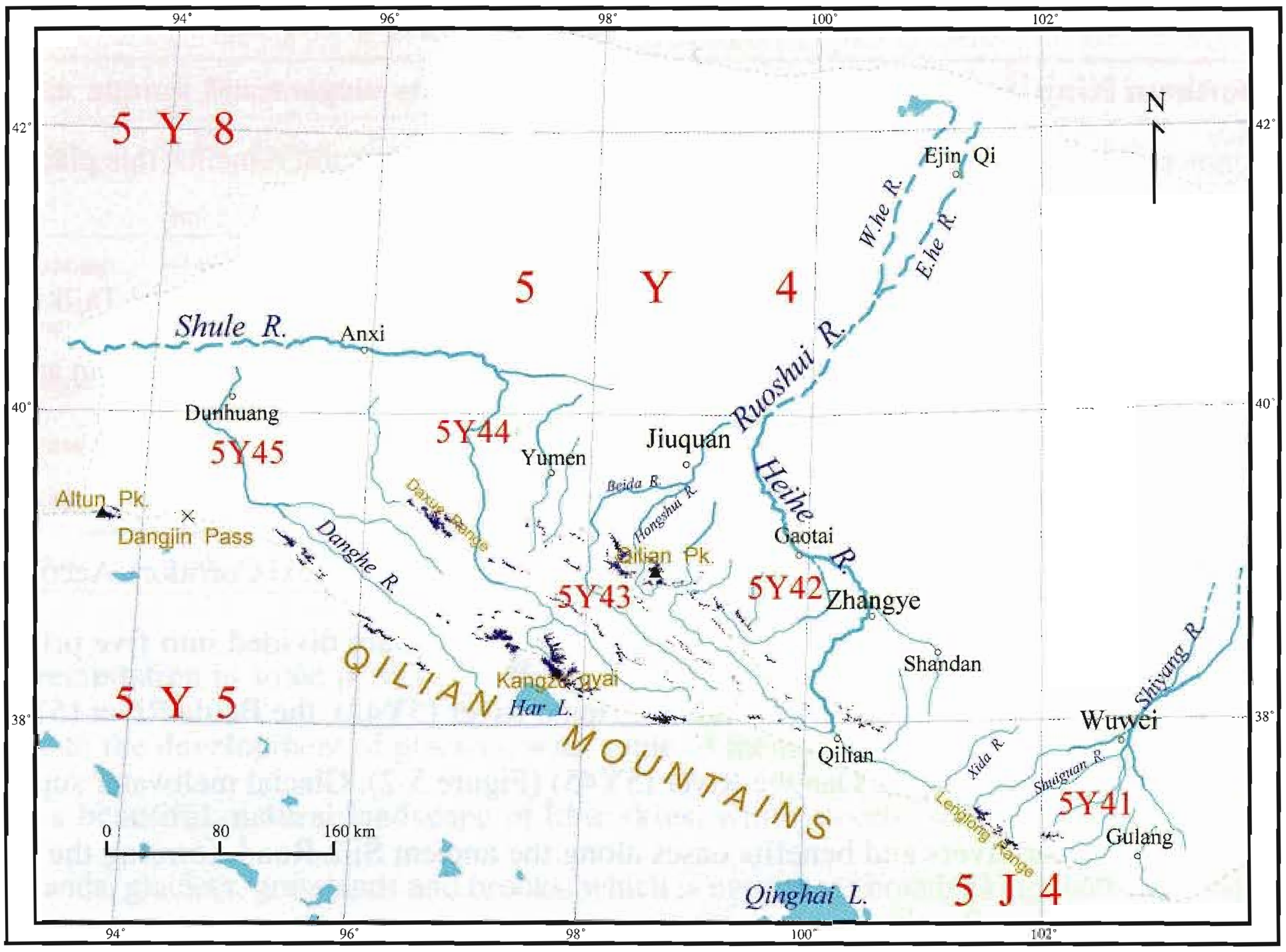


Figure 5-2 Glacier distribution in the Hexi Interior Basin (5Y4)

Terrain and climatic conditions vary greatly from the east to the west in the Qilian Mountains, resulting in different features and sizes of glaciers. The Shiyang River originates from the north slope of the Lenglong Range in the eastern Qilian Mountains. Although annual precipitation near the snowline altitude (SLA) may be greater than 700 mm, and the glaciers are the smallest due to the low elevations of the section of the Qilian Mountains. Glaciers here cover an area of 64.84 km^2 with volume of 2.14 km^3, only 2.1% and 3.5%, respectively, of the corresponding totals of HIB. The average area of glaciers is 0.46 km^2, about two-thirds of that in the whole Hexi basin (0.61 km^2). Small glaciers (<1 km^2) in the basin have a total area of 36 km^2, accounting for 55.5% of the total area of glaciers which is larger than the average value in the HIB (39.5%). The largest glacier, a cirque glacier type, has an area of only 3.16 km^2 (5Y416G2). Moving westward, as the elevation of mountains increases, both the glacier number and the size gradually increase.

The source of the Beida River is located in the middle section of the Qilian Mountains. This basin contains 650 glaciers, with a total area of 290.76 km^2 and a total volume of 10.37 km^3,

Table 5-7 Glacier distribution in various area classes in the Hexi Interior Basin (5Y4)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.50	1570	71.56	306.18	22.94	5.74	9.33	0.19
0.51~1.00	310	14.13	221.22	16.57	6.62	10.76	0.71
1.01~2.00	184	8.39	256.40	19.21	10.38	16.87	1.39
2.01~5.00	105	4.79	311.14	23.31	17.65	28.68	2.96
5.01~10.00	16	0.73	107.70	8.07	8.51	13.83	6.73
10.01~15.00	6	0.27	75.68	5.67	6.21	10.09	12.61
15.01~20.00	2	0.09	34.54	2.59	3.80	6.17	17.27
>20.0	1	0.04	21.91	1.64	2.63	4.27	21.91
Total	2194	100.00	1334.77	100.00	61.54	100.00	0.61

accounting for 29.6%, 21.8% and 16.9% of the corresponding totals of the HIB, respectively. The largest glacier, 7.02 km^2 in area, is the Bieshennia Glacier in the basin, a type of complex valley glacier located in the Hongshuiba sub-basin. The Qiyi glacier in this basin (Photo 5-2) is a cirque-valley glacier with an area of only 2.78 km^2 and length of 3.8 km. This glacier has been observed since the late 1958, and it was developed into a tourist site.

Photo 5-2 The Qiyi Glacier in the Qilian Mountains (Pu Jianchen)

Photo 5-3 The Glacier No. 12 in the Laohugou Valley in the Qilian Mountains (Cited from *Chinese Glaciers*, 1980)

The Shule River, originating in the western section of the Qilian Mountains, is a larger glacierized basin. Glacier area and volume account for 44.2% and 54.2%, respectively, of that in the HIB. The average area of glaciers is 0.92 km^2. 507 glaciers are smaller than 1 km^2 with a total area of 145.45 km^2, 24.7% of the basin's total glacier area. Eight of the nine glaciers larger than 10 km^2 are located in the river basin (Table 5-8). Glacier No.12 in the Laohugou Valley (5Y448D12) is the largest valley glacier in the Shule River and the HIB, with an area of 21.9 km^2 and length of 10.1 km (Figure 5-3). This beautiful, complex-valley glacier lies in the northern slope of the Daxue Range (Photo 5-3). It will soon become a special tourist site.

Table 5-8 Glacier list with an area larger than 10 km^2 in the Hexi Interior Basin (5Y4)

Glacier code	Mountain	Glacier area (km^2)	Glacier length (km)	Maximum altitude (m)	SLA (m)	Terminus altitude (m)	Average thickness (m)	AAR*	Glacier type
5Y448D12	Daxue Range	21.91	10.1	5481	4820	4260	120	0.77	Valley
5Y444G8	Shule South	19.05	8.8	5248	4810	4280	110	0.61	Valley
5Y445G20	Shule South	15.49	6.1	5593	4800	4400	110	0.77	Valley
5Y446F1	Shule South	14.81	5.6	5366	4740	4540	50	0.94	Flat-topped
5Y446F3	Shule South	14.07	7.5	5472	5080	4610	100	0.71	Valley
5Y445H14	Shule South	12.06	8.0	5567	4950	4300	100	0.70	Valley
5Y446G2	Shule South	12.28	5.8	5530	4790	4540	50	0.92	Cirque
5Y452H4	Daxue Range	11.68	6.4	5462	4870	4460	100	0.72	Valley
5Y445F5	Shule South	10.24	6.2	5527	4890	4480	100	0.71	Valley

* AAR is accumulation area ratio of glacier.

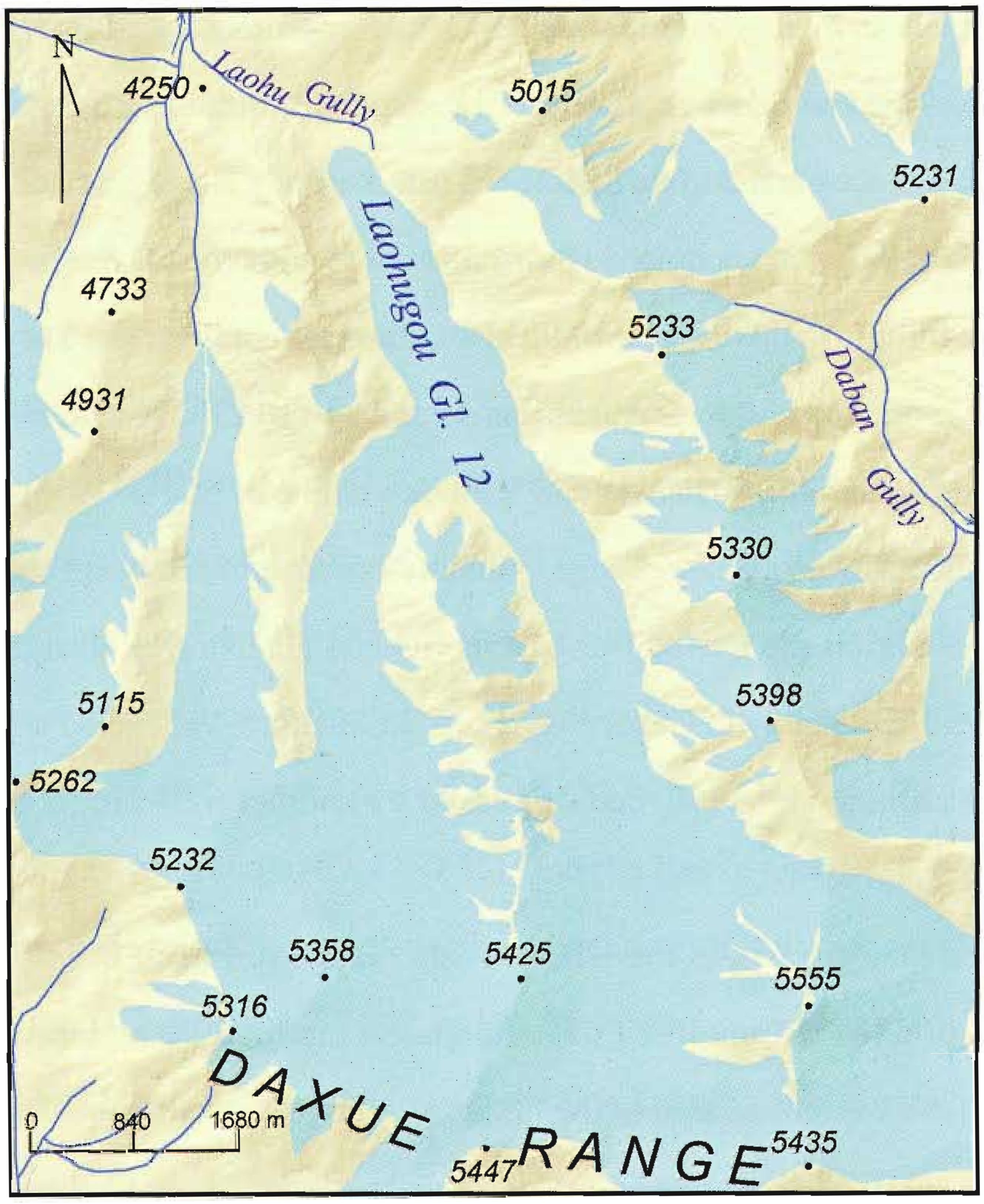


Figure 5-3 The Glacier No. 12 in the Laohugou Valley in the Qilian Mountains

A study on more than 800 glaciers in the HIB shows this glacier area was 575.3 km^2 during the Little Ice Age (LIA) maximum, and has shrunk by 75.9 km^2 by 1956, 13.2% of that in LIA maximum. Changes in glacier area since the LIA indicate that glaciers in the east section of the Qilian Mountains shrunk by 46.1% in area, 22.5% in the middle section and 10% ~ 13% in the west section, whereas the average shrinking rate in the Daxue Range is only 4.7% (Wang Zongtai, 1991;1992).

Since the extensive survey in the Qilian Mountains in 1958, investigations and field observations have been conducted to some glaciers in the east, middle and west parts of the Qilian Mountains in the mid 1970s and 1980s (Xie Zichu *et al.*, 1984; Liu Chaohai *et al.*, 1992). It was found that the rate of glacial shrinkage since the mid 1980s has slowed down, as compared with that in the mid 1970s, increases in ice thickness in the west and middle sections of the Qilian Mountains, and increases in the number of glaciers possibly in advancing state or stable state.

However, the glaciers in the east section are still retreating intensely, although their shrinkage rate has somewhat slowed down, apparently in response to the temperature decrease and precipitation increase since the end of the 1960s. Climate warming has aggravated glacier shrinkage since the mid-1980s. The data acquired from Landsat-TM image for the 691 glaciers during 1956~1990 in the middle and west section of the Qilian Mountains (Liu Shiyin *et al.*, 2002a) indicate that the glacier area of three main basins shrunk by 116.21 km^2 with ice volume reduced by 5.0 km^3, accounting for 10.2% in area and 8.9% in volume of that in 1956, respectively. The Beida River has the greatest glacier change, possibly because of the basin's small glacier size (Table 5-9). In this period the Daxue Range experienced glacier area shrinkage of 7.82 km^2, 4.8% of the total in 1956. Area of Glacier No.12 in the Laohugou Valley had shrunk by 0.99 km^2 during the LIA maximum and 1960, and decreased by another 0.64 km^2, 2.9% during the 30 years between 1960 and 1990.

It is estimated that glaciers in the HIB provide glacial runoff of 8.7×10^8 m^3 annually, occupying 12.7% of the river runoff. Of the total glacial runoff, 80% replenish the Shule River and other rivers in the western section of the Qilian Mountains. Due to global warming since the mid-1980s and the accelerated retreat of glaciers, glacial runoff has been likely increasing, perhaps amounting to 11.97×10^8 m^3 (Xie Zichu *et al.*, 2004 correspondence), about 17.5% of the total river runoff in the whole Hexi Corridor.

Annual precipitation has been estimated to be 700 mm in the eastern section of the Qilian Mountains and decreased 300~400 mm to the western section (The Investigation Team on Utilization of Snow and Ice Resources in Mountain Region, the Chinese Academy of Sciences, 1959). Total glacier volume in the HIB is 520×10^8 m^3, 7.7 times as the annual surface runoff (68.3×10^8 m^3)

Table 5-9 Glacier changes during 1956~1990 in the middle and west sections of the Qilian Mountains

Basins	Number	Glacier area (km^2)	Area change (km^2)	Area change rate (%)	Glacier volume (km^3)	Volume change (km^3)	Volume change rate (%)
Beida R.	650	290.8	−41.6	−14.3	10.4	−1.5	−14.0
Shule R.	639	589.6	−49.6	−8.4	33.3	−2.4	−7.1
Danghe R.	336	259.7	−25.0	−9.6	12.4	−1.1	−8.9
Total/Average	1625	1140.1	−116.2	−10.2	56.1	−5.0	−8.9

or 87 times as the total capacity of 146 reservoirs in the region (6×10^8 m^3). The west section holds 91.2% of the region's ice volume (the Beida River, the Shule River and the Danghe River), with only 8.8% in the Shiyang and Heihe Rivers in the eastern and central sections. To a certain extent, the glacier runoff offsets the effect of precipitation variation on annual discharge, helping preserve the stability of river runoff in the west section and alleviate drought.

5.3 The Qaidam Interior Basin (5Y5)*

The Qaidam Interior Basin (QIB) (5Y5) consists of over 70 independent rivers that all flow toward the region's center, with 40 of them supplied by glacial meltwater. According to landscape features with water flow direction, the Qaidam Interior Basin has been divided into three areas with nine basins: 1) the northern area, with rivers originating from the southern ranges of the Qilian Mountains, including the Buh River-Qinghai Lake (5Y51), the Haltang River (5Y56), the Har Lake (5Y57), the Iqe River-Tataling Gol (5Y58), and the Bayan Gol; 2) the southern area, with rivers originating from the East Kunlun Mountains, including the Qaidam River (5Y52), the Golmud River (5Y53) and the Taijnar River (5Y54); and 3) the western area, with rivers originating in the Altun Mountains and Qiman Tag, including only the Gas Lake(5Y55) (Figure 5-4).

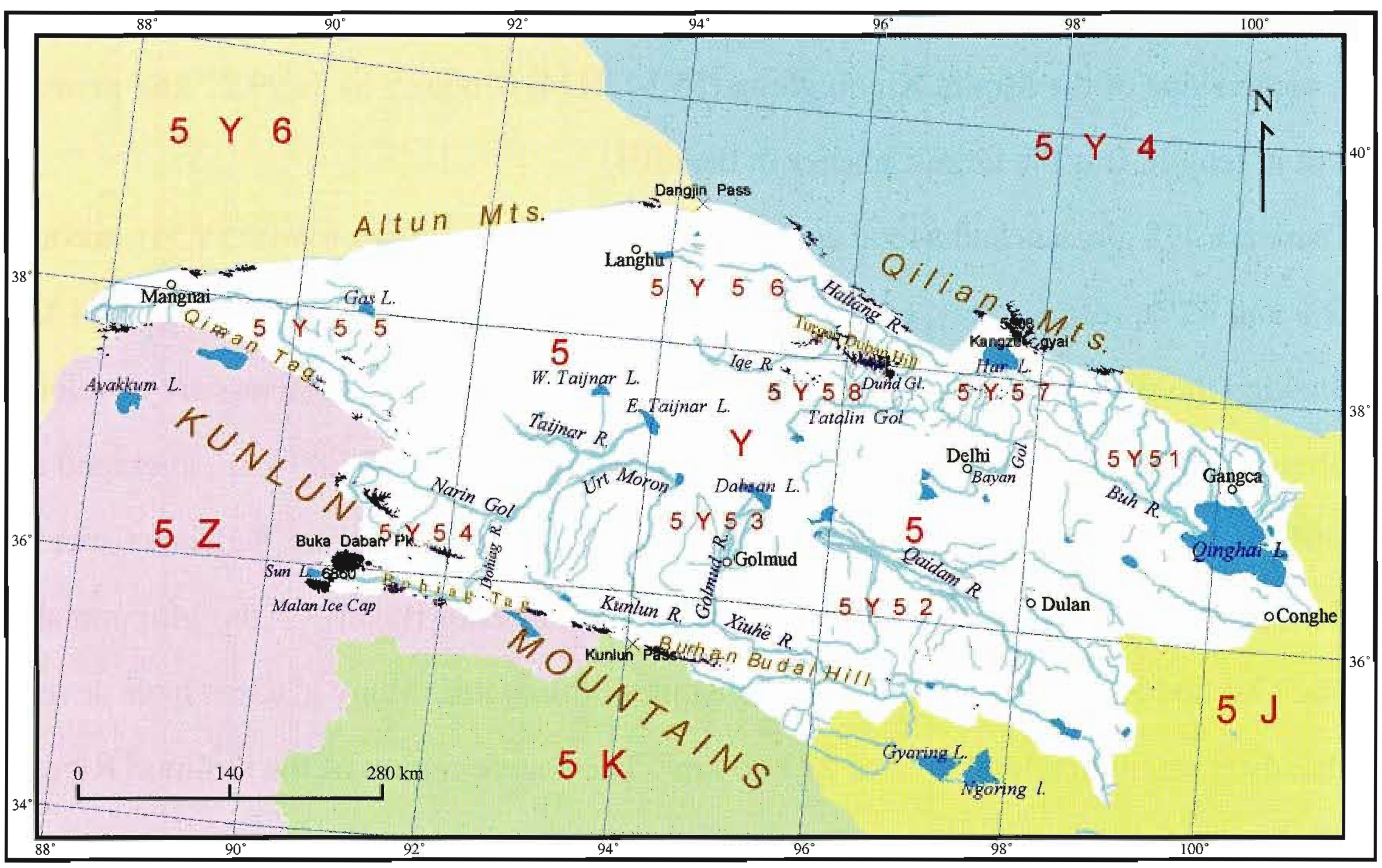


Figure 5-4 Glacier distribution in the Qaidam Interior basin

* This subsection is prepared by Wang Zongtai.

Situated in the northeastern part of the Qinghai-Tibetan Plateau, the Qaidam Basin is a faulted interior basin with a minimum altitude of 2675 m a.s.l., while the surrounding mountains are all above 4000m a.s.l. and contain many glaciers. There are 1581 glaciers in the Qaidam Interior Basin with a total area of 1865.05 km^2, ice volume of 128.66 km^3 (Table 5-10). Nineteen glaciers are larger than 10 km^2 in area (Table 5-11). Although the glacier number in the QIB is less than that of the HIB, the average glacier area is much larger, so that the Qaidam Interior Basin is the basin with the second largest mean glacier area in China.

The span between the southern and northern mountains is 200 km, and extends over 700 km in the east-west direction. Climatic conditions vary largely, but the main factor that determines glacier size is the topography. The main ridges of the eastern Kunlun Mountains are all above 4500 m a.s.l. and the Mount Xinqingfeng is the highest peak (Photo 5-4), 6860 m a.s.l. This high altitudes provide a favorable condition for glacier development. The total area of glaciers in the eastern Kunlun Mountains is 1072.62 km^2, 57.4% of the total area in the entire Qaidam basin, and the average glacier area is 1.36 km^2, larger than the corresponding value for the whole basin (1.18 km^2). There are 19 glaciers greater than 10 km^2 in the Qaidam basin, and 10 of them located in the southern mountain area. Among those largest glaciers, the Monuomaha Glacier, an ice cap on the south slope of the Mount Xinqingfeng (5Y542H34) (Photo 5-5), is 99.27 km^2 in area and 24.5 km in length. It is the largest glacier in the QIB.

There are 478 glaciers and a total area of 785.34 km^2 in the Taijnar River (5Y54), accounting for 30% and 42%, respectively, of the totals in the QIB. Glaciers are averaged as 1.64 km^2 in area, making the river mostly glacierized basin. In this river basin, 218 glaciers are developed in the tributary of the Hongshui River (5Y542), with a total area of 487.89 km^2, averaged as 2.2 km^2, 46% and 62%, respectively, of the relevant totals in the Taijnar River. 8 glaciers area larger than 10 km^2, including the largest glacier in the Qaidam Interior Basin——the Monuomaha ice cap. The Golmud River originates in the mid Kunlun Mountains. Many glaciers have developed in its headstream, with a total area of 273.80 km^2. The source region of the Golmud River near Xidatan is mostly glacierized (Photo 5-6).

The Qaidam Interior Basin in the northeast part of the Qinghai-Tibetan Plateau developed some special glacier types, such as the extended valley Monuomaha glacier, the flat-topped Dund

Table 5-10 Glaciers in the Qaidam Interior Basin (5Y5)

	River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
			Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Northern area	Buh R.-Qinghai L.	5Y51	22	1.39	13.29	0.71	0.59	0.46	0.60	4600~4900	3.76	3.3
	Haltang R.	5Y56	250	15.81	322.46	17.29	18.58	14.44	1.29	4900	19.57	6.7
	Har L.	5Y57	106	6.70	89.27	4.79	4.97	3.86	0.84	4900	14.81	8.4
	Iqe R.-Tataling Gol.	5Y58	168	10.63	168.89	9.06	8.57	6.66	1.01	4900~5100	57.07	6.2
	Bayan Gol	5Y59	11	0.70	2.87	0.15	0.06	0.05	0.26	4900	0.63	1.3
Southern area	Qaidam R.	5Y52	39	2.47	13.48	0.72	0.39	0.30	0.36	5070~5200	1.18	2.1
	Golmud R.	5Y53	269	17.02	273.80	14.68	15.66	12.17	1.02	4930~5340	13.26	4.5
	Taijnar R.	5Y54	478	30.23	785.34	42.11	70.17	54.54	1.64	5100~5760	99.27	24.5
Western area	Gas L.	5Y55	238	15.05	195.65	10.49	9.67	7.52	0.82	5080~5360	12.50	7.0
	Total	5Y5	1581	100.00	1865.05	100.00	128.66	100.00	1.18	4600~5760	99.27	24.5

Table 5-11 Glacier distribution with various area classes in the Qaidam Interior Basin (5Y5)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.50	861	54.46	219.11	11.75	4.94	3.84	0.25
0.51~1.00	313	19.80	219.05	11.74	7.58	5.89	0.70
1.01~2.00	210	13.28	299.62	16.07	13.70	10.65	1.43
2.01~5.00	137	8.67	416.75	22.35	24.71	19.21	3.04
5.01~10.00	41	2.59	271.36	14.55	22.30	17.33	6.62
10.01~15.00	11	0.70	138.57	7.43	13.68	10.63	12.60
15.01~20.00	4	0.25	73.77	3.96	7.21	5.60	18.44
20.01~30.00	1	0.06	21.91	1.17	2.69	2.09	21.91
40.01~50.00	1	0.06	48.57	2.60	7.72	6.00	48.57
50.01~100.00	2	0.13	156.34	8.38	24.13	18.76	78.19
Total	1581	100.00	1865.05	100.00	128.66	100.00	1.18

Glacier, and the ice cap-shaped Malan glacier.

The Dund Flat-topped Glacier (5Y582J2), with an area of 57.07 km^2 and top altitude of 5352 m a.s.l., is cold glacier with ice temperature in the active layer of −7.3℃. There are 9 glacier tongues flowing out of the ice cap, with the mean equilibrium line altitude (ELA) of 4900 m a.s.l. and average thickness of 94 ~ 167 m. (Figure 5-5). This flat-topped glacier has been investigated during 1984~1987 by a joint expedition from Lanzhou Institute of Glaciology and Geocryology, CAS, and the Byrd Polar Research Center of Ohio State University. They have drilled two shallow ice cores of 34.5 m and 32 m, and three deep ice cores of 139.8 m, 136.6 m, and 138.4 m long, respectively. This marked the beginning of China's ice core study on the Qinghai-Tibetan Plateau. From analysis of these ice cores, the research team revealed significant information about climate change since the end of Pleistocene (Yao Tandong *et al.*, 2000).

The Malan ice cap, 172.8 km^2 in area, is composed of approximately 30 glaciers within the Sun Lake basin (5Y542) and the Hoh Xil Lake (5Z122) in the Qinhai-Xizang Plateau (Photo 5-5). The Mount Malan has a round top. The northern slope is relatively steep with an altitudinal span of 800~1100 m, whereas it becomes gentle on the southern slope with the altitudinal span of 600~950 m.

Photo 5-4 The Mount Xinqingfeng and its glaciers in the eastern section of the Kunlun Mountains (Pu Jianchen)

Ice volume in the Qaidam Interior Basin is around 1094×10^8 m^3, 24 times of its surface runoff (45×10^8 m^3) and much larger than the corresponding 520×10^8 m^3 in the HIB. The basin gets 3574.3 hours of sunshine each year, and solar radiation is greater than 690 J · cm^{-2}, making it one of the sunniest and most radiated regions in China. There are fewer than 50 rainy

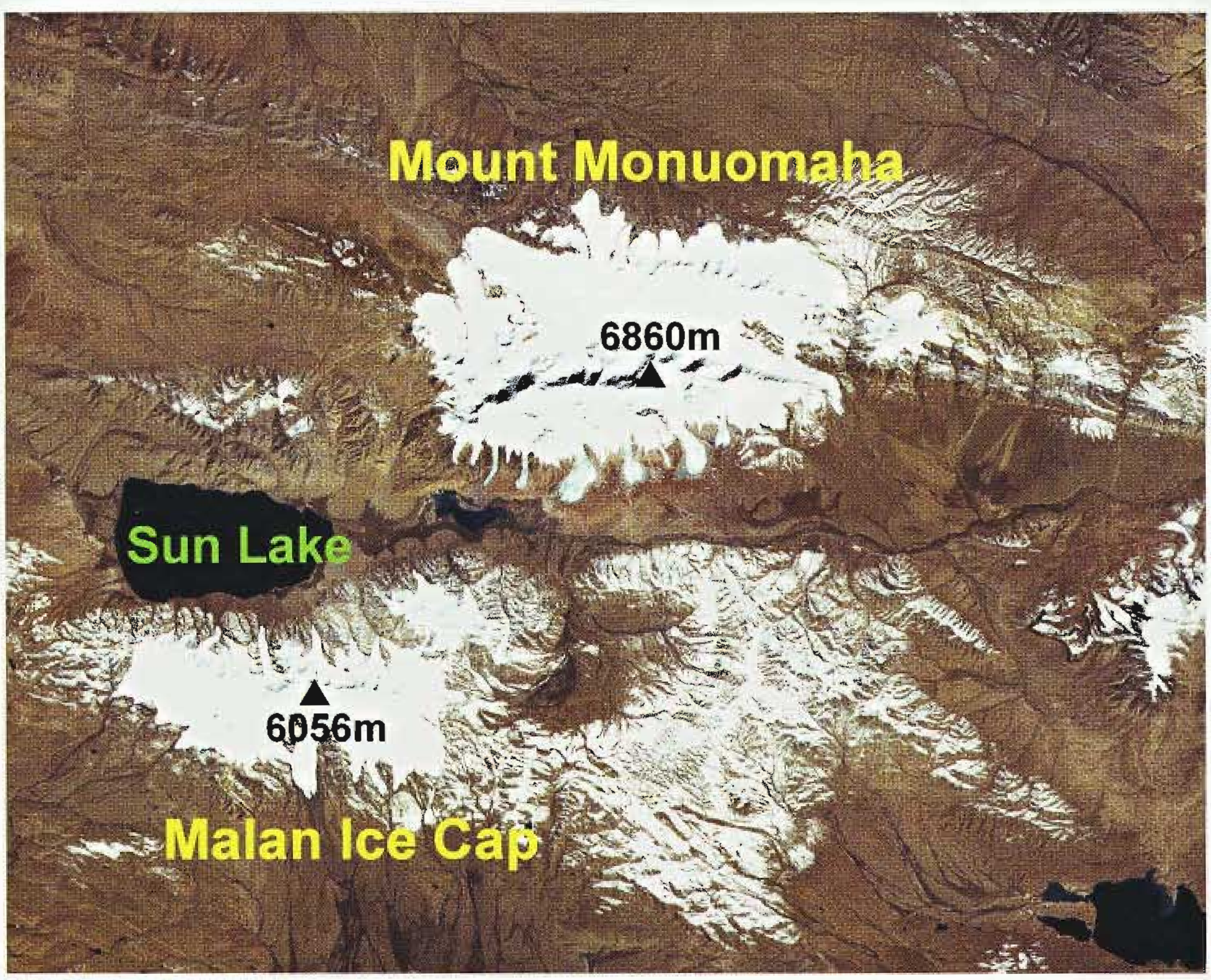


Photo 5-5 The Monuomaha and Malan ice caps (Landsat -TM 2000.10.07; Lu Anxin)

days in a year and the annual precipitation is less than 25 mm. The Lenghu Lake, one of the driest areas in the country, only receives 17.8 mm precipitation annually (Wu Guanghe,1989). Nevertheless, the surrounding mountains in the Qaidam Interior Basin contain many large glaciers, which have important economic value for the development of petrochemical engineering and agricultural irrigation.

The annual glacier meltwater runoff is about 6.31×10^8 m^3 in the Qaidam Interior Basin, 13.3% of total river runoff (Kang Ersi *et al.*, 2000). The glaciers of this drainage area belong to the extreme continental type, which has low melting intensity. The estimated annual glacial meltwater discharge is 30~50 $L \cdot km^{-2} \cdot s^{-1}$, much lower than 40~70 $L \cdot km^{-2} \cdot s^{-1}$ in the Hexi Interior Basin. These estimations for glacial meltwater runoff are based on glaciers and climatic condition in the 1980s. Subsequent climate warming has increased the volume of meltwater. It was estimated that the glacial runoff increased by 3.7% during 1960 and 1995, or 3.2×10^8 m^3 (Shi Yafeng, 2001).

With climate warming, glaciers in the Qaidam Interior Basin are generally shrinking. The

Photo 5-6 Glaciers in the Kunlun Mountain near Xidatan (Pu Jianchen)

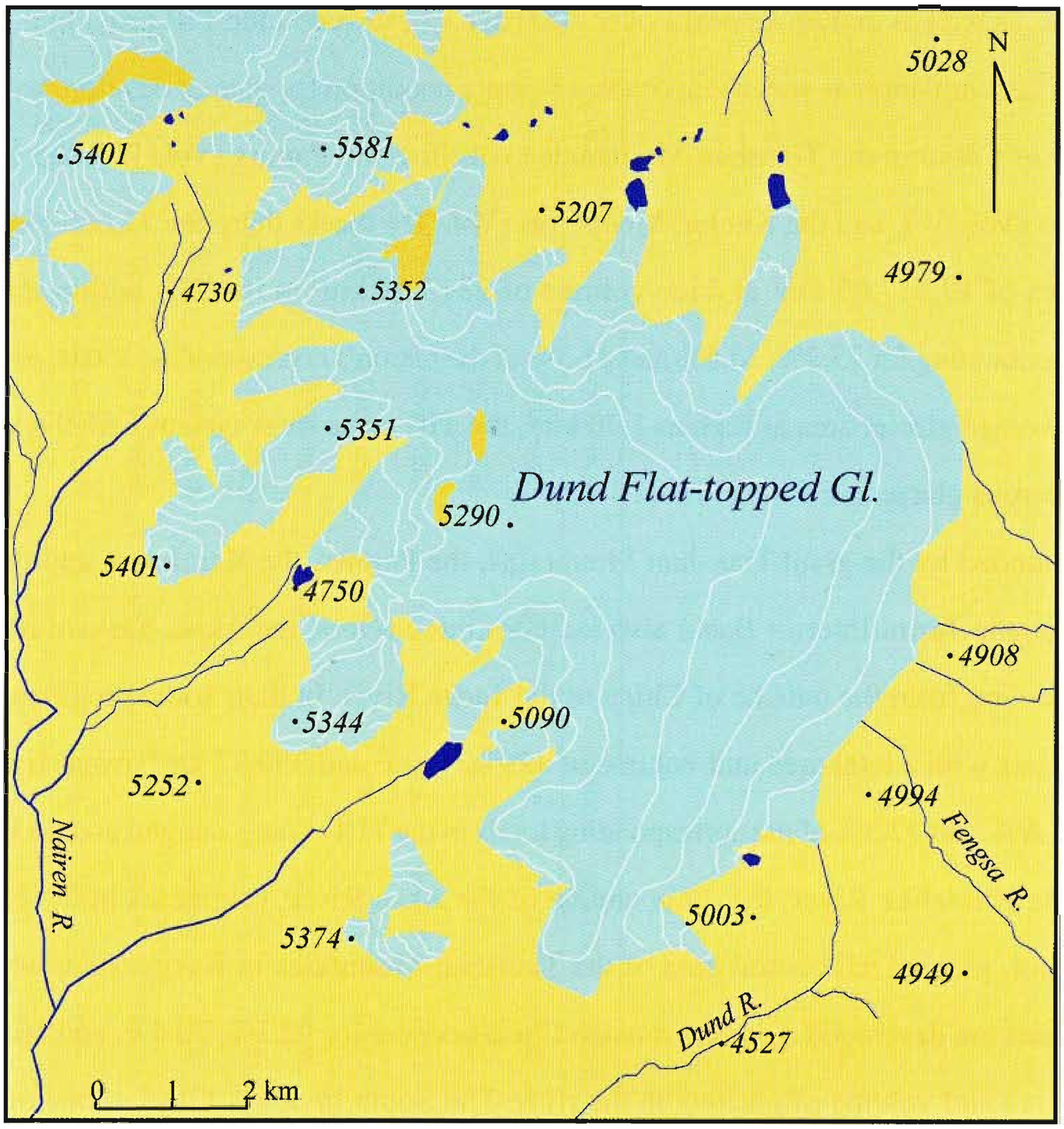


Figure 5-5 The Dund Flat-topped Glacier in the Qilian Mountains

glacier area of the Har Lake basin during 1956 and 1990 shrank by 8.9% (Liu Shiyin *et al.*, 2002a). More than 20 glaciers on the northern slope of the Mount Malan also retreated in the past decade (Pu Jianchen *et al.*, 2001).

5.4 The Tarim Interior Basin (5Y6)*

The Tarim Interior Basin (TIB) is surrounded by the Kunlun Mountains in the south, the Karakoum Mountains and the Pamirs in the southwest, and the Tianshan Mountains in the north. Its east end borders the Turpan-Hami Basin and the Hexi Interior Basin. There are 9 large rivers in the TIB, the Hotan, the Keriya, the Yarkant, the Kaxgar, the Aksu and the Ogan and so on, originated from these mountains, forming the gigantic Tarim interior water system (Figure 5-6).

Giant mountains, such as the Kunlun Mountains, the Karakoum, the Pamirs and the Tianshan

* This subsection is prepared by Yang Hui'an.

Mountains, as well as numerous peaks over 7000 m a.s.l., surround the TIB providing vast space for glacial accumulation as well as favorable moisture condition for glacier development. *Glacier Inventory of China* in the Tianshan Mountains (Vol. Ⅲ), the Pamirs (Vol. Ⅳ), the Karakoum Mountains (Vol. Ⅴ), and the Kunlun Mountains (Vol. Ⅵ) shows there are 11,665 glaciers with a total area of 19,877.65 km^2 and ice volume of 2313.29 km^3 in the TIB within the Chinese territory, accounting for 25.2%, 33.5% and 41.3% of the nation's corresponding totals, respectively. With an average glacier area as high as 1.70 km^2, the TIB is the river system with the largest and most numerous glaciers in China (Table 5-12)

Surrounded by the giant Tianshan Mountains, the Pamirs, the Karakoum and the Kunlun Mountains, the Tarim Interior Basin also includes three rivers, the Aksu, Yarkant and Kaxgar Rivers, flowing from the outside of China to the Tarim River. In their source regions, there are 2248 glaciers with a total area and volume of 4297.24 km^2 and 399.37 km^3, respectively, about 19.3%, 21.6%, and 17.3% of the corresponding totals in the TIB (Wang Zongtai and Su Hongchao, 2003). The Kumalike River, the main source of the Aksu River, originates in the Hantengri-Tomur Knot, glacierized central area of the Tianshan Mountains in Kyrgyzstan, where some large glaciers are developed. Glaciers outside China account for 92.1%, 70.4%, and 46.0% of the number, area and volume of glaciers in the river. The South Inylchek Glacier, one of the eight largest glaciers with a length greater than 50 km in the mid- and low-latitudes, is 63.5 km long and 567.20 km^2 in area. Another tributary of the Aksu River, the Toxgan River, also originates from the southwest Tianshan Mountains in Kyrgyzstan, where there are 566 glaciers with 688.30 km^2 in area. The Kaxgar River originates from the western Pamirs in Tajikistan, where 239 glaciers are in the source region with an area of 345.70 km^2. The Kulqin River in the upstream of the Yarkant River, a region under controlled by Pakistan, has 142 glaciers with an area of 609.54 km^2 and volume of 72.3721 km^3. Considering all glaciers that supply meltwater to the TIB, there are totally 13,913 glaciers with an area of 24,174.89 km^2 and ice volume of 2712.66 km^3, corresponding to 2441.39 km^3 water equivalent, 62 times of the annual mean surface runoff (392.74×10^8 m^3) of the TIB.

Mountains surrounding the TIB have been divided into two opposit groups, the southern mountainous region including the Kunlun Mountains, the Karakoram Mountains and the Pamirs,

Table 5-12 Glaciers in tributary of the Tarim Interior Basin (5Y6)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Miran R.	5Y61	69	0.59	88.01	0.44	5.09	0.22	1.28	4820~5260	8.01	2.2
Qarqan R.	5Y62	404	3.46	686.86	3.46	67.60	2.92	1.70	4920~5640	103.53	14.0
Keriya R.	5Y63	895	7.67	1357.27	6.83	100.66	4.35	1.52	4620~6060	39.69	10.6
Hotan R.	5Y64	3555	30.48	5336.98	26.85	578.71	25.02	1.50	4780~6260	251.70	31.0
Yarkant R.	5Y65	2917	25.01	5315.31	26.74	612.10	26.46	1.82	4790~6010	379.97	42.0
Kaxgar R.	5Y66	1135	9.73	2422.82	12.19	230.62	9.97	2.13	4280~4910	128.15	20.3
Aksu R.	5Y67	1005	8.62	2411.56	12.13	436.99	18.89	2.40	4290~4390	392.84	63.5
Ogan R.	5Y68	853	7.31	1783.86	8.97	258.27	11.16	2.09	3920~4230	313.69	36.1
Kaidu R.	5Y69	832	7.13	474.98	2.39	23.25	1.01	0.57	3850~4010	16.68	7.8
Total	5Y6	11,665	100.00	19,877.65	100.00	2313.29	100.00	1.70	3850~6260	392.84	63.5

the northern mountainous region including the mountains to the south of Tianshan Mountains watershed (Table 5-13). Glaciers in the southern mountainous region cover a total area of 15,784.42 km^2 (65.3% of the total area in the TIB). Glaciers in northern regions occupy an area of 8390.47 km^2.

There are some mostly glacierized centers, like the Muz Tag in the central Kunlun Mountains, the Muztag Ata-Konggur in the Pamirs, the Mount Kunlun in the western Kunlun Mountains, the Mount Qogir in the Karakorum, and the Hantengri-Tomur Knot in the Tianshan Mountains around peaks above 7000 m a.s.l. The Muz Tag (6973 m a.s.l., 36°30′ N, 87°25′ E) shows as a huge, irregular pyramid-like mountain with an average ridge height of 6200 m a.s.l. There are 116 glaciers, with a total area of 681.17 km^2 and ice volume of 92.13 km^3. Glaciers form as a huge compound ice cap, the largest glacierized center in the Kunlun Mountains (Figure 5-7). Glaciers on the northern slope is the source of the Qarqan River (5Y62), where they cover 45.7%, 45.4%, and 49.0% of total number, area and volume of all glacier in the glacierized center. Various glacier types are found in the area, including the Yulinchuan Glacier, the largest complex valley glacier in the southeastern part of the Tarim Interior Basin (103.53 km^2 in area and 14 km in length), the flat-topped Muz Tag Glacier that covers the western half of the highest peak (glacier area of 71.70 km^2), and also some smaller valley glaciers, cirque glaciers and hanging glaciers (Li Jijun, 1980).

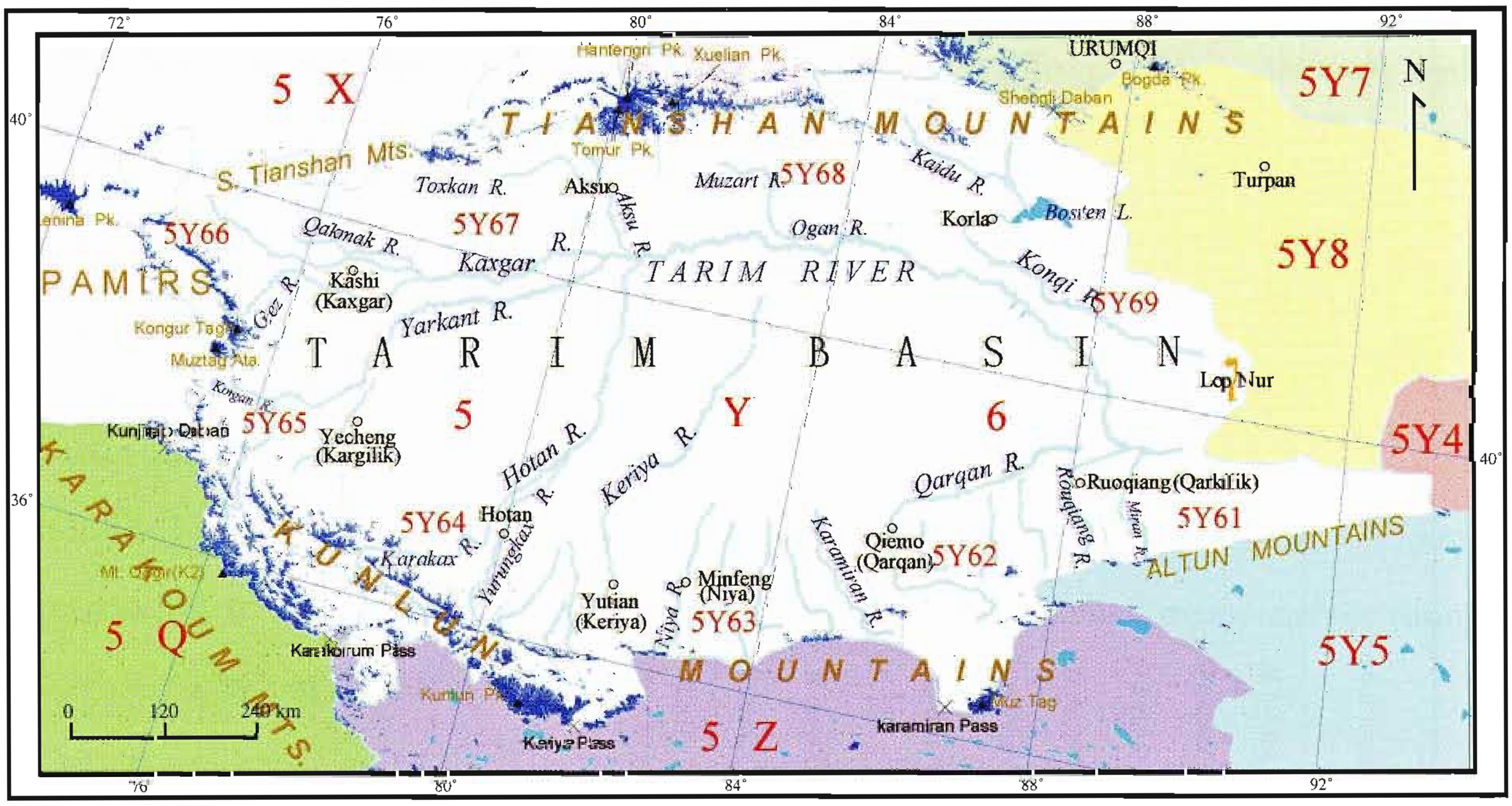


Figure 5-6 Glacier distribution in the Tarim Interior Basin

Table 5-13 Glaciers in the mountains of the TIB (5Y6)

	Mountains	Glacier number		Glacier area		Glacier volume		Mean area per glacier
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
	Totals for TIB	13,913	100.00	24,174.89	100.00	2712.66	100.00	1.74
domestic glaciers	Kunlun Mt.	5744	41.30	8244.26	34.10	797.88	29.40	1.44
	Karakoum Mt.	1819	13.00	4260.01	17.60	548.77	20.20	2.34
	Pamirs	1277	9.20	2670.61	11.00	247.14	9.20	2.09
	Tianshan Mt.	2825	20.30	4702.77	19.50	719.50	26.50	1.66
	Total	11,665	83.80	19,877.65	82.20	2313.29	85.30	1.70
foreign glaciers	Karakoum Mt.	142	1.10	609.54	2.50	72.37	2.70	4.29
	Pamirs	239	1.70	345.70	1.50	33.00	1.20	1.45
	Tianshan Mt.	1867	13.40	3342.00	13.80	294.00	10.80	1.79
	Total	2248	16.20	4297.24	17.80	399.37	14.70	1.91

The Mount Kunlun is the highest peak of the Kunlun Mountains with 7167m a.s.l. at the head of the Yurungkax River and the Keriya River, being the largest glacierized center in the western Kunlun Mountains (Figure 3-2). There are 349 glaciers, forming a large compound ice cap with an area of 2962.91 km^2. The glacierization rate is 41% (30% on southern slope, and 55% on northern slope). All of the 10 glaciers larger than 100 km^2 in the Kunlun Mountains, except for the Yulinchuan Glacier, are located at this glacierized center. The topography of the Mount Kunlun demonstrates large differences between the southern and northern slopes. The southern slope belongs to the Qinghai-Tibetan Plateau Interior Basin and the inclination is gentle, with the dominant type of flat-topped glaciers. The northern side displays steep slopes, deep valleys and long rivers, favoring the development of many complex valley glaciers and dendritic valley glaciers. The largest Duofeng Glacier, a dendritic valley glacier consisting of 12 glaciers, is 251.70 km^2 in area, 31 km in length.

The Karakoum Mountains are one of the world's largest and most magnificent mountain ranges. Of the 14 highest peaks above 8000 m a.s.l. in the world, four peaks are located here. Fifteen peaks are above 7000 m a.s.l., with the Mount Qogir, 8611 m a.s.l., the highest peak in the Karakoum Mountains. The mountains are wide, and their valleys usually lie in the same direction as the mountains, resulting in abundant precipitation in high mountains and the formation of some large glaciers here. The northern slope of the Mount Qogir is the highest glacierized area of the Karakoum Mountains, with an area up to 2234.81 km^2, or 45.9% of the total area of the mountains. There are five glaciers larger than 100 km^2 in area (Figure 5-8). The Yengisogat Glacier, a dendritic valley glacier, conjuncted with four branches and over ten smaller glaciers, is 42.0 km long with an area of 379.97 km^2 and ice volume of 115.89 km^3. Being the longest and largest (by glacier area) valley glacier within China, the equilibrium line altitude of the Yengisogat Glacier is 5420 m a.s.l., and the terminus of its tongue extends down into a valley at 4000 m a.s.l. (Figure 3-9). Thick debris layer covers the ablation area of the glacier, and numerous ice crevasses and seracs give it the additional name of "crevasse glacier". In riverhead area of the Yarkant River, there are some large glaciers, such as the Teram Kangri and the Kyagar, blocking the main river channel, the Kulqin River, forming the ice dammed lake as the Kyagar Thso Lake (Figure 5-9). This lake has outbursted many times, resulting in sudden floods and disasters in the lower reach of the Yarkant River (Photo 5-7) (Zhang Xiangsong and Zhou Yuchao, 1990).

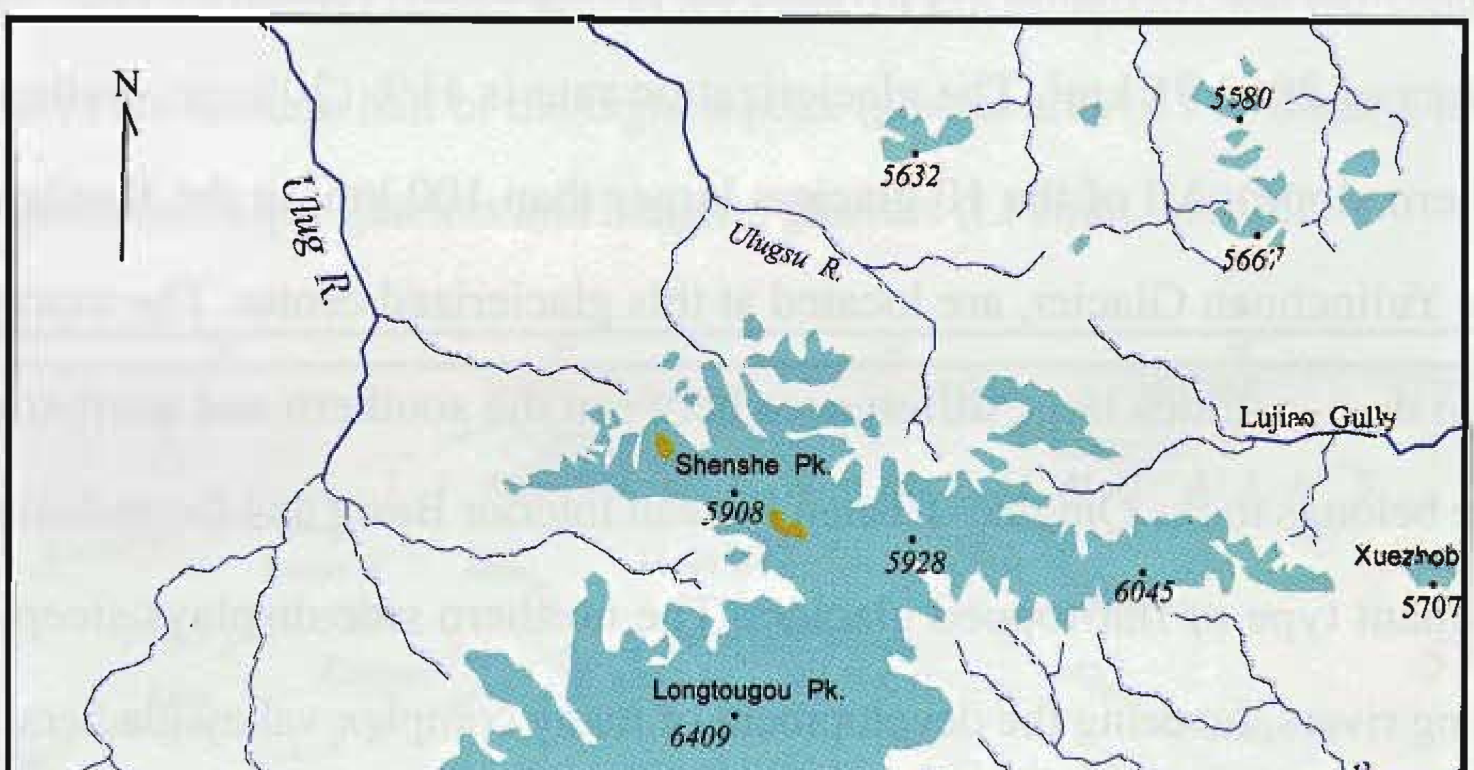


Figure 5-7 Glacier distribution in the Muz Tag in the central Kunlun Mountains

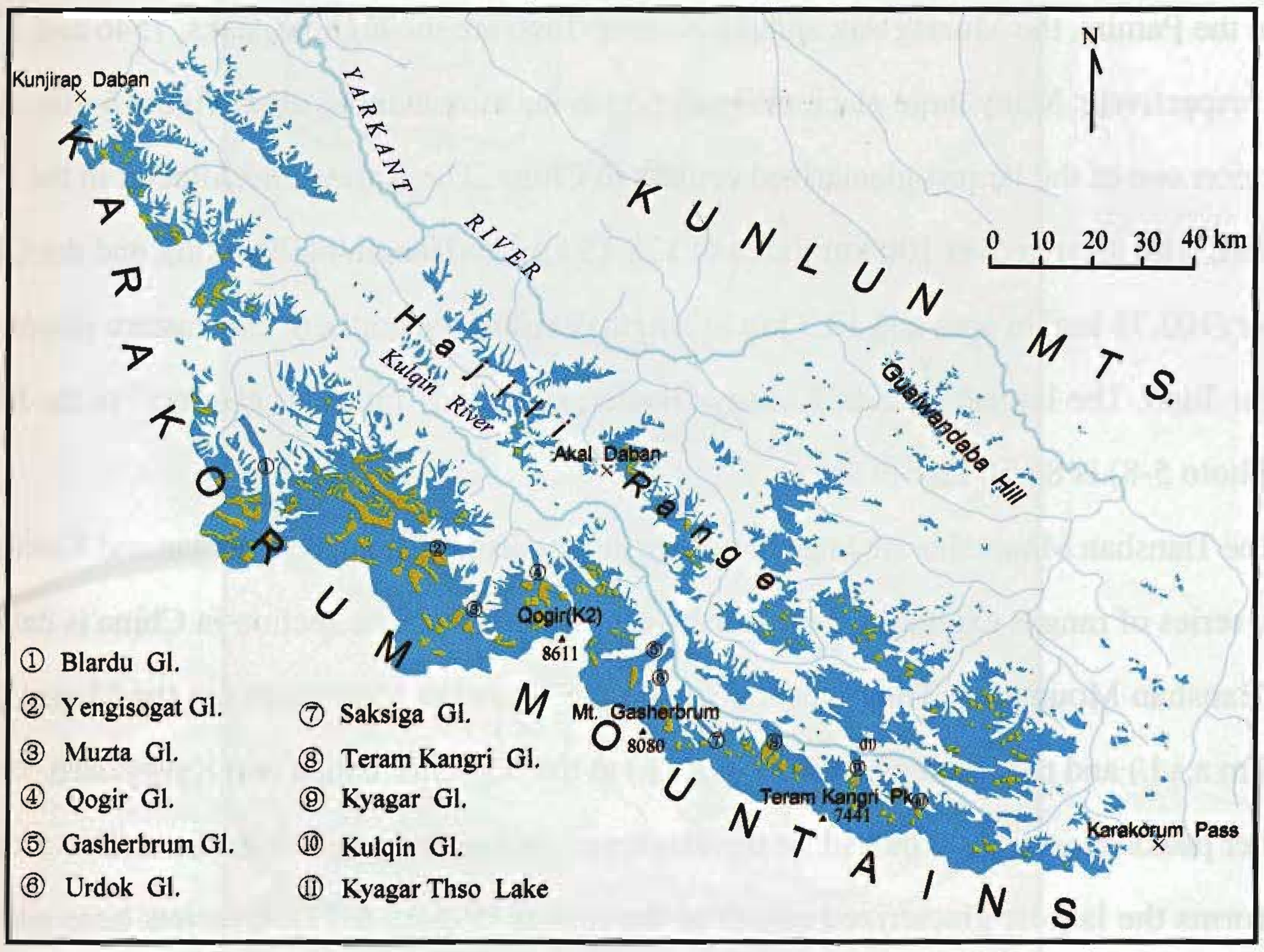


Figure 5-8 Glaciers on the northern slope of the Mount Qogir in the Karakoum Mountains

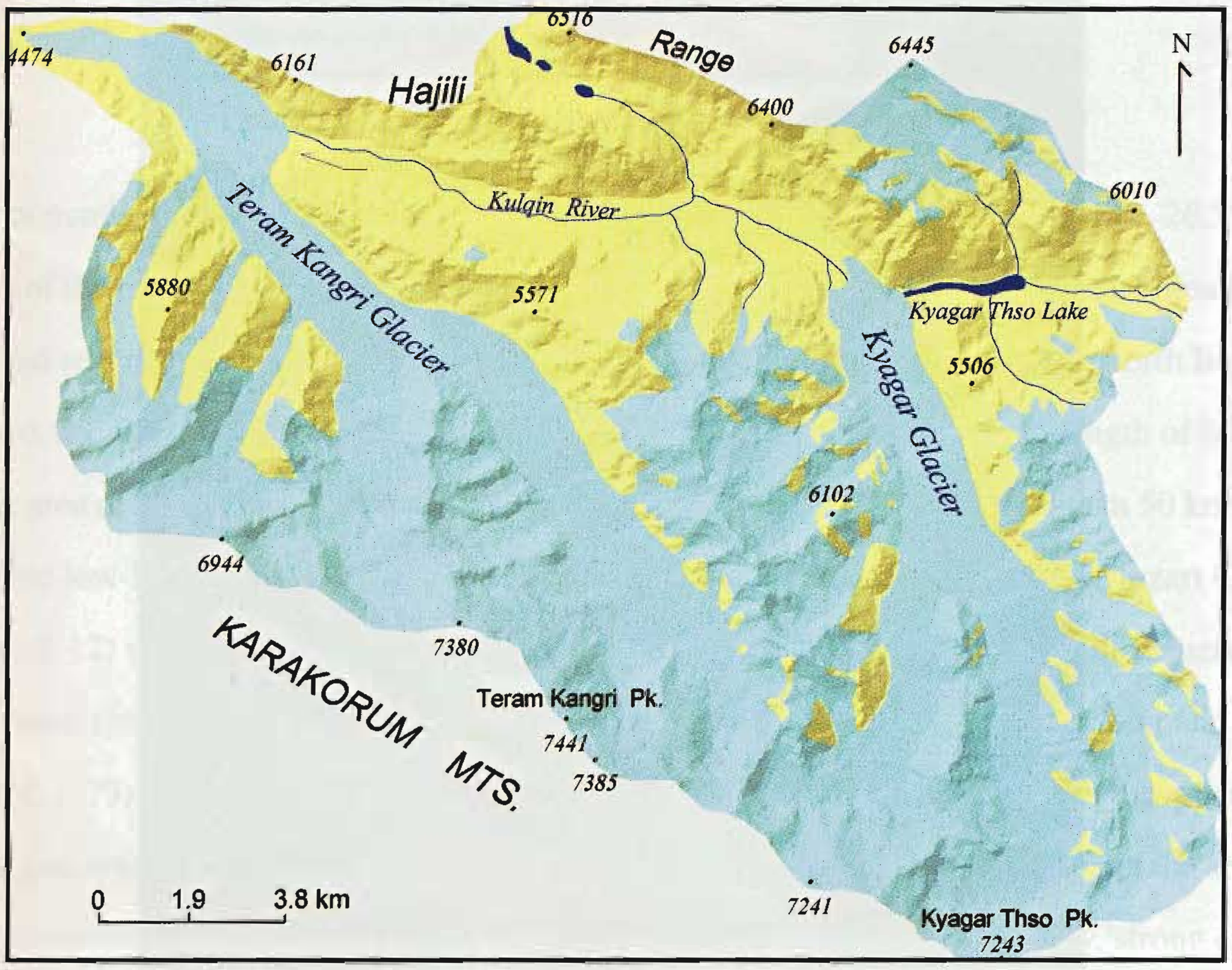


Figure 5-9 The Kyagar Glacier and its dammed Kyagar Thso Lake

In the Pamirs, the Muztag Ata and the Kongur Tagh are the highest peaks, 7546 and 7719 m a.s.l., respectively. Many large glaciers developed in the mountainous area (Figure 5-10), making the region one of the largest glacierized centers in China. The Karayaylak Glacier in the Pamirs in China, with an area over 100 km^2 (area of 128.15 km^2 and length of 20.3 km), and the Qimgan Glacier (103.71 km^2 in area and 12.3 km in length) exist in the northern and eastern slopes of the Kongur Tagh. The largest glacier, Koksay Glacier, so-called "father of glaciers" in the Muztag Ata (Photo 5-8) is 86.50 km^2 in area.

The Tianshan Mountains are huge mountain ranges across China, Kyrgyzstan and Kazakhstan, with a series of ranges extending from northwest to southeast. The section in China is called the East Tianshan Mountains. The highest peaks in the Tianshan Mountains are the Mount Tomur (7435 m a.s.l.) and the Hantengri (6995 m a.s.l.) at the border of China and Kyrgyzstan, besides, 40 other peaks exceed 6000 m a.s.l. in the Hantengri (Khan Tengri)-Tomur Knot. This mountain knot forms the largest glacierized center in the region (Figure 5-11). Glaciers here add up to

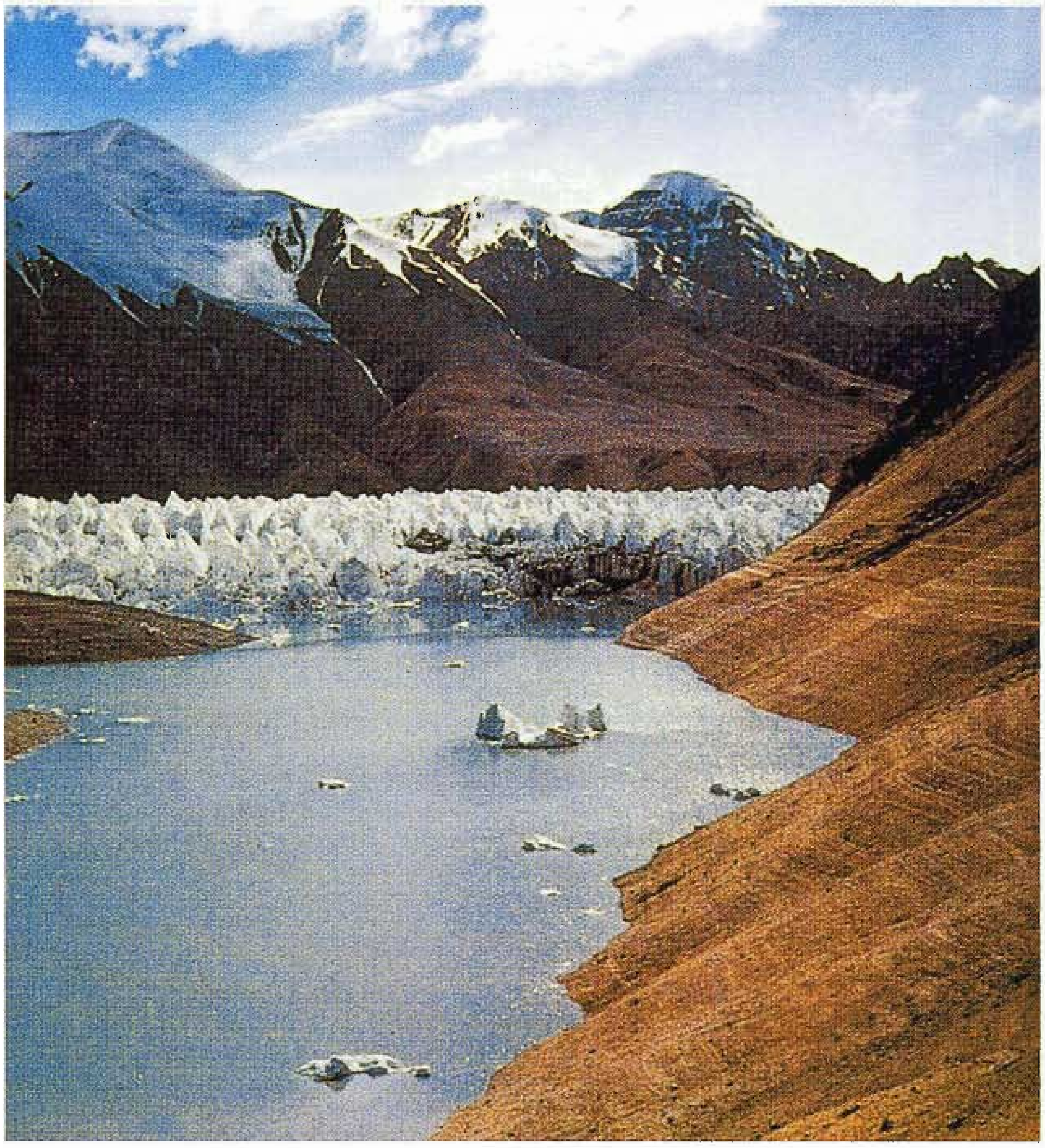


Photo 5-7 The Kyagar Thso Lake formed by the blockage of the Kyagar Glacier to the Kulqin River (Ma Qiuhua)

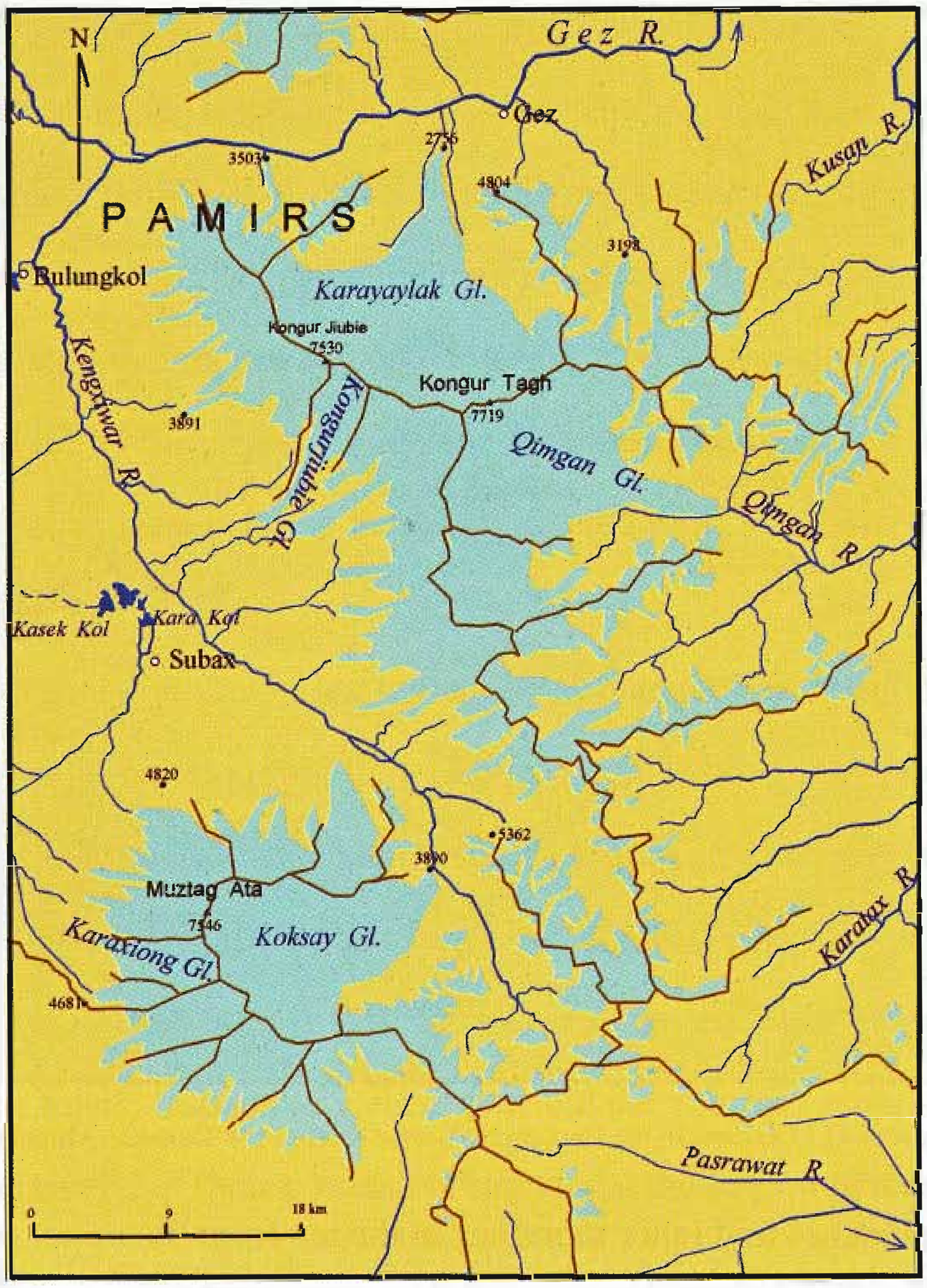


Figure 5-10 Glacier distribution in the Kongur Tagh —— Muztag Ata

1357 in number with a total area of 4093 km² and ice volume of 424 km³, or 8.5%, 26.5% and 40.5% of the respective totals in the whole Tianshan Mountains. The average glacier area is 3.02 km², and seven glaciers have an area exceeding 100 km², such as the South and North Inylchek Glaciers and the Tomur Glacier in China. The South Inylchek Glacier with a length of 60.5 km and an area of 567.20 km² is one of the eight largest glaciers which are longer than 50 km in the mid- and low-latitudinal regions. The largest glacier on the eastern slope is the Muzart Glacier (Figure 5-12) with a length of 33 km and an area of 137.7 km². Since olden days the Muzart pass is the most convenient link between the southern and northern Xinjiang (Shi Yafeng and Wang Zongtai, 1979). A considerable altitude span exists between the top and terminus of these dendritic valley glaciers. Abundant solid precipitation in the firn basins and intense ablation in the ablation areas demonstrate that glaciers here are much active with a fast surface velocity, strong erosive and transport capacity. Avalanches bring large amounts of rock debris onto the ice surface. The

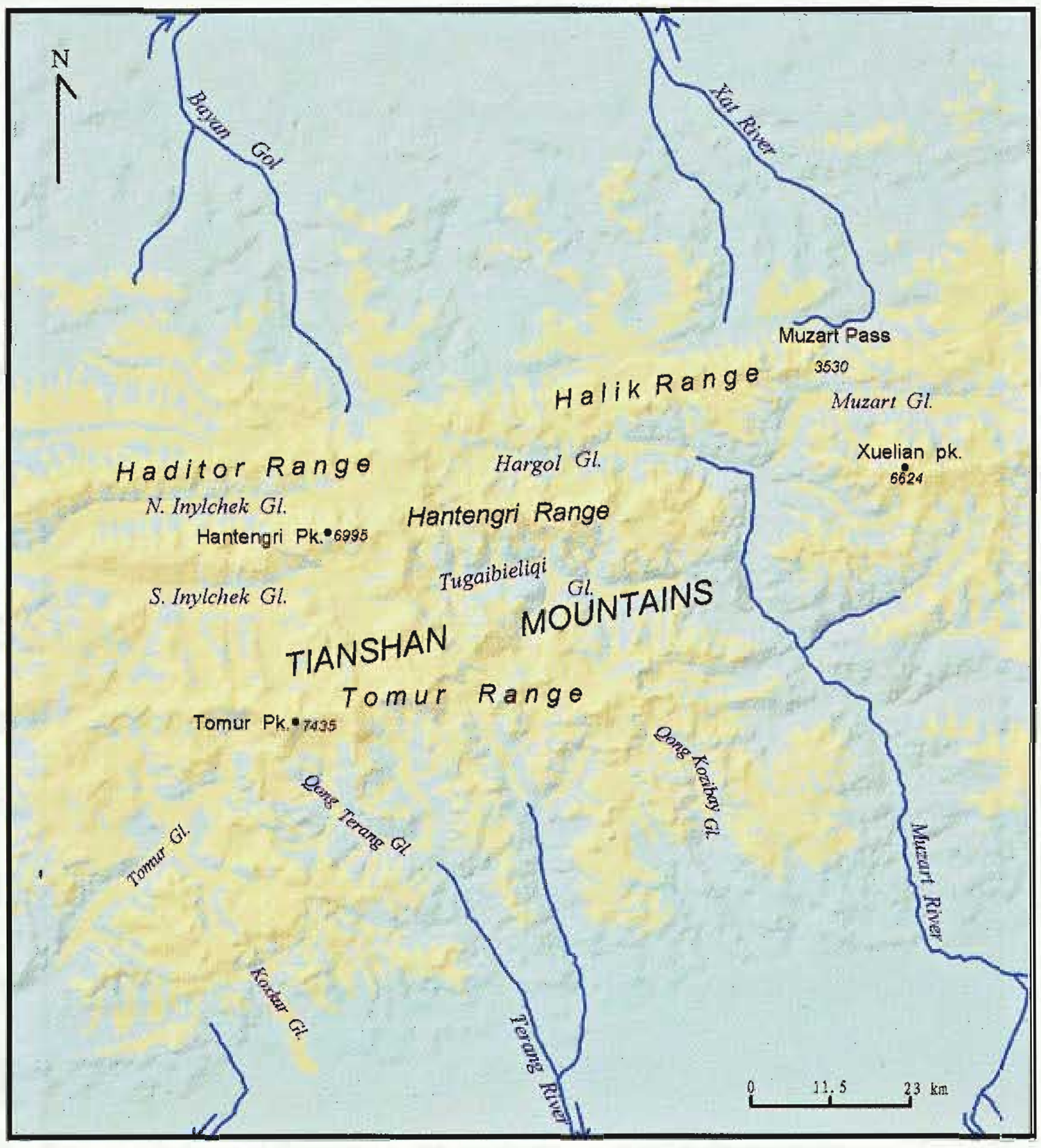


Figure 5-11 Glaciers in the Hantengri -Tomur Knot of the Tianshan Mountains

rock debris from avalanches and inner moraines in the ice from the upper reaches of glacier has transported down and formed the medial or lateral moraine belts in glacier branch ends, and has finally formed a debris cover in the glacier terminus. Because of the heavy debris cover on

Photo 5-8 Glaciers in the Mount Muztag Ata of the Pamirs(Pu Jianchen)

ablation areas of glacier, they are the typical type of "Turkestan glacier".

Statistics for glaciers in the Tarim Interior Basin (including glaciers at the head of the Yarkant River outside the Chinese territory) (Table 5-14) indicate that the hanging glaciers dominates the glacier number (38.4%), while valley and cirque -valley glaciers dominate the total area of glaciers. The area of these valley glaciers occupy 65.6% and 85.7% of the total area and volume in the basin, respectively. Twenty large valley glaciers with more than 100 km^2 in the Tarim Interior Basin, all dendritic-valley type glaciers, have a total area of 3776.42 km^2 (18.4% of all glacier area).

Statistics for glacier length and area in the Tarim Interior Basin (including glaciers at the head of the Yarkant River outside China) (Table 5-15, Table 5-16) provide the following information: Glaciers less than 1.0 km in length and 1 km^2 in area account for 52.7% and 72.2%, respectively, of the totals, the smallest percentages among all the river basins in China; however, although the number of glaciers longer than 10.0 km and larger than 10.0 km^2 accounts for only 0.8% and 2.4% of the totals, respectively, their area and ice volume comprise 32.9%, 46.5% and 61.4%, 74.4%, respectively, of their corresponding totals, the largest percentages among all the country's river basins, for example, the twenty glaciers larger than 100 km^2 take the percentage of 18.4% and 41.7% of the total area and volume of glaciers in the basin. In addition, the all four largest glaciers larger than 300 km^2 in China are all located here, again demonstrating the large size of glaciers in the Tarim Interior Basin.

Glacier sizes expressed as exponential with 2 as the base demonstrate a normal distribution

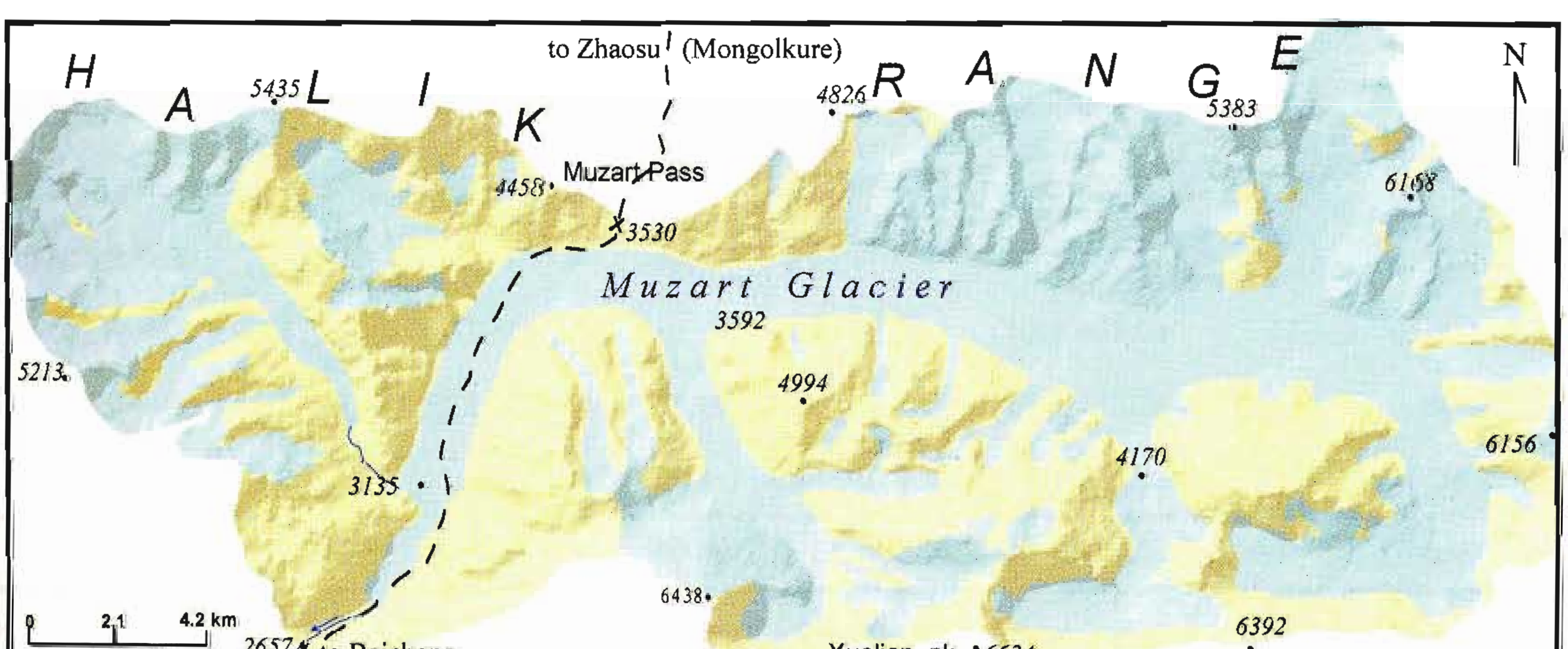


Figure 5-12 Muzart Glacier in the Tianshan Mountains

Table 5-14 Vavious types of glaciers in the Tarim Interior Basin (5Y6)*

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)
	Number	(%)	(km²)	(%)	(km³)	(%)	
Hanging glacier	4530	38.37	887.94	4.33	16.66	0.70	0.20
Cirque-hanging glacier	1666	14.11	820.44	4.01	27.89	1.17	0.49
Cirque glacier	4079	34.55	4985.32	24.33	262.65	11.01	1.22
Cirque-valley glacier	590	5.00	2006.01	9.79	147.01	6.16	3.40
Valley glacier	794	6.72	11,435.58	55.82	1897.04	79.52	14.40
Canyon glacier	31	0.26	52.67	0.26	3.02	0.12	1.70
Mountain slope glacier	106	0.90	189.34	0.92	15.20	0.64	1.79
Flat-topped glacier	11	0.09	109.89	0.54	16.19	0.68	9.99
Total	11,807	100.00	20,487.19	100.00	2385.66	100.00	1.74

* Including glaciers at the head of the Yarkant River outside the Chinese territory.

Table 5-15 Glacier distribution in various length classes in the TIB (5Y6)*

Length classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)
(km)	Number	(%)	(km²)	(%)	(km³)	(%)	
⩽ 0.5	2181	18.47	322.28	1.57	5.81	0.24	0.15
0.6~1.0	4043	34.24	1380.69	6.74	38.84	1.63	0.34
1.1~2.0	3079	26.08	2599.33	12.69	111.64	4.68	0.84
2.1~5.0	1953	16.54	5077.71	24.79	326.86	13.70	2.60
5.1~10.0	455	3.85	4373.99	21.35	437.37	18.33	9.61
10.1~15.0	53	0.45	1564.14	7.63	223.77	9.38	29.51
15.1~20.0	17	0.15	950.99	4.64	167.43	7.02	55.94
20.1~25.0	11	0.09	1290.27	6.30	277.45	11.63	117.30
25.1~30.0	7	0.06	790.02	3.86	167.98	7.04	112.86
30.1~35.0	4	0.03	713.42	3.48	173.98	7.29	178.36
35.1~40.0	1	0.01	313.69	1.53	90.03	3.78	313.69
40.1~45.0	2	0.02	717.82	3.50	215.22	9.02	358.91
⩾ 60.0	1	0.01	392.84	1.92	149.28	6.26	392.84
Total	11,807	100.00	20,487.19	100.00	2385.66	100.00	1.74

*Including glaciers at the head of the Yarkant River outside the Chinese territory.

(Figure 5-13). Cumulated glacier number, area and volume (Figure 5-14) indicate that the percentage of glacier number decreases following the increases of the percentages of glacier area and ice volume. This also shows that large glaciers play an important role in the area and volume in the basin.

In the past 40 years, climate change in the Tarim Interior Basin also experienced warming, for example, air temperature during 1987~2000 was 0.2~0.8℃ higher than that during 1961~1986 and most glaciers were retreating due to this warming. However, glaciers in different parts of the

Table 5-16 Glacier distribution in various area classes in the TIB (5Y6)*

Area classes (km^2)	Glacier number: Number	Glacier number: (%)	Glacier area (km^2)	Glacier area (%)	Glacier volume (km^3)	Glacier volume (%)	Mean area per glacier (km^2)
≤ 0.50	6344	53.73	1503.17	7.34	33.97	1.42	0.24
0.51~1.00	2180	18.47	1547.90	7.56	56.60	2.37	0.71
1.01~2.00	1551	13.14	2181.64	10.65	105.12	4.41	1.41
2.01~5.00	1116	9.45	3441.73	16.80	220.97	9.26	3.08
5.01~10.00	333	2.82	2292.39	11.19	193.48	8.11	6.88
10.01~15.00	135	1.14	1650.15	8.05	167.89	7.04	12.22
15.01~20.00	44	0.37	761.41	3.72	86.89	3.64	17.30
20.01~30.00	34	0.29	804.48	3.93	102.34	4.29	23.66
30.01~40.00	25	0.21	850.81	4.15	121.81	5.11	34.03
40.01~50.00	8	0.07	347.06	1.69	53.31	2.23	43.38
50.01~60.00	3	0.03	161.01	0.79	26.47	1.11	53.67
60.01~70.00	1	0.01	64.27	0.31	11.18	0.47	64.27
70.01~80.00	4	0.03	294.91	1.44	53.61	2.25	73.73
80.01~90.00	4	0.03	337.87	1.65	64.11	2.69	84.47
90.01~100.00	5	0.04	471.97	2.30	92.92	3.89	94.39
100.01~150.00	11	0.09	1353.26	6.61	290.60	12.18	123.02
150.01~200.00	3	0.03	547.09	2.67	132.60	5.56	182.36
200.01~300.00	2	0.02	451.72	2.20	117.26	4.92	225.86
≥ 300.01	4	0.03	1424.35	6.95	454.53	19.05	356.09
Total	11,807	100.00	20,487.19	100.00	2385.66	100.00	1.74

* Including glaciers at the head of the Yarkant River outside the Chinese territory.

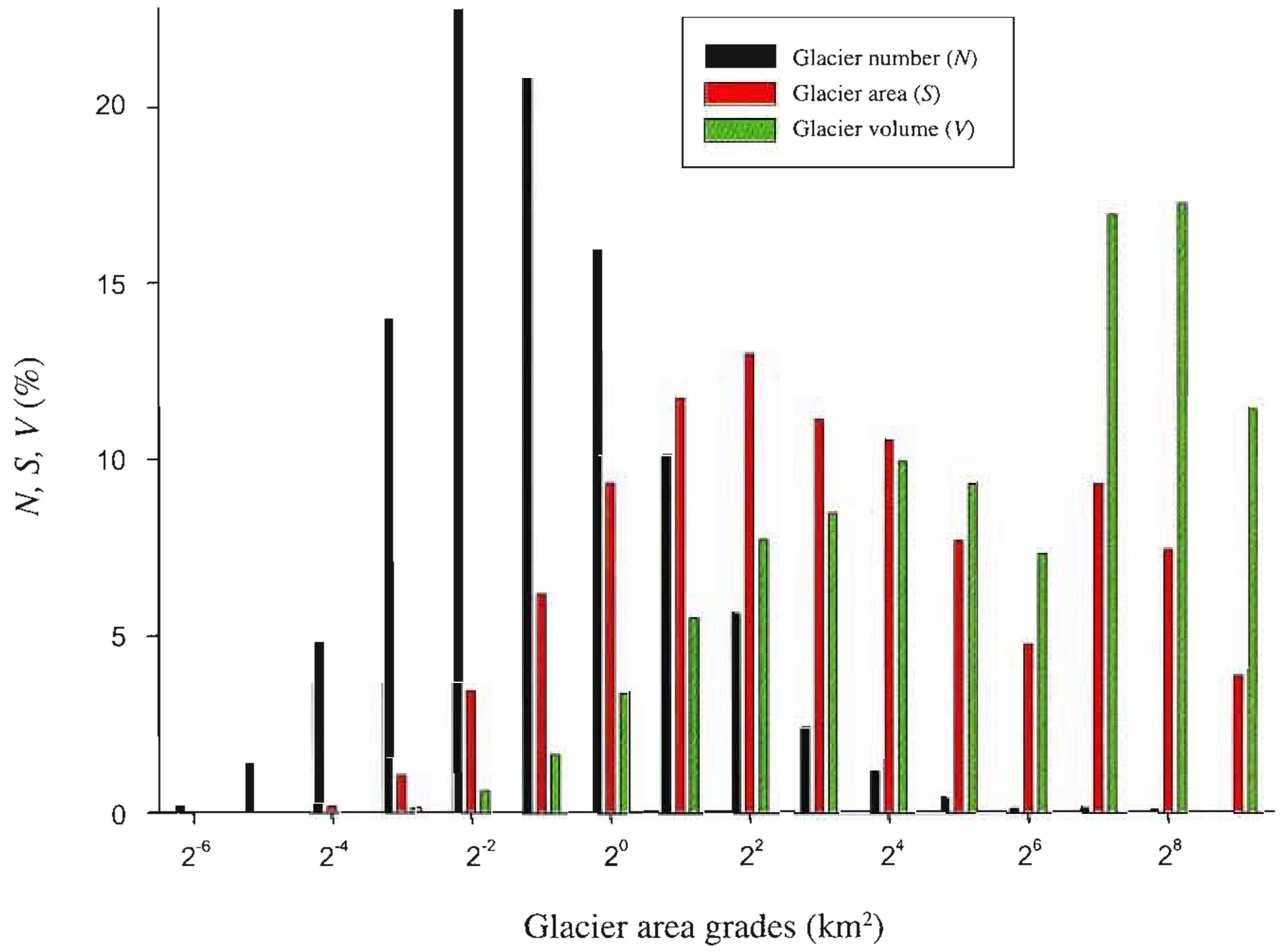


Figure 5-13 Distribution of glacier resources (*N,S,V*) versus area grades in the Tarim Interior Basin

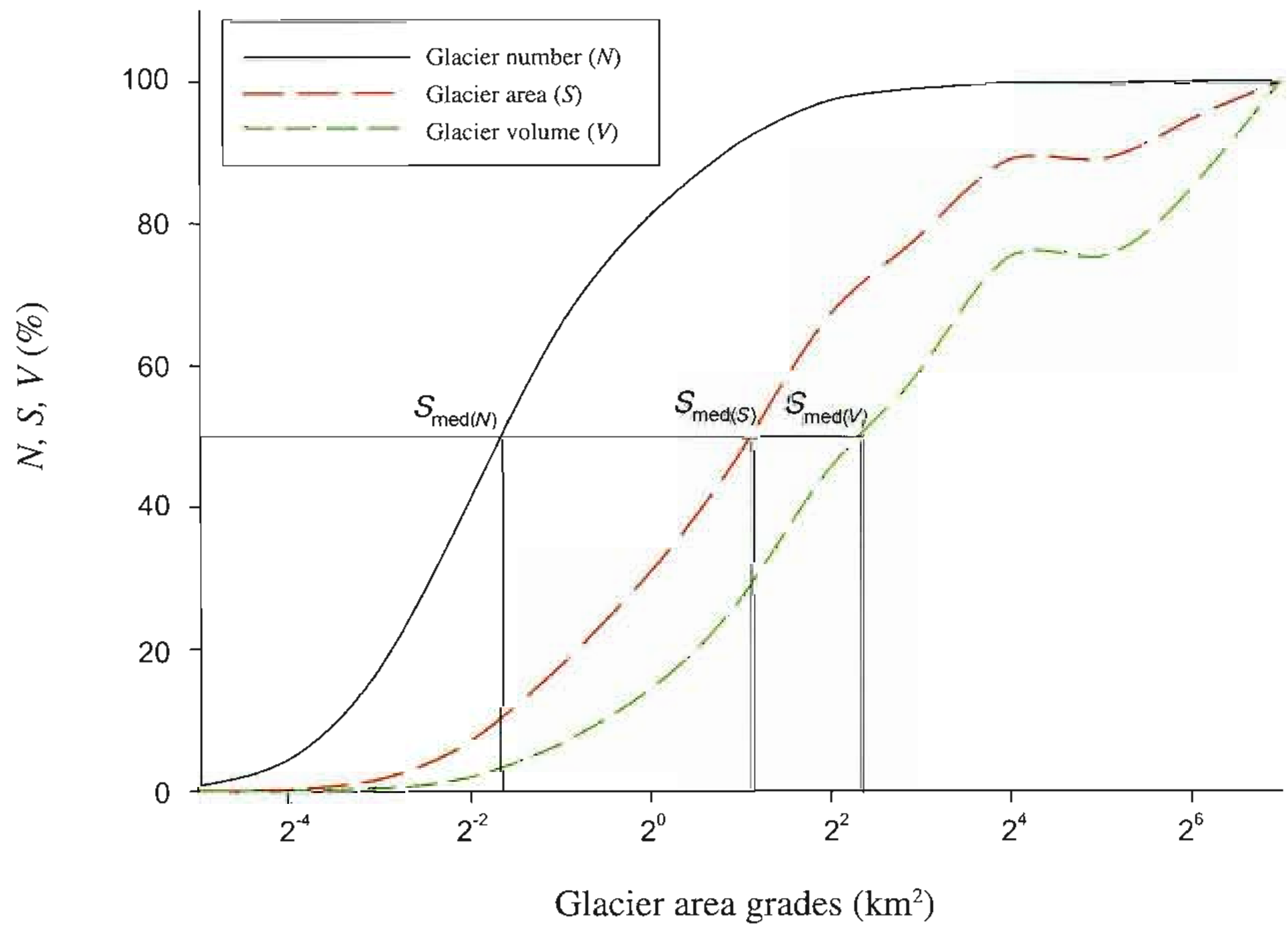


Figure 5-14 Cumulative curve of glacier resources (*N*, *S*, *V*) versus area grades in the Tarim Interior Basin

basin display a diversified patterns of changes. Glaciers at the source of the Yurungkax River changed less during 1970~2001, due to the physical characteristics of extreme continental glaciers. A study shows that glaciers in the Yurungkax River reduced by 4.94 km^2 in area and 0.6032km^3 in volume, or 0.3% and 0.2%, respectively, of the corresponding totals in 1970 (Shangguan Donghui *et al.*, 2004). On the other hand, the east and west branches of the Qong Terang Glacier, a sub-continental type glaciers, were connected before 1942. A survey in 1978 showed that the west Qong Terang Glacier had separated from the east Qong Terang Glacier during 1942~1976, and has retreated by 600 m (Su Zhen *et al.*, 1985). Another observation on the glacier in 1997 revealed it was still retreating at a rate of 17 m annually, and its area reduced by 0.374 km^2, the ice surface has lowered by 23 m within a surveyed area of the 1.09 km^2 (Liu Chaohai *et al*, 2002a).

It was also observed that precipitation was increasing since the late 1980s, for example, precipitation during 1987~2000 was 40 mm, about 12%, more than that during 1961~1986. Even more remarkable is the increase in glacier meltwater. The amount of glacier meltwater in the TIB during 1960~1980 amounted to 40% of total runoff in the basin. The meltwater percentages of the Yarkant River, the Yurungkax River and the Kumalike River of the TIB reach 50%~80% (Yang Zhenniang, 1991). According to the research (Ye Baisheng *et al.*, 1999), glacial meltwater runoff increased by 10.9% during 1960~1995. It is expected that the additional meltwater runoff from the Aksu River, the Hotan River and the Yarkant River basins may exceed $10 \times 10^8\ m^3 \cdot a^{-1}$ in the near future. In rivers with small glaciers dominated, such as the Gez River in the Pamirs, the Muzart River and the Terang River in the south slope of the Tianshan Mountains, the increasing

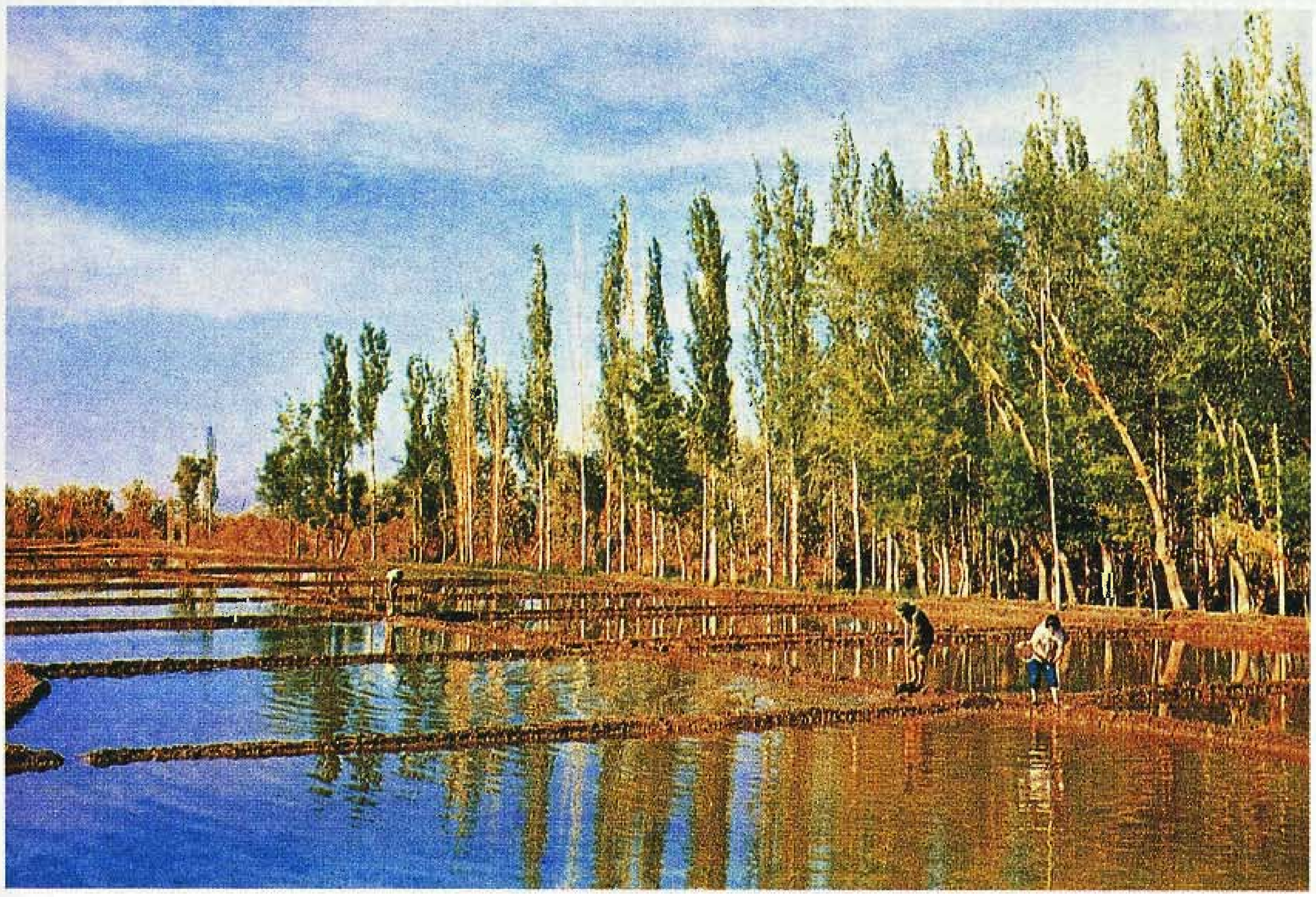


Photo 5-9 An Oasis inside the Taklimakan Desert replenished by glacier meltwater (*Photography Collection for Chinese Desert Control*, 1997)

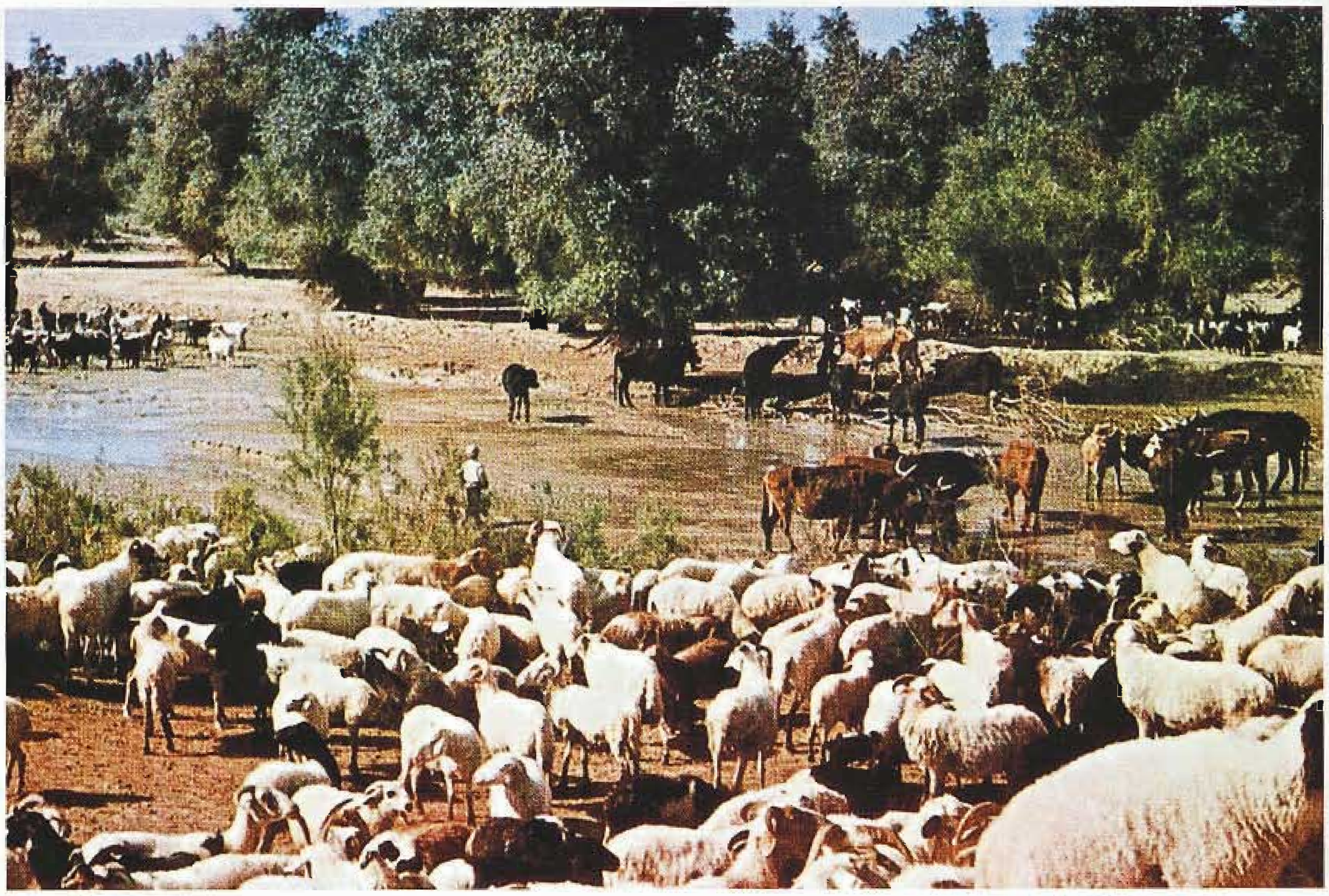


Photo 5-10 An Oasis inside the Taklimakan Desert replenished by glacier meltwater
(*Photography Collection for Chinese Desert Control*, 1997)

glacier meltwater may exceed $1 \times 10^8\ m^3 \cdot a^{-1}$. Such an increase in glacier runoff will significantly benefit the social and economic development in the Tarim Interior Basin (Shi Yafeng *et al.*, 2001) (Photo 5-9, Photo 5-10).

5.5 The Junggar Interior Basin (5Y7)*

There are about one hundred small dependent rivers in the Junggar Interior Basin (JIB) (5Y7), a basin surrounded by the Tianshan Mountains in the south and the Altay Mountains in the north. Of all these rivers, about 40 are replenished by glacier meltwater. These rivers can be classified into two regions with seven river systems according to similar topography and routing direction. Rivers in the south area originating from the northern slopes of the northern and eastern Tianshan Mountains include four rivers: the Yiwu (5Y71), the Baiyang (5Y72), the Manas (5Y73) and the Ebinur Lake (5Y74). The northern section originating in the Sawir Range and the Altay Mountains, includes rivers of the Hobok (5Y75), the Ulungur (5Y76) and the Kebuduo (5Y12) (Figure 5-15). In addtion, a small river belonging to 5Y1 of the East Asia water system, the Kebuduo River, originates in the Altay Mountains and flows

* This subsection is prepared by Wang Zongtai.

into Mongol. Only six small glaciers are distributed in the rivers within China, so they are discussed in this chapter.

Glacier Inventory of China for the Tianshan and Altay Mountains shows that there are 3412 glaciers with a total area of 2254.10 km^2 and ice volume of 137.43 km^3 in the JIB (Table 5-17). Twenty of these glaciers are larger than 10 km^2. Glacier number in the JIB is second largest to that of the TIB, but its average glacier size is only 0.66 km^2, the second smallest next to that in the HIB in northwest China. The largest glacier is 39.6 km^2 in area and 9.0 km in length. Glaciers with less than 1 km^2 account for 86.4% of all glaciers in the basin, similar to that in the Turpan-Hami Interior Basin. The Manas River (5Y73) and the Ebinur Lake (5Y74) basin has most of glaciers (Table 5-18, Table 5-19), which contain 92.6% of the total area of glaciers in the JIB.

The Tianshan Mountains, bordering the southern Junggar Basin, compose a series of ranges extending 1300 km from the west to east, where 99.6% of the total area of glaciers in the JIB are distributed. The Eren Habirga Range is 320 km from the west to the east and 110 km from the north to the south, with most part of the range above 4000 m a.s.l. and 21 peaks exceeding 5000 m a.s.l. Glacier size is largely determined by mountainous altitudes, especially the mountainous area above the snowline altitude, glacier size increases as the area above the snowline altitude

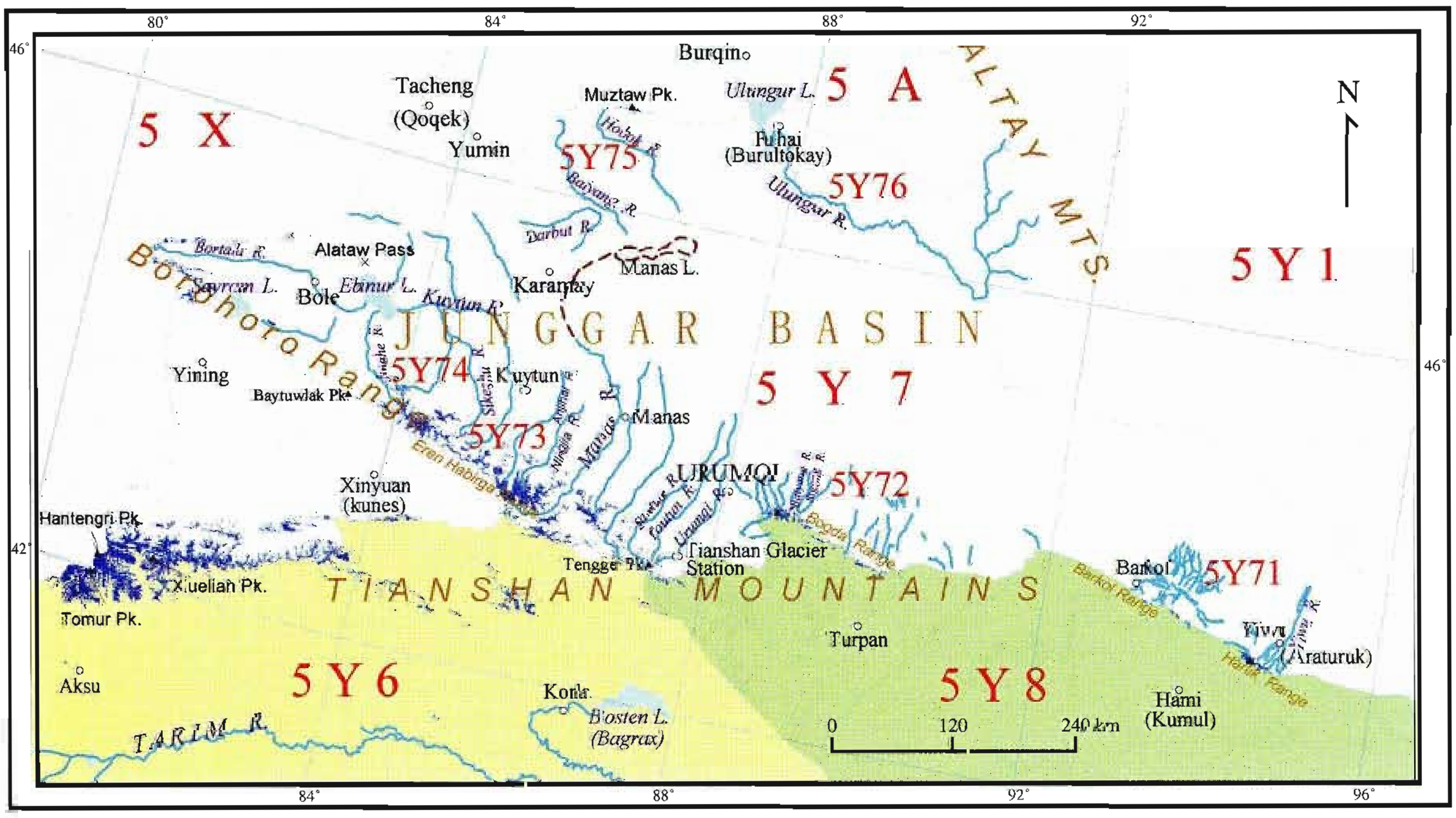


Figure 5-15 Glacier distribution in the Junggar Interior Basin

increases. The area above the average snowline altitude in the Eren Habirga Range is 1822 km^2, 12.9% of the total area of the range. The ratio of glacier area to the land area above snowline altitude is 0.78, so glaciers in the range are relatively bigger. 1892 glaciers, 1422.04 km^2 in area, are in the Eren Habirga Range, about 21.3% and 15.5% of the corresponding totals in the Tianshan Mountains, respectively, making the range the one of the highly glacierized areas next to the Hantengri-Tomur Knot and the Halik Range in the Tianshan Mountains (Figure 5-16). Moving east and west away from the Eren Habirga Range, the terrain gradually becomes lower and narrower, where glacier number and size decrease.

The glacierization in rivers in the JIB is diversified. The Manas River system consists of

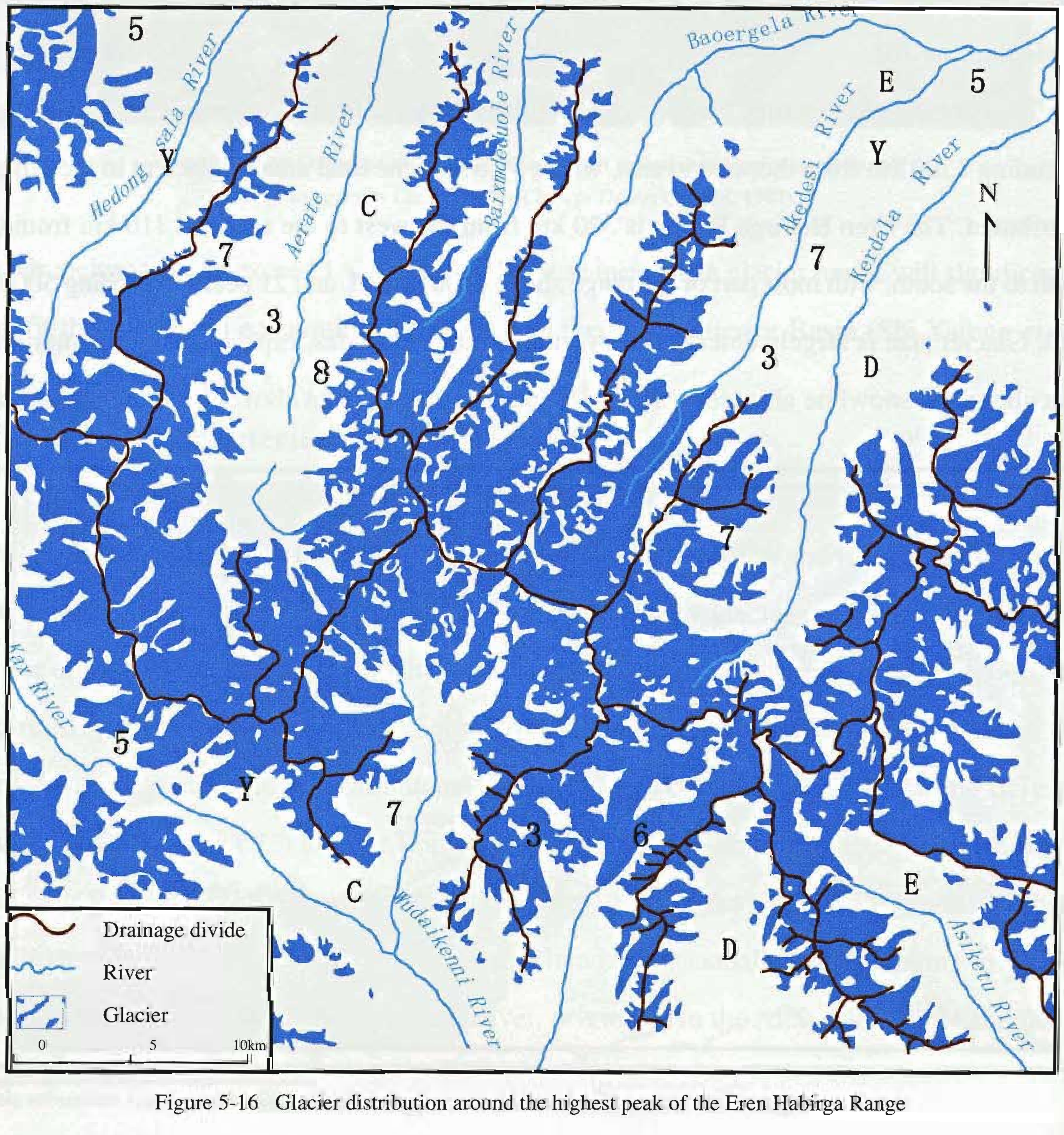


Figure 5-16 Glacier distribution around the highest peak of the Eren Habirga Range

Table 5-17 Glaciers in the Junggar Interior Basin (5Y7)

	River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
			Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
South section	Yiwu R.	5Y71	85	2.49	67.14	2.98	3.26	2.37	0.79	3860	5.23	5.5
	Baiyang R.	5Y72	213	6.24	91.50	4.06	4.20	3.06	0.43	3740	10.27	7.4
	Manas R.	5Y73	1989	58.29	1264.94	56.12	82.21	59.82	0.64	3850	39.60	9.0
	Ebinur L.	5Y74	1104	32.36	823.06	36.51	47.53	34.59	0.75	3650	22.96	14.0
North section	Hobok R.	5Y75	8	0.23	3.55	0.16	0.13	0.09	0.44	3380	1.49	1.8
	Ulungur R.	5Y76	7	0.21	1.22	0.05	0.03	0.02	0.17	3350	1.71	1.7
	Kebuduo R	5Y12	6	0.18	2.69	0.12	0.07	0.05	0.45	—	0.87	1.4
	Total	5Y7	3412	100.00	2254.10	100.00	137.43	100.00	0.66	3350~3860	39.60	9.0

Table 5-18 Glacier distribution in various area classes in the Junggar Internal Basin (5Y7)

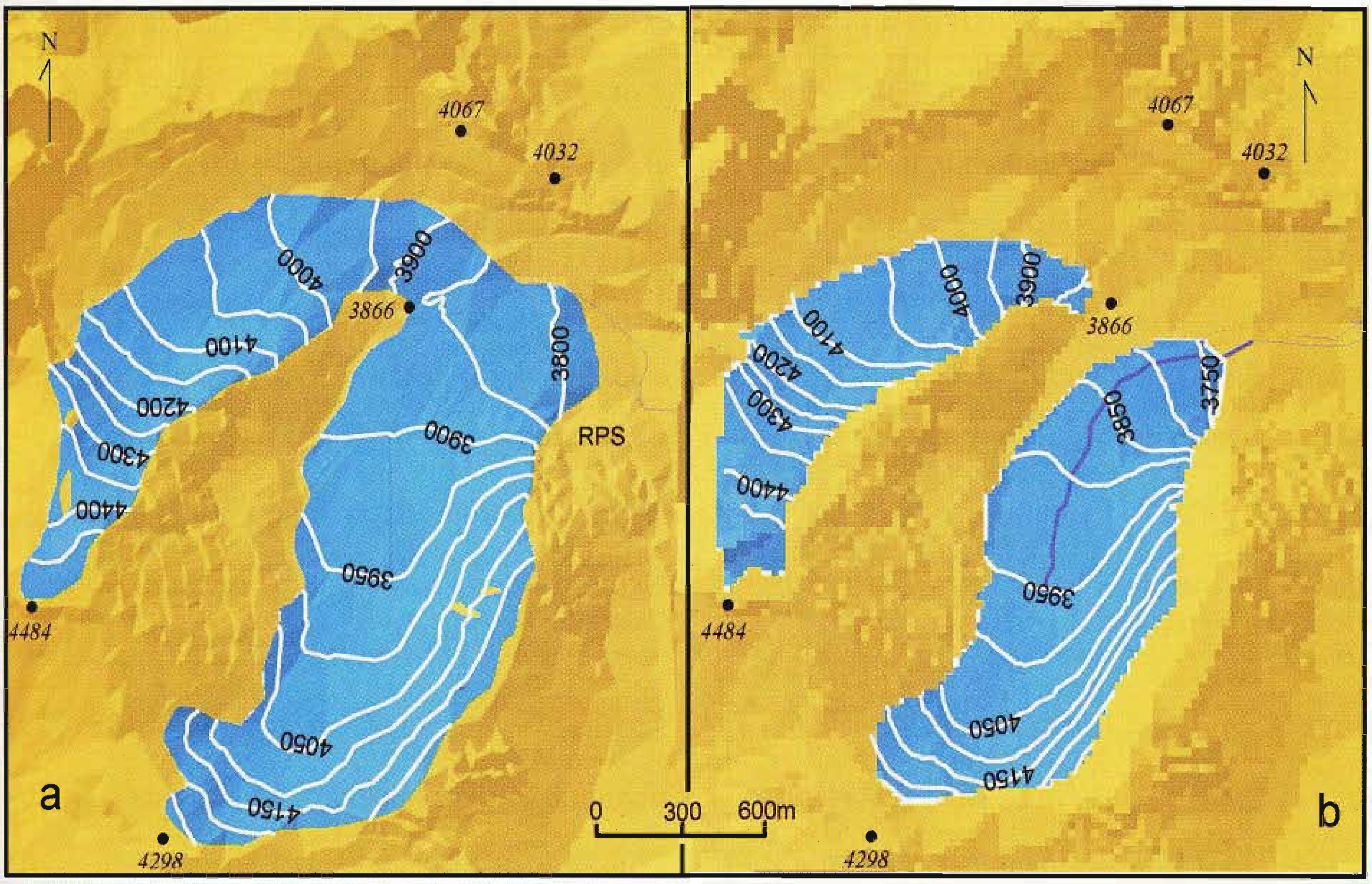
Area classes (km²)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)
	Number	(%)	(km²)	(%)	(km³)	(%)	
⩽ 0.50	2444	71.63	445.17	19.75	9.69	7.05	0.18
0.51~1.00	504	14.77	355.76	15.78	13.09	9.53	0.71
1.01~2.00	266	7.79	364.36	16.16	17.27	12.57	1.37
2.01~5.00	135	3.96	407.83	18.09	25.95	18.88	3.02
5.01~10.00	43	1.26	314.32	13.95	27.12	19.73	7.31
10.01~20.00	12	0.35	149.94	6.65	15.45	11.24	12.49
20.01~30.00	5	0.15	115.14	5.11	14.40	10.48	23.02
30.01~40.00	3	0.09	101.58	4.51	14.46	10.52	33.86
Total	3412	100.00	2254.10	100.00	137.43	100.00	0.66

nine rivers, such as the Urumqi, the Hutubi, the Toutun, the Horgos and the Anjihai. There are 1989 glaciers, 1264.94 km² in area and 82.21 km³ in volume, or 58.3%, 56.1% and 59.8% of the corresponding totals in the JIB, respectively. This makes the river system the highly glacierized basin in the JIB.

The long-term monitoring of the Glacier No.1 at the headwater of the Urumqi River in the Tianshan Mountains (shorted as the Glacier U-1) research on repeated photogrammetry of the Urumqi River and the Sikeshu River indicate that glaciers in the JIB were retreating during the last decades. The Glacier U-1 has been retreating since the 1960s when observation records began. The total retreat was 139.72 m during 1962~2001 (Table 5-20). The glacier tongues of the

Table 5-19 Glacier distribution in various length classes in the Junggar Internal Basin (5Y7)

Length classes (km)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)
	Number	(%)	(km²)	(%)	(km³)	(%)	
⩽ 0.5	1070	31.36	95.73	4.25	1.33	0.97	0.09
0.6~1.0	1167	34.20	295.25	13.10	7.23	5.26	0.25
1.1~2.0	804	23.56	559.29	24.81	21.58	15.70	0.70
2.1~5.0	320	9.38	720.39	31.96	44.30	32.24	2.25
5.1~10.0	45	1.32	428.71	19.02	42.81	31.15	9.53
10.1~15.0	6	0.18	154.73	6.86	20.18	14.68	25.79
Total	3412	100.00	2254.10	100.00	137.43	100.00	0.66



(a) the glacier in 1962 based on topographic map; (b) the glacier state

Figure 5-17 Changes in surface area of the Glacier U-1 (Liu Chaohai *et al.*, 2000) in 1994 based on ground-based mapping

east and west branches completely separated and became two independent glaciers in 1993 (Figure 5-17). From 1993 to 2001, the east branch retreated by 3.7 $m \cdot a^{-1}$, while the west branch was 5.7 $m \cdot a^{-1}$. The glacier area reduced in acceleration, and area shrinkage was 0.12 km^2 from 1962~1992, almost equivalent to that from 1992 to 2001 (0.10 km^2). Mass balance of Glacier U-1 (Figure 5-18) has been negative trend since 1959, and mass loss increased after 1985. During 1986~2000, average annual mass balance on the glacier was −358.4 mm, while it was only −94.4 mm from

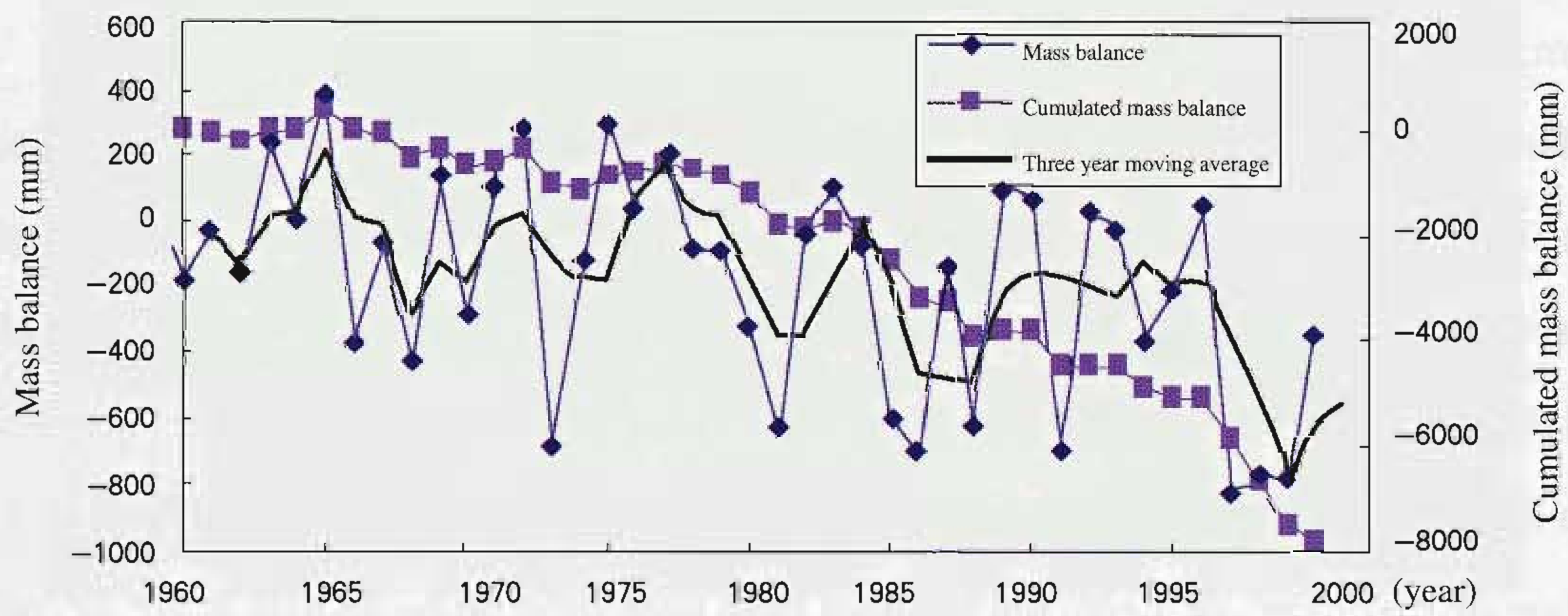


Figure 5-18 The mass balance change of the Glacier U-1

Table 5-20 Terminus changes of the Glacier U-1 in the Urumqi River

Period (year, month)	Retreat distance (m)	Period (year, month)	Retreat distance East branch (m)	Retreat distance West branch (m)
1962.9~1973.8	−65.60	1993.8~1994.8	−4.85	−6.75
1973.8~1980.8	−22.99	1994.8~1995.8	−3.95	−6.17
1980.8~1981.8	−4.83	1995.8~1996.8	−3.40	−4.60
1981.8~1982.8	−2.06	1996.8~1997.8	−3.65	−4.80
1982.8~1986.8	−14.30	1997.8~1998.8	−3.47	−4.47
1986.8~1987.8	−3.68	1998.8~1999.8	−3.41	−4.85
1987.8~1988.8	−3.80	1999.8~2000.8	−3.40	−6.92
1988.8~1989.8	−5.10	2000.8~2001.8	−3.10	−6.95
1989.8~1990.8	−3.57			
1990.8~1991.8	−6.51			
1991.8~1992.8	−3.44			
1992.8~1993.8	−3.84			

1959 to 1985 (Li Zhongqin *et al.*, 2003). 1997, 1998 and 1999 are years with the largest mass loss during all observational years.

From the repeated photogrammetry, glacier changes in the Urumqi River during 1964~1992 were derived (Liu Chaohai *et al.*, 1996). All 155 glaciers in the basin have been retreating. The terminus retreat of all glaciers was averaged as 98 m or 12.4%. Glaciers have lost a total area and ice volume of 6.648 km^2 and 2.8×10^8 m^3, or 13.8% and 16.8%, respectively, during 1964~1992. At the same time, ice surface in the ablation areas and the whole glacier areas lowered by 10.2 m and 5.9 m on average, with the equilibrium line altitude rising by an average of 30 m.

The monitored 30 glaciers at the Sikeshu riverhead on the northern slope of the Borohoro Range from the western section of the north Tianshan Mountains indicated that most glaciers retreated with only one advancing glacier (5Y472G8) (by 35m) and three stable glaciers (5Y742C24, 5Y742F51 and 5Y742F52) during 1963~1989. In average, glaciers here retreated 150 m or 4.8%. Glacier area decreased from 102.215 km^2 in 1962 to 99.538 km^2 in 1989, a reduction of 2.677 km^2, or 2.6%. Ice volumes have been reduced by $48{,}410 \times 10^4$ m^3, or 5.2%, with an average ice thickness thinning of 4.7 m (Liu Chaohai *et al.*, 2002b).

Glaciers provide meltwater of 16.89×10^8 m^3 annually in the JIB (Yang Zhenniang, 1991), being 13.5% of the total stream runoff (Photo 5-11). It is 34.7% in the Manas River, 50.9% in the Horgos and Anjihai Rivers, and less than 10% in the Urumqi River and other rivers on the northern slope of the Barkol and Harlik Ranges. This estimation based on the climate and glacier states in the 1980s may not reflect the status of glacier runoff at present because of the recent climatic warming. Zhang Cunjie *et al.* (2003) found the average temperature in northern section of Xinjiang Uygur Autonomous Region between 1987 and 2000 was 0.8℃ higher than that during 1961~1986, and the glacier retreat and glacier meltwater runoff increase. Take the Glacier U-1 in the Urumqi River as an example, the mean glacial runoff depth during 1958~1985 was 508.4 $mm \cdot a^{-1}$ (Yang Zhenniang, 1991), but it became 936.6 $mm \cdot a^{-1}$ during 1986~2001, almost increased by 84.2%. It is estimated that air temperature will rise 2.1℃ in average by 2050 in Xinjiang Uygur Autonomous Region. For those rivers dominated by glaciers less than 1 km^2, such as the Urumqi River, the Toutun River, the Taxi River and the Jinghe River, glacial runoff will increase by 5%~10% at the beginning of this century, and it is expected glacial runoff will decrease by another 8%~15% till 2050. With the disappearance of small glaciers, glaciers larger than 5 km^2 will experience the intensive melting, so the increase in meltwater is expected in the Manas

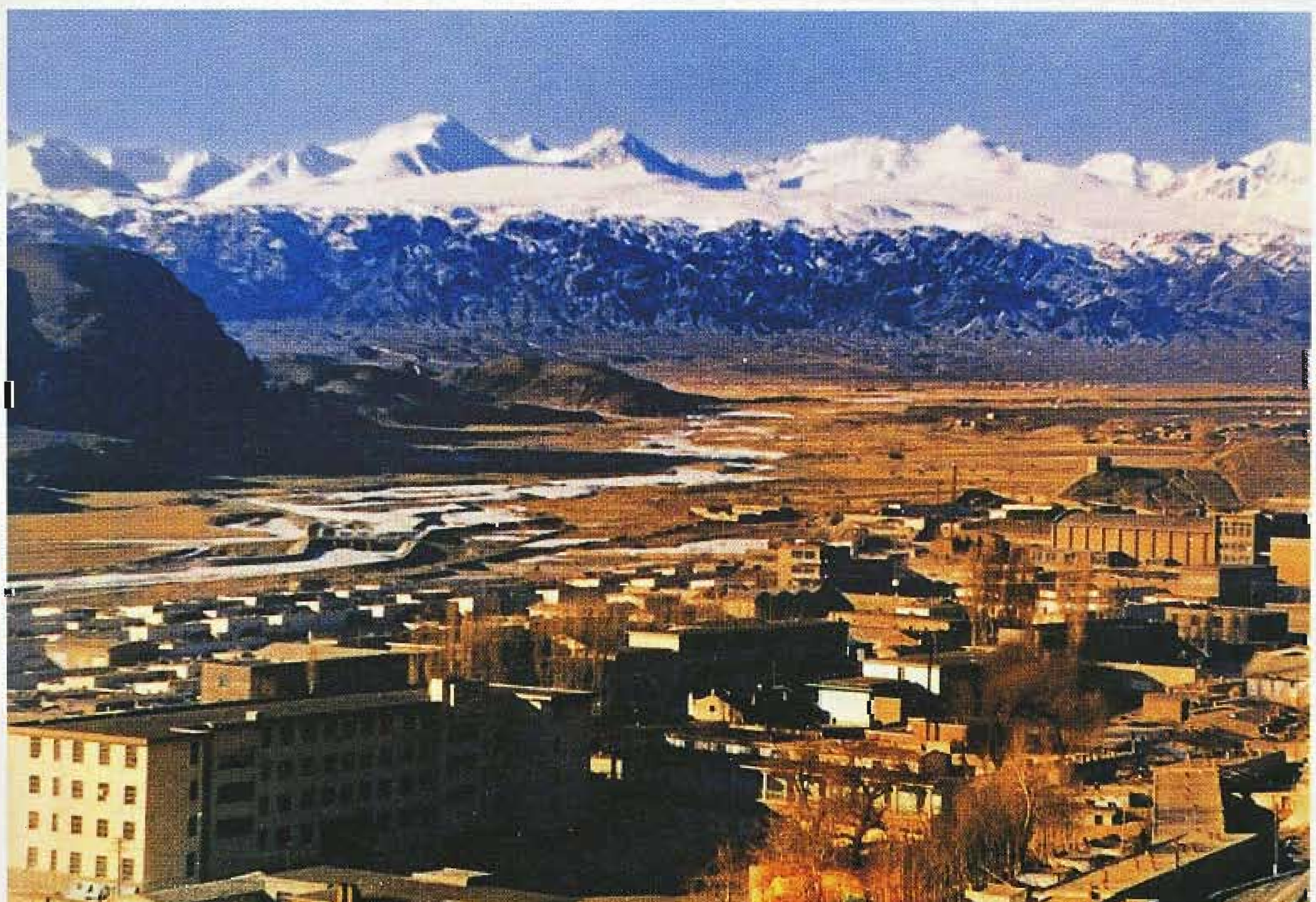


Photo 5-11 Yiwu City on the northern slope of the Eastern Tianshan Mountains —— a city completely relying on glacier meltwater (Wang Zongtai)

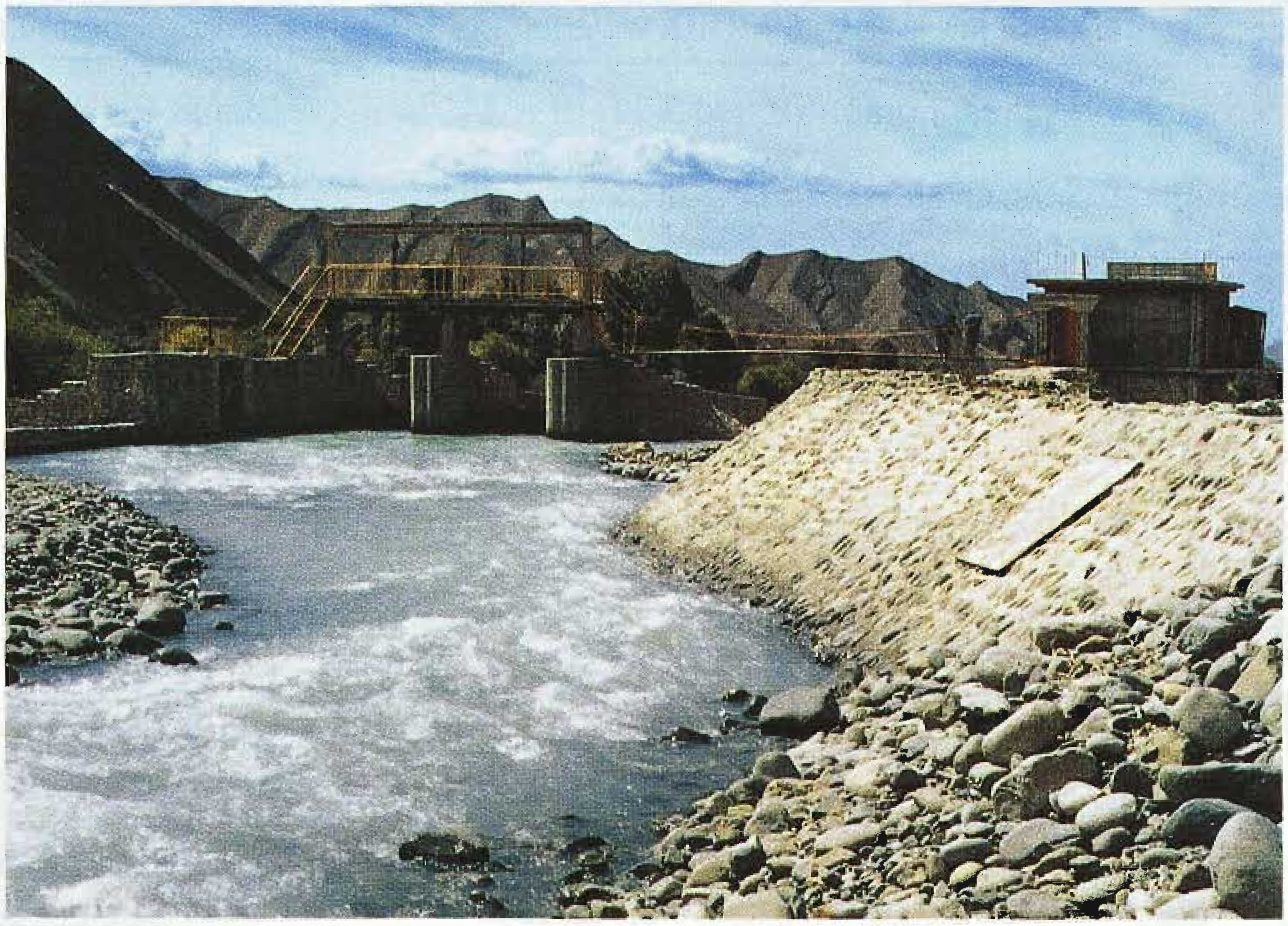


Photo 5-12 The glacier meltwater diversion sluice on the Heigou mouth in the southern slope of the Bogda Range (Wang Zongtai)

River, the Horgos River and the Anjihai River. Meltwater runoff will be higher than the current amount by approximately 1.0×10^8 m^3, temporarily benefiting the economic development of lower reaches of the river (Shi Yafeng and Liu Shiyin, 2000).

The total surface water resource is only 148×10^8 m^3 in the JIB located in the arid inland region. The available supply in 2000 was 96.2×10^8 m^3, with a shortage of 10.8×10^8 m^3 (10.1%). The current exploitation level of water resources in the JIB is up to 66.3% (Photo 5-12). There is little capacity for water resource exploitation, but great potential for water conservation in the region (Chen Zhikai *et al.*, 2004). In this regard, we should take full advantage of the glacier meltwater increase in the region.

5.6 The Turpan-Hami Interior Basin (5Y8)*

The Turpan-Hami Basin (THIB) (Tu-Ha Basin for short) is generated into an interior drainage area with scattered flows in the Eastern Tianshan Mountains by *Glacier Inventory of China*. The THIB is within a block from 41°15′N~43°50′N and from 87°20′E~95°30′E and delimited by the Kuruk Tag in the south, the Bogda Range, the Barkol Range and the Harlik Range of the East Tianshan Mountains in the north, the Alagou Range and the Tengger Range in the west, and the

* This subsection is prepared by Ding Liangfu.

Mazong Range and the Hexi Corridor in the east (Figure 5-19).

The THIB is the lowest and driest intermountain basin in China. The lowest place in the basin is 155 m below sea level. Annual mean precipitation at Toksun Meteorological Station is only 6.7 mm. The THIB is also the country's hottest place, the highest air temperature ever recorded there was 48.1℃ and the highest ground temperature ever recorded was 82.3℃ in the Turpan Gobi desert, which is called "the burning land".

All the rivers in the THIB are short. Their length is mostly between 30~40 km, and the longest is shorter than 50 km. Its main rivers include the Miaoer Gully, the Wudao Gully, the Daheyan River, the Baiyang River and the Ala Gully. The basin's average surface runoff is 19.2×10^8 m^3.

There are 446 glaciers in the THIB, with a total glacier area of 252.73 km^2 and ice volume of 12.63 km^3. The largest glacier is the Glacier No.10 in the Baiyang River on the southern slope of the Bogda Range (5Y813C10), 10.27 km^2 in area and 7.4 km in length. It is a valley glacier supplied by multiple firn basins (Table 5-21).

Glaciers in the basin are characterized by low glacierization and small glacier size, of which 70.4% glaciers are shorter than 1 km and 86.6% glaciers are no bigger than 1.0 km^2 (Table 5-22,

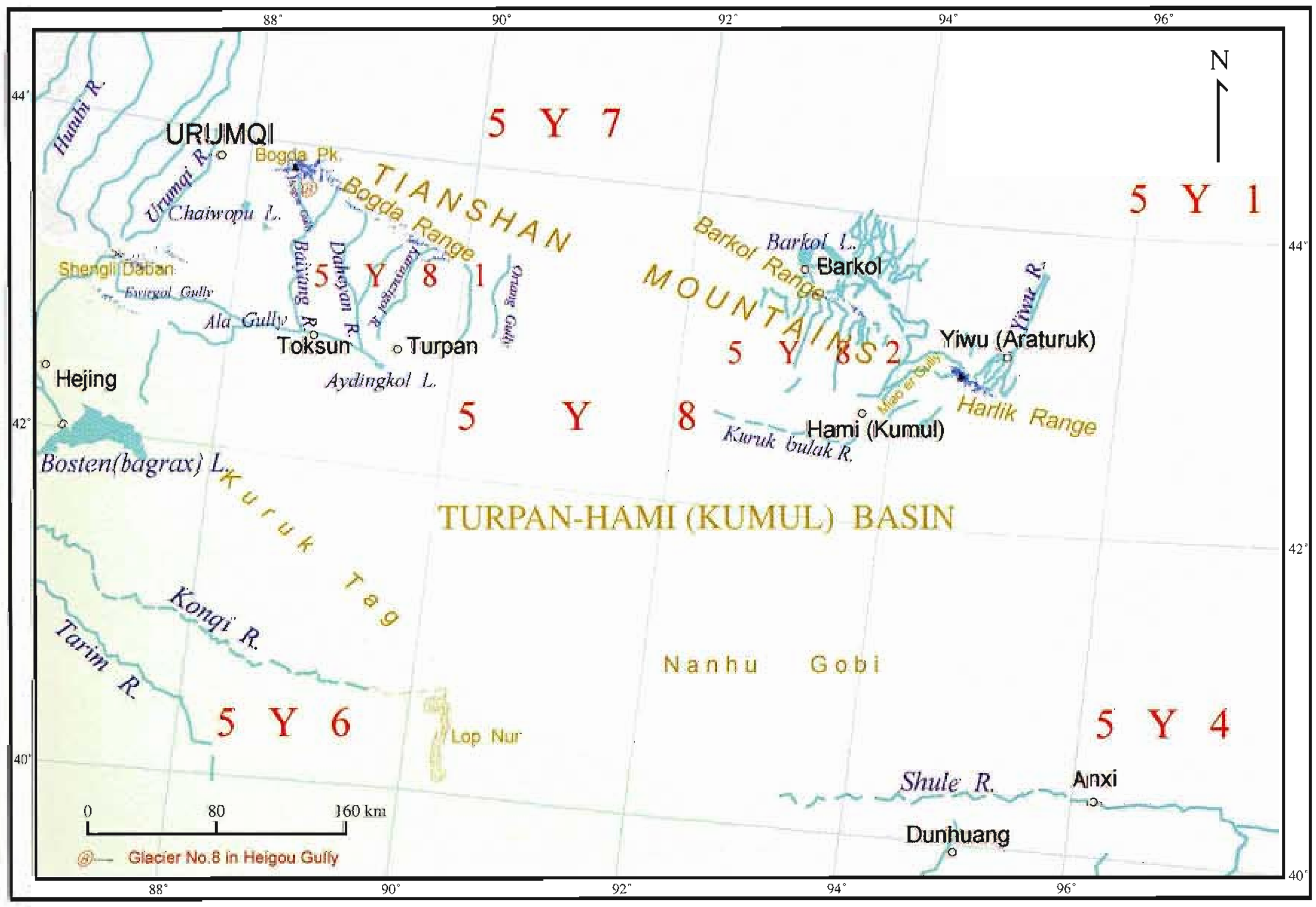


Figure 5-19 Glacier distribution in the Turpan-Hami Interior Basin

Table 5-23). Due to the unfavorable conditions for glacier development, 79.6% glaciers are hanging and cirque-hanging glaciers (Table 5-24). More glaciers are on the southern slope of the Bogda Range, occupying 57.4% number and 48.4% area of glaciers in the basin. Next to the Bogda is the Harlik Range with high glacierization. Glaciers in the two ranges own 83.4% the ice volume of the total in the basin. The Glacier No.8 at Heigou Gully (5Y813B8) (Photo 5-13) is a glacier ever observed in the basin during 1985~1986 (Shi Yafeng *et al.*, 1989).

Table 5-21 Glaciers in the Tu-Ha Interior Basin(5Y8)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Aydingkol L.	5Y81	352	78.92	164.04	64.91	7.72	61.12	0.47	3880	10.27	7.4
Miaoer Gully	5Y82	94	21.08	88.69	35.09	4.91	38.88	0.94	3960	6.59	6.5
Total	5Y8	446	100.00	252.73	100.00	12.63	100.00	0.57	3920	10.27	7.4

Table 5-22 Glacier distribution in various length classes in the THIB (5Y8)

Length classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier
(km)	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
≤ 0.5	153	34.30	12.60	4.99	0.16	1.28	0.08
0.6~1.0	161	36.10	46.12	18.25	1.14	9.04	0.29
1.1~2.0	94	21.08	74.83	29.61	2.99	23.63	0.80
2.1~5.0	34	7.62	89.30	35.33	5.74	45.46	2.63
5.1~10.0	4	0.90	29.88	11.82	2.60	20.59	7.47
Total	446	100.00	252.73	100.00	12.63	100.00	0.57

Table 5-23 Glacier distribution in various area classes in the THIB (5Y8)

Area classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier
(km^2)	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
≤ 0.5	316	70.85	54.34	21.50	1.07	8.46	0.17
0.51~1.00	70	15.70	48.61	19.23	1.76	13.98	0.69
1.01~2.00	36	8.07	48.26	19.10	2.26	17.87	1.34
2.01~5.00	18	4.04	57.75	22.85	3.76	29.77	3.21
5.01~10.00	5	1.12	33.56	13.28	2.80	22.16	6.72
10.01~15.00	1	0.22	10.21	4.04	0.98	7.76	10.21
Total	446	100.00	252.73	100.00	12.63	100.00	0.57

Table 5-24 Glacier type in the THIB (5Y8)

Glacier type	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging glacier	290	65.02	45.29	17.92	0.80	6.34	0.16
Cirque-hanging glacier	65	14.57	42.51	16.82	1.57	12.42	0.65
Cirque glacier	44	9.87	53.13	21.02	2.85	22.59	1.21
Cirque-valley glacier	23	5.16	45.00	17.80	2.58	20.41	1.96
Valley glacier	11	2.47	40.91	16.19	3.08	24.41	3.72
Flat-topped glacier	9	2.02	17.56	6.95	1.26	9.95	1.95
Canyon glacier	3	0.67	6.97	2.76	0.44	3.52	2.32
Mountain slope glacier	1	0.22	1.36	0.54	0.05	0.36	1.36
Total	446	100.00	252.73	100.00	12.63	100.00	0.57

To deal with the problem of water shortage in the region, people living here have developed a special hydraulic engineering——Karez, an underground channel systerm inducing meltwater from the high mountain glaciers to conserve patched oases so that the irrigated agriculture in the region has been developed.

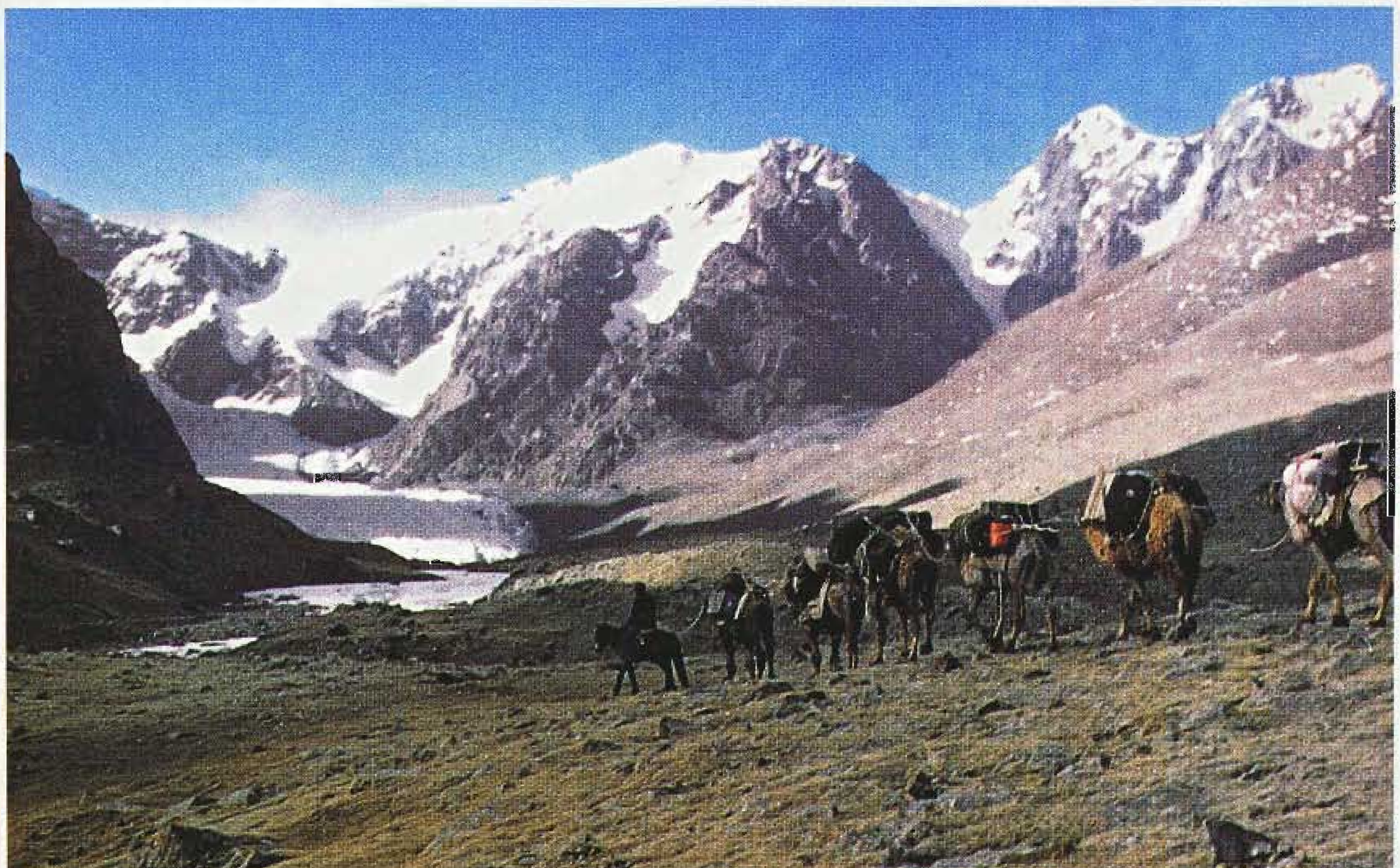


Photo 5-13 The Heigou Glacier No.8 on the southern slope of the Bogda Range

"Turpan's grapes, Hami's melon" —— the lyrics of this popular Xinjiang ballad reflect the richness of the basin's local products. Located in 155 m below sea level, the Aydingkol Lake is well-known as the second lowest region next to the Dead Sea of Jordan. Boundless deserts and high mountain glaciers with pure white snow sharply contrast each other. Other sights include the "Mountain of Flames" and its various legends and the beautiful Grape Valley, not to mention the famous remains on the Silk Road —— the ancient towns of Jiaohe and Gaochang, now becoming ideal places for exploration and tourism.

5.7 The Qinghai-Tibetan Plateau Interior Area (5Z)*

The Qinghai-Tibetan Plateau Interior Area (QTPIA) covers a wide area, from the Kunlun Mountains in the north, to the Gangdise Range in the south (Figure 5-20). The Changjiang (Yangtze) River and the Nujiang river system lie beyond its east border, and the Indus River system in its west. Composed of many separate high mountains and lake basins, its total area is 730,000 km^2. The code for the river system is 5Z, which is further divided into six sub-

Figure 5-20 Glacier distribution in the Qinghai-Tibetan Plateau Interior Area

* This subsection is prepared by Jiao Keqin.

basins. 5Z1 refers to drainage area in the northeast of QTPIA, including some intermountain lake basins of the central Kunlun Mountains and a series of small lake basins in the Hoh Xil Range, which is called the Ayakkum Lake and Hoh Xil Lake basins. 5Z2, also as Siling Co basin, refers to the drainage area in the southeast of QTPIA, including the southern slope of the Hoh Xil Range, the western section of Tanggula Range, the northwest of the Nyainqentanglha Range, the northeast of the Gangdise Range, as well as part of the Qiangtan Plateau. 5Z3, also as the Zhari Namco basin, refers to the drainage area, which includes the southern slopes of the eastern Karakorum Mountains, part of the Qiangtan Plateau, and northwest section (Mount Naimonanyi) of the Himalayas. 5Z4, also as the Bangong Co basin, refers to the area including the southern part of the western Kunlun Mountains, and the northeast section of the Karakorum Mountains and the western flank of the Gangdise Range. 5Z5, also as the Dogai Coying basin, refers to the drainage area mainly composed of the central and northern parts of the Qiangtan Plateau. 5Z6, the Yibug Cako basin, refers to the area of central and southern parts of the Qiangtan Plateau (Figure 5-20).

The glacier inventory compilation has used the 1:100,000 topographical maps which were published in 1970s and were further verified using aerial photographs acquired from 1968~1974 during the inventory work period. However, the 1 : 1,000,000 satellite photos of the Bangong Co basin taken in 1976 were applied to compile a brief glacier inventory due to the lack of larger scale maps. The inventory of the basins was modified after publication of the 1 : 50,000 topographical maps produced in the 1980s (Yang Hui'an *et al.*, 2003). Table 5-25 shows the statistics of glaciers in the drainage region.

There are 5341 glaciers with a total area and volume of 7836.10 km^2 and 777.48 km^3, respectively, in the region. The snowline altitudes are between 5140 and 6200 m a.s.l. The quantity of glaciers in the QTPIA is only second to the Tarim and Yarlung Zangbo River basins in China. Inside this area, 5Z4 has glaciers as many as 1824 with a total area of 2958.37 km^2 and volume of about 352.12 km^3, accounting for 34.2%, 37.8% and 45.3%, respectively, of relevant totals in the QTPIA. This high glacierization is attributed to the topographical conditions in the western Kunlun Mountains, where the mountain is a broad planation surface above 6000 m a.s.l. Large glaciers developed here, particularly on the

Table 5-25 Glaciers in the QTPIA(5Z)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Ayakkum L.	5Z11	300	5.62	338.16	4.32	37.82	4.86	1.13	5140~5480	67.91	16.0
Hoh Xil L.	5Z12	74	1.38	185.34	2.36	19.56	2.52	2.50	5340~5500	37.76	8.1
Xiangyang L. etc.	5Z13	26	0.49	140.31	1.79	16.49	2.12	5.40	5520~5940	37.89	10.8
Aqqikko l, and Jingyu L.	5Z14	86	1.61	322.03	4.11	37.33	4.80	3.74	5300~5700	66.70	19.1
Sub-total	5Z1	486	9.10	985.84	12.58	111.20	14.30	2.03	5140~5940	67.91	16.0
Chibuzhang Co etc.	5Z21	157	2.94	517.96	6.61	53.97	6.94	3.30	5480~5940	74.94	9.2
Siling Co	5Z22	642	12.02	593.09	7.57	36.37	4.68	0.92	5620~5910	7.84	7.9
Sub-total	5Z2	799	14.96	1111.05	14.18	90.34	11.62	1.39	5480~5940	74.94	9.2
Tangra Yumco etc.	5Z31	222	4.15	142.75	1.82	6.92	0.89	0.64	5810~5940	7.84	4.2
Zhari Namco	5Z32	267	5.00	126.29	1.61	5.23	0.67	0.47	5760~5800	5.55	3.9
Taro Co etc.	5Z33	479	8.97	485.81	6.20	29.18	3.75	1.01	5820~6200	16.39	8.1
Ngangla Ringco	5Z34	746	13.97	575.83	7.35	33.62	4.33	0.77	5440~6140	22.87	8.3
Sub-total	5Z3	1714	32.09	1330.68	16.98	74.95	9.64	0.78	5440~6200	22.87	8.3
Lumajiangdong Co	5Z41	273	5.11	480.39	6.13	39.34	5.06	1.76	5460~6100	46.56	12.6
Bangong Co	5Z42	959	17.96	665.35	8.49	39.23	5.05	0.69	5460~6100	23.68	10.5
Aksayqin L.	5Z43	592	11.08	1812.63	23.13	273.55	35.18	3.06	5820~6120	241.00	23.4
Sub-total	5Z4	1824	34.15	2958.37	37.75	352.12	45.29	1.62	5460~6120	241.00	23.4
Dogai Coring	5Z51	129	2.41	516.27	6.59	56.44	7.26	4.00	5580~6020	47.34	14.5
Yanghu L	5Z52	206	3.86	418.60	5.34	37.56	4.83	2.03	5640~6060	44.30	7.3
Sub-total	5Z5	335	6.27	934.87	11.93	94.00	12.09	2.79	5640~6060	47.34	14.5

(continued)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Yibug Cako	5Z61	73	1.37	225.76	2.88	25.20	3.24	3.09	5720~5820	51.49	10.8
Xiaga Co.	5Z62	42	0.79	51.76	0.66	2.77	0.36	1.23	5700~5850	6.73	5.5
Gemu Co	5Z63	68	1.27	237.77	3.04	26.90	3.46	3.50	5700~5870	68.90	12.6
Sub-total	5Z6	183	3.43	515.29	6.58	54.87	7.06	2.82	5700~5870	68.90	12.6
Total	5Z	5341	100.00	7836.10	100.00	777.48	100.00	1.47	5140~6200	241.00	23.4

The Tuze Kangri (34°45′N, 82°23′E) is located in the northwestern part of this drainage area. There are 48 glaciers with an area of 147.00 km^2 and ice volume of 13.61 km^3 in the Tuze Kangri. The largest glacier (5Z523J9) lies in the eastern slope of the Tuze Kangri with a length of 7.3 km, an area of 26.34 km^2. It is a complex valley glacier facing the east. Many glaciers developed at broad planation surface of the Tuze Kangri assemble as a classic small ice cap (Photo 5-17).

The Jinyang Kangri (35°36′N, 89°48′E) and the Kangzhag Ri (35°35′N, 89°40′E) are located in the northeastern part of the region (Photo 5-18). There are 38 glaciers around the highest peak covering an area of 167.20 km^2 with ice volume of 16.39 km^3. The largest glacier, a typical flat-topped glacier, originates from the western slope of the Kangzhag Ri (5Z512A1), a glacier of 5.0 km in length and 20.34 km^2 in area.

The Muz Tag (36°30′N, 87°25′E) lies in the middle section of the Kunlun Mountains in the

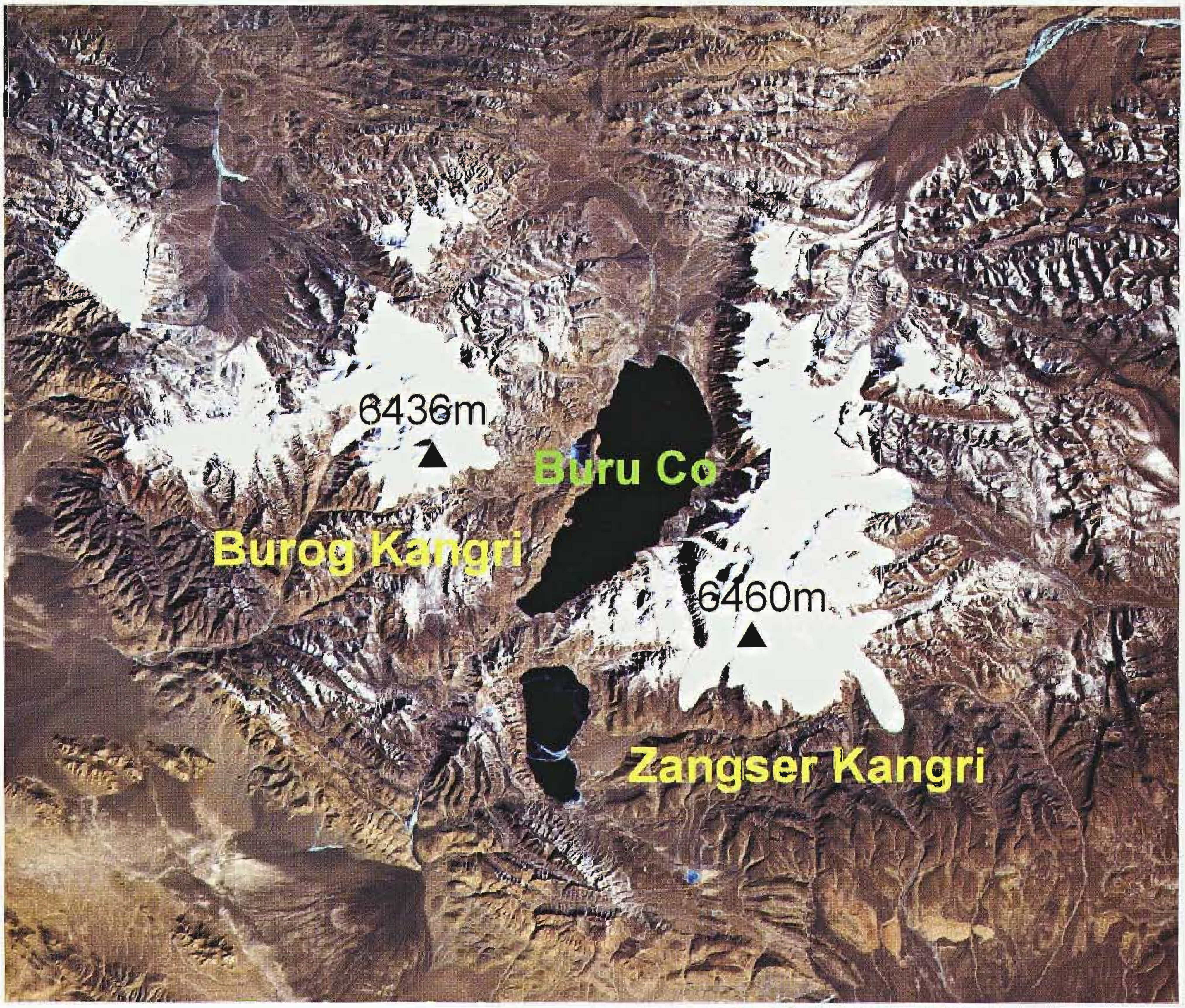


Photo 5-16 The Zangser Kangri and Burog Kangri glaciers (Landsat - TM 1999.11.10; Lu Anxin)

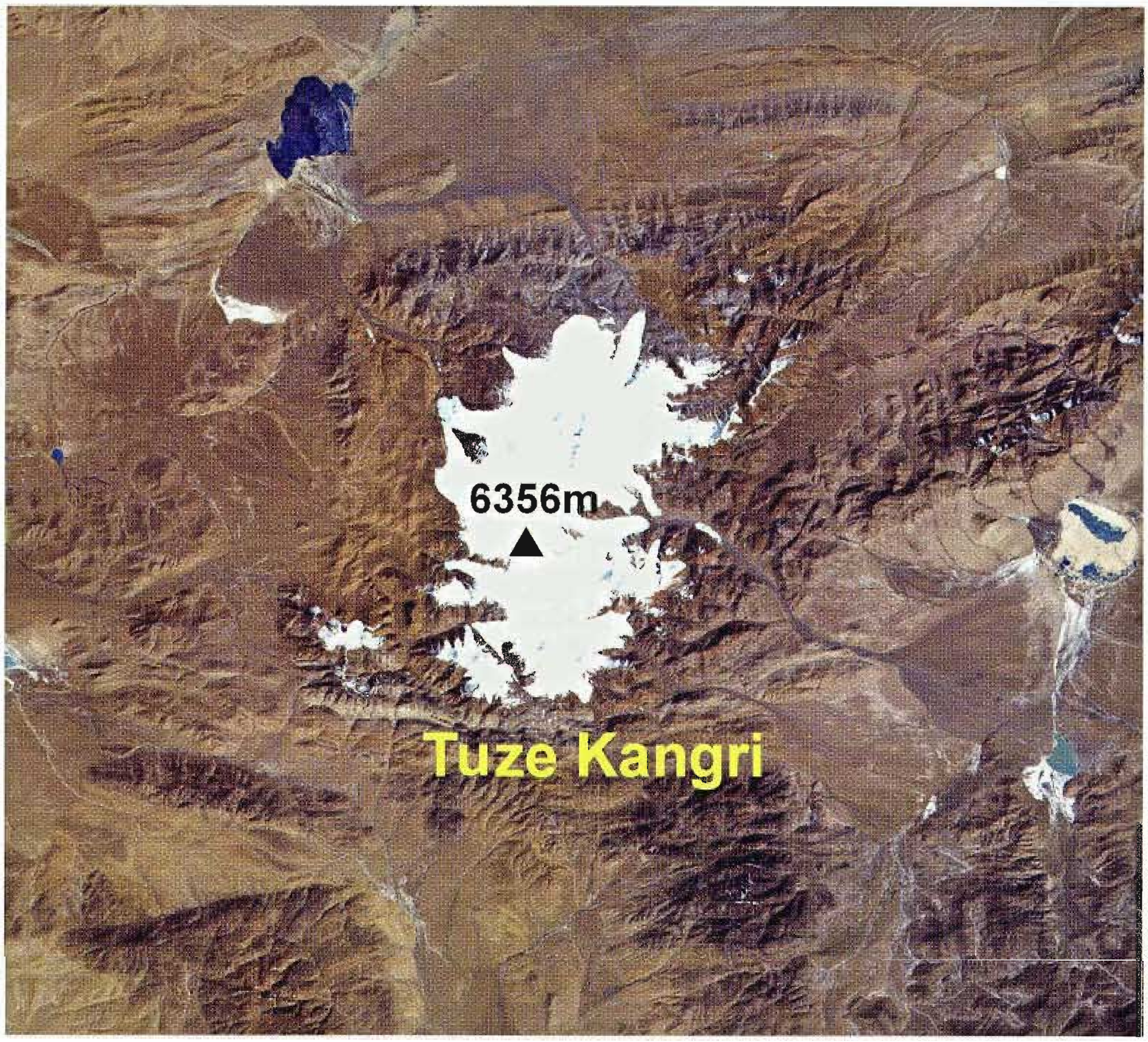


Photo 5-17 The Tuze Kangri glacier(Landsat - TM 1992.10.12; Lu Anxin)

northeastern part of the region. The altitude of the highest peak is 6973 m a.s.l. and its snowline altitude is 5500~5750 m a.s.l. 116 glaciers develop here with a total area of 681.17 km^2 and ice volume around 92.13 km^3. Glaciers on the southern and northern slopes jointly form a large ice cap, with glaciers on the southern slope of the area comprising 54.3%, 54.6% and 51.0% respectively of the total number, area and volume of that in the Muz Tag (Photo 5-19). The largest glacier, Binglinchuan Glacier (5Z141E14), has a length of 19.1 km, an area of 66.70 km^2. The Mount Monuomaha, also called the Mount Xinqingfeng or the Buka Daban Peak, covered by a huge ice cap, which is 350 km to the east of the Muz Tag (36°05′N, 90°55′E). The ice cap is 443.33 km^2, and ice volume is 65.19 km^3. The largest glacier, Ximonuomaha Glacier (5Z112D8), is 16.0 km in length and 67.91 km^2 in area, with a snowline altitude at 5480 m a.s.l. and a terminal altitude at 5080 m a.s.l.. Some 50 km to the southwest of the Mount Monuomaha is the Malan Ice Cap (35°50′N, 90°47′E), with highest elevation of 6056 m a.s.l. The Malan Ice Cap has 42 ice tongues spreading out from the central peak. Its total glacier area is 195.12 km^2 and volume is around 24.95 km^3. Their largest glacier of the Malan

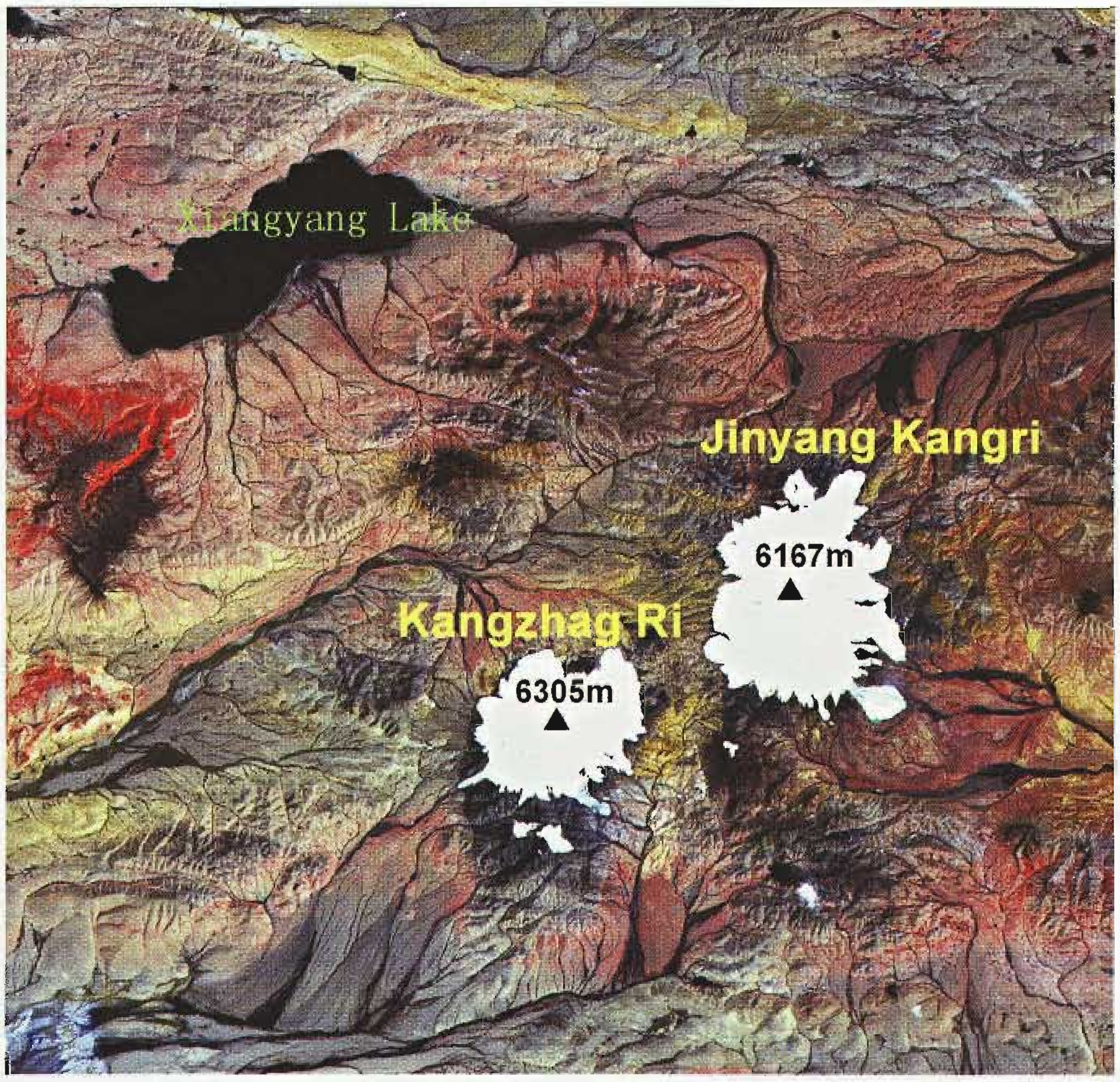


Photo 5-18 The Jinyang Kangri and Kangzhag Ri glaciers(Landsat -TM 1999.08.25; Lu Anxin)

Ice Cap (5Z122B1) is 8.1 km long with an area of 37.76 km^2. Since the Little Ice Age, the Malan Ice Cap has retreated 140~170 m, its area and volume have decreased by 4.6% (8.98 km^2) and 6.2%, respectively. According to aerial photographs and field surveys, glaciers in southern section of the Malan Ice Cap have retreated 45~60 m in the past 100 years (Pu Jianchen *et al.*, 2001). An ice core drilled in 1999 at the summit of the Malan Ice Cap indicates that the temperature increase during the summer period (May to October) is approximately 1.2℃ since the end of the 19th century. Yet, although climate warming has been evident since the end of 1970s, this ice core shows a temperature dropping during the late 1970s to 1990s (Wang Ninglian *et al.*, 2003). This change may cause a short-term expansion of the ice cap in the Mount Monuomaha and the Malan in recent years, especially the 65 glaciers with an area of 81.48 km^2 in 1976 increased by 0.98km^2 or 1.2% in 1998 in the Malan ice cap (Pu Jianchen *et al.*, 2001).

Most of glaciers in the QTPIA are small. Glaciers with less than 1.00 km^2 account for 76.7% of the total number (Table 5-26, Table 5-27), but they only occupy 16.6% and 4.5% of the total area and volume of glaciers, respectively. There are 111 glaciers larger than 10 km^2 in the QTPIA.

However, they take 42.9% and 68.2% of the total area and ice volume of the whole region, respectively, of which four glaciers are larger than 100 km^2. The largest one is the Zhongfeng Glacier (5Z433D8) with a length of 23.4 km, an area of 241.00 km^2, and an estimated ice volume of 63.87 km^3. Clearly the amount of glacier resources is determined by the quantity and size of large glaciers (Figure 5-21).

In terms of glacier types, hanging, cirque-hanging and cirque glaciers account for 60.3%, 11.7% and 19.0% in number, while their areas account for 10.6%, 5.2% and 23.6%, and their ice volume comprise 2.4%, 2.1% and 15.3%, respectively, of all glaciers in the region. Although valley glaciers are only 5.4% of the total glacier number, their area comprises 44.4%, and ice volume is 60.6% of the corresponding totals (Table 5-28). Due to the flat surface of some isolated mountains in the QTPIA, glaciers here can be ideal places for ice core drilling and climate change research.

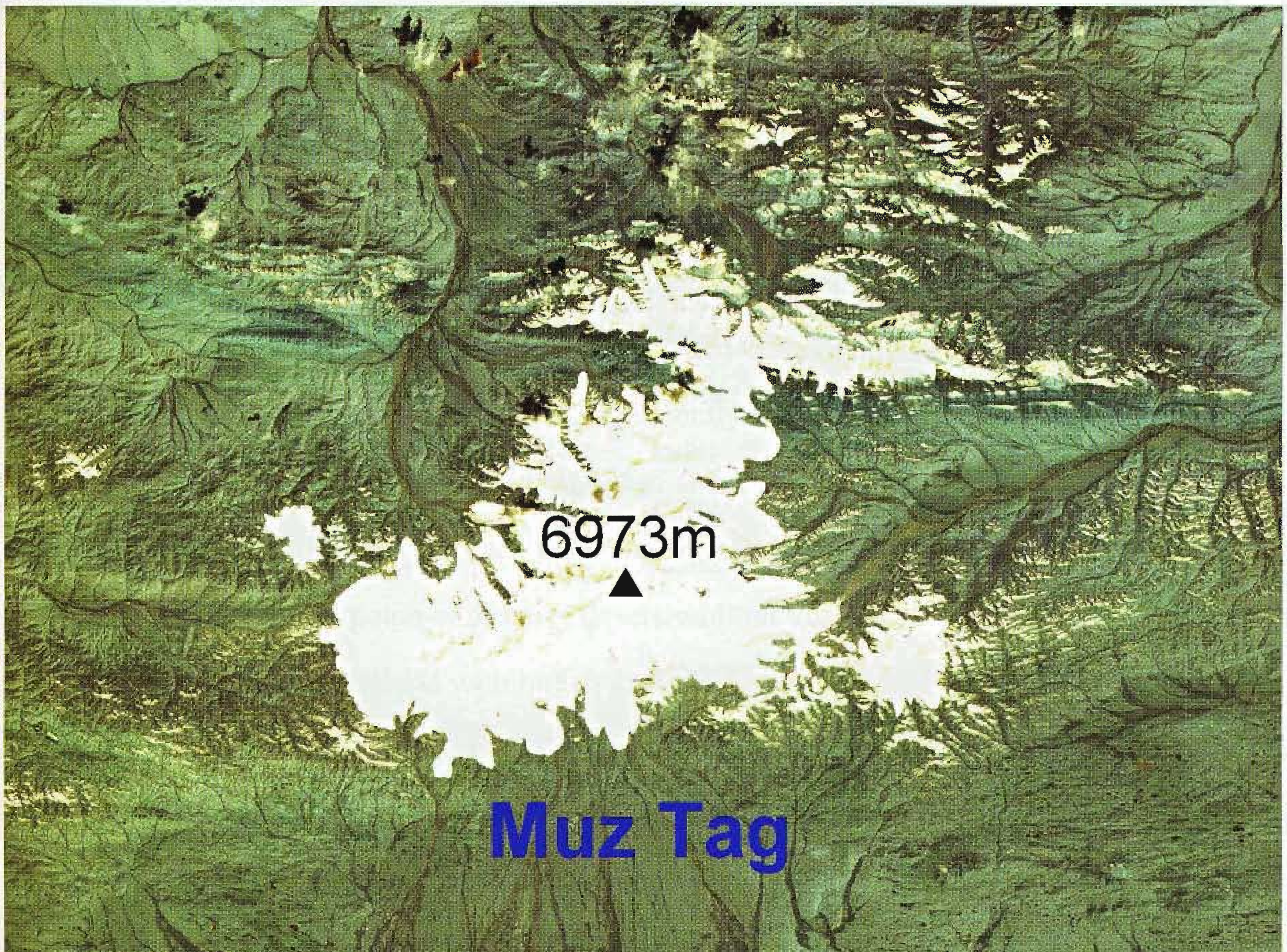


Photo 5-19 Glaciers on the Muz Tag (Landsat -TM 1999.9.17; Lu Anxin)

Table 5-26 Glacier distribution on various length classes in the QTPIA (5Z)

Length classes (km)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.5	1643	30.76	218.14	2.78	3.53	0.45	0.13
0.6~1.0	1709	32.00	605.08	7.72	15.71	2.02	0.35
1.1~2.0	1136	21.27	1045.25	13.34	42.70	5.49	0.92
2.1~5.0	680	12.73	2272.59	29.00	165.03	21.23	3.34
5.1~10.0	139	2.60	1869.84	23.86	214.04	27.53	13.45
10.1~15.0	26	0.49	957.28	12.22	147.40	18.96	36.82
15.1~20.0	5	0.09	350.06	4.47	63.27	8.14	70.01
20.1~25.0	2	0.04	354.80	4.53	87.65	11.27	177.40
25.1~30.0	1	0.02	163.06	2.08	38.15	4.91	163.06
Total	5341	100.00	7836.10	100.00	777.48	100.00	1.47

Table 5-27 Glacier distribution on various area classes in the QTPIA (5Z)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.5	3232	60.51	679.75	8.67	13.78	1.77	0.21
0.51~1.00	867	16.23	615.43	7.85	21.15	2.72	0.71
1.01~2.00	564	10.56	788.37	10.06	36.79	4.73	1.40
2.01~5.00	402	7.53	1242.31	15.85	78.42	10.09	3.09
5.01~10.00	165	3.09	1160.97	14.82	97.34	12.52	7.04
10.01~15.00	32	0.60	410.00	5.23	42.49	5.47	12.81
15.01~20.00	24	0.45	418.40	5.34	47.82	6.15	17.43
20.01~30.00	24	0.45	583.73	7.45	74.53	9.59	24.32
30.01~40.00	11	0.20	376.23	4.80	54.69	7.03	34.20
40.01~50.00	8	0.15	369.59	4.72	59.91	7.71	46.20
50.01~60.00	2	0.04	106.28	1.36	17.44	2.24	53.14
60.01~70.00	3	0.05	203.51	2.60	36.02	4.63	67.84
70.01~80.00	1	0.02	74.94	0.96	13.71	1.76	74.94
80.01~90.00	2	0.04	169.40	2.16	32.28	4.15	84.70
100.01~150.00	2	0.04	233.13	2.97	49.08	6.31	116.57
150.01~200.00	1	0.02	163.06	2.08	38.16	4.91	163.06
200.01~300.00	1	0.02	241.00	3.08	63.87	8.22	241.00
Total	5341	100.00	7836.10	100.00	777.48	100.00	1.47

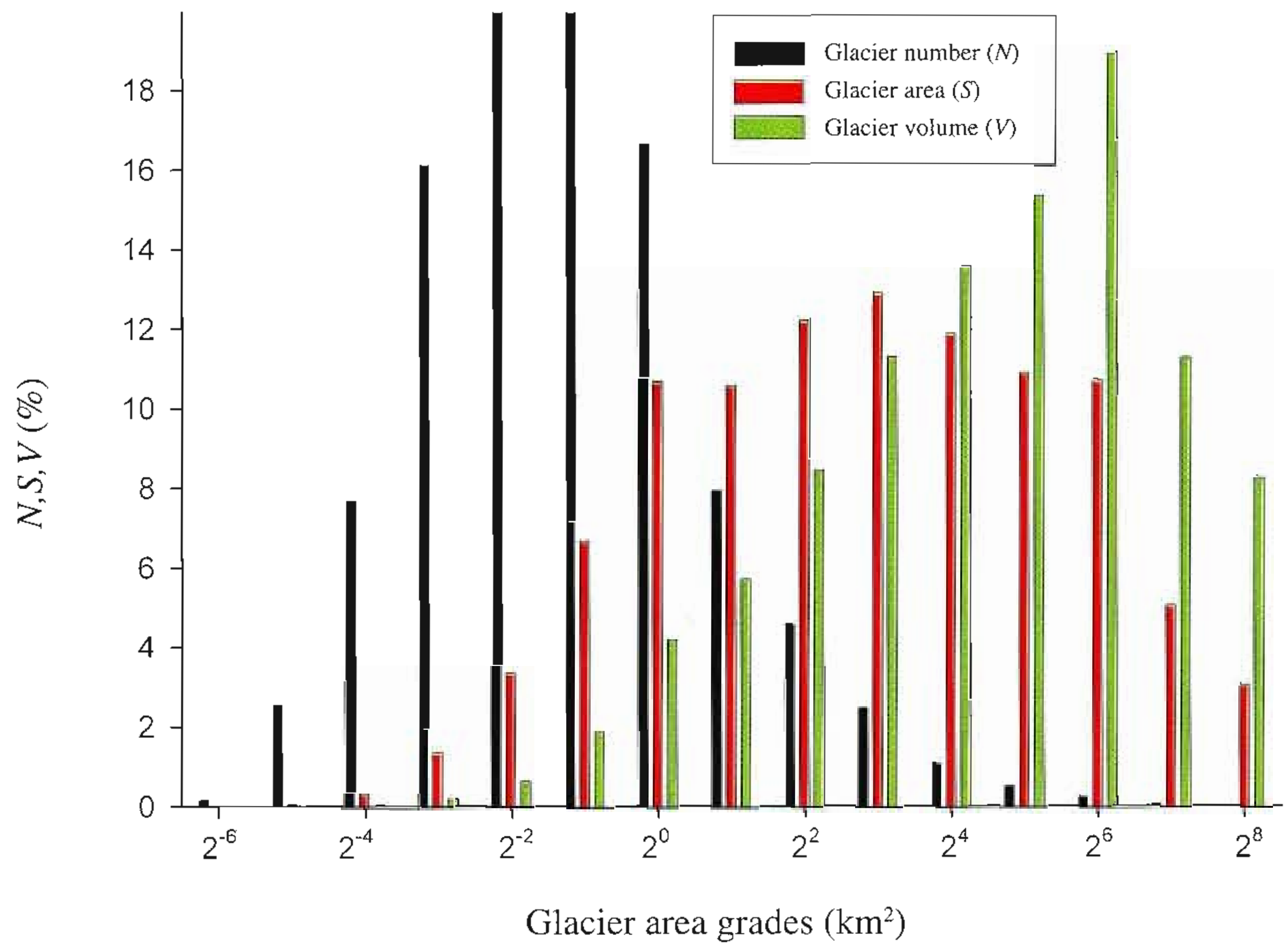


Figure 5-21 Distribution of glacier resources (*N, S, V*) versus area grades in the QTPIA

The northwest part of the Qinghai-Tibetan Plateau is a pole with the coldest, driest and highest altitude in the world (Zheng Du *et al.*, 1996). The permafrost and the extreme continental type (or polar type) glaciers prevail. The annual average temperature at the equilibrium line altitude is lower than −10.0℃ with the summer temperature below −1.0℃. And annual precipitation is between 200 mm and 500 mm (Shi Yafeng and Liu Shiyin, 2000). The northwest part of the Plateau has less precipitation. The amount of precipitation is as low as 50~100 mm in the low-lying lake basins. The Plateau's cold and arid climate and strong solar radiation mean that ice and water surface evaporation occurs frequently. As a result, the water of most lakes here becomes salty and some lakes even change into saline. In terms of regional ecosystems, the Kunlun Mountain and lake basin areas are of high altitude and arid desert; the Aksayqin Lake basin is a region of large patches of bare, desert without vegetation. The Qiangtan Plateau is mainly a high and cold grassland with bunch grass and sedge grass. Tibetan Sheep are the main livestock there (Li Wenhua *et al.*, 1998). The area is sparsely populated. Yet the area contains many wild animals, such as the Tibetan Antelope, Kyang, and Wild Yak, which are a protected species. For this reason, China has established several nature reserves to protect the natural ecosystems of this uncontaminated and precious region, as well as its endangered species. The Qiangtan Nature Reserve in the northern Tibet, Asia's largest nature reserve, has an area of 24×10^4 km^2. In addition, both the Altun Mountain Nature Reserve (managed by Xinjiang Uygur

Autonomous Region) and the Hoh Xil Nature Reserve (managed by Qinghai Province) are closed and onsite protection type reserves (Luosang Lingzhiduojie, 1996; Zhang Mingtao *et al.*, 1998).

Table 5-28 Statistics for glacier type in the QTPIA(5Z)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier
	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
Hanging	3222	60.33	829.30	10.58	18.54	2.39	0.26
Cirque-hanging	621	11.63	408.77	5.22	16.33	2.10	0.66
Cirque	1016	19.02	1848.59	23.59	118.72	15.27	1.82
Cirque-valley	98	1.83	353.01	4.50	25.77	3.31	3.60
Valley	289	5.41	3476.77	44.37	471.48	60.64	12.03
Canyon	9	0.17	10.39	0.13	0.47	0.06	1.15
Mountain slope	54	1.01	223.73	2.86	22.46	2.89	4.14
Ice cap	1	0.02	9.98	0.13	0.95	0.12	9.98
Flat-topped	31	0.58	675.56	8.62	102.76	13.22	21.79
Total	5341	100.00	7836.10	100.00	777.48	100.00	1.47

We currently lack reliable measurements of river runoff in the QTPIA, and assessments from different researchers are inconsistent. For example, He Xiwu (1996) calculated that the Tibetan inland rivers have an annual runoff amount of 202 $\times$ 10^8 m^3. Yang Zhenniang *et al.* (2000), on the other hand, calculated an amount of 246 $\times$ 10^8 m^3. Glacier meltwater runoff can be observed for only a short period on the southern slope of the west Kunlun Mountains. Observation and research on the Gozha glacier (No.1 and 2) in 1987 indicate that the glacial meltwater runoff are 200 mm $\cdot$ a^{-1} and 228 mm $\cdot$ a^{-1}, respectively, the corresponding runoff modulus are 17.7 L $\cdot$ km^{-2} $\cdot$ s^{-1} and 20.7 L $\cdot$ km^{-2} $\cdot$ s^{-1}, respectively, and the annual meltwater runoff are lower than 400 mm $\cdot$ a^{-1} (Cao Zhentang and Ai Site, 1989). The accumulated snow and glacier meltwater are not plentiful, but the nearly pure freshwater is much better than saline lake water. This freshwater irrigates the grasslands and supports the growth and survival of animals and plants in this desert region. For this reason, snow and ice meltwater is a precious water resource. With global warming, the ice and snow meltwater will further increase, benefiting even more the reproduction of animals and plants as well as human activities.

The extreme continental glaciers of this region are less sensitive to climate warming. An ice core record of the Guriya Ice Cap indicates that the temperature has increased 2.0℃ since the 17th century when Little Ice Age was at its maximum, but the glacier retreat is relatively small. By rough estimation, extreme continental glaciers have retreated less than 10% since the Little Ice Age. In recent years, the retreat velocities of the Purog Kangri Ice Field and the Malan Ice Cap are less than 10 m · a^{-1}. Judging by these facts, the Tanggula Range, the west Kunlun Mountains and the Qiangtan Plateau are the regions with the least degree of glacier retreat (Yao Tandong *et al.*, 2004).

To summarize, the QTPIA is a vast region, where climate and environment are influenced by high elevation, severe cold and extreme aridity. Its glaciers have a total area of 7836.10 km^2. Large glaciers and large ice caps mainly develop in the southern sides of the Kunlun Mountains. On the Qiangtan Plateau some flat and isolated high mountains above 6000 m a.s.l. are centers of radial ice cap and ice field development. The glaciers of this region are all the extreme continental type, which is relatively insensitive to the climate warming. The glacier meltwater runoff is not abundant. Meltwater, however, is the life source of multifarious animals and plants in the deserts and grasslands of a cold and high altitude area. As the temperature increases, the volume of ice and snow meltwater will also increases, enabling the development of agriculture, animal husbandry, and human activities. In addition, through the process of snow turning into ice, information about climatic and environmental changes over hundreds of thousands of years has been recorded, which attaches great importance to the research on glaciers and climate of Quaternary Period.

CHAPTER 6 GLACIERS IN THE EXTERIOR RIVERS

Liu Chaohai, Wang Zongtai and Pu Jianchen

6.1 The Ertix River (5A25)*

The Ertix River, a tributary of the Ob River originated from the Altay Mountains, is the only river in China that flows into the Arctic Ocean. In the Chinese territory, the Ertix River is converged by the Haba, Burqin, Kiran, Kara Ertix and Kayirti Rivers to the north side, and the Last and Ülken Ulast Rivers to the south side of the Ertix River (Figure 6-1).

The Ertix River basin is mainly influenced by the westerly in summer season, which transports humid air masses and brings cloudy weather and abundant precipitation in the glacierized area, and the Arctic air masses from the north in winter that produces low temperatures and heavy

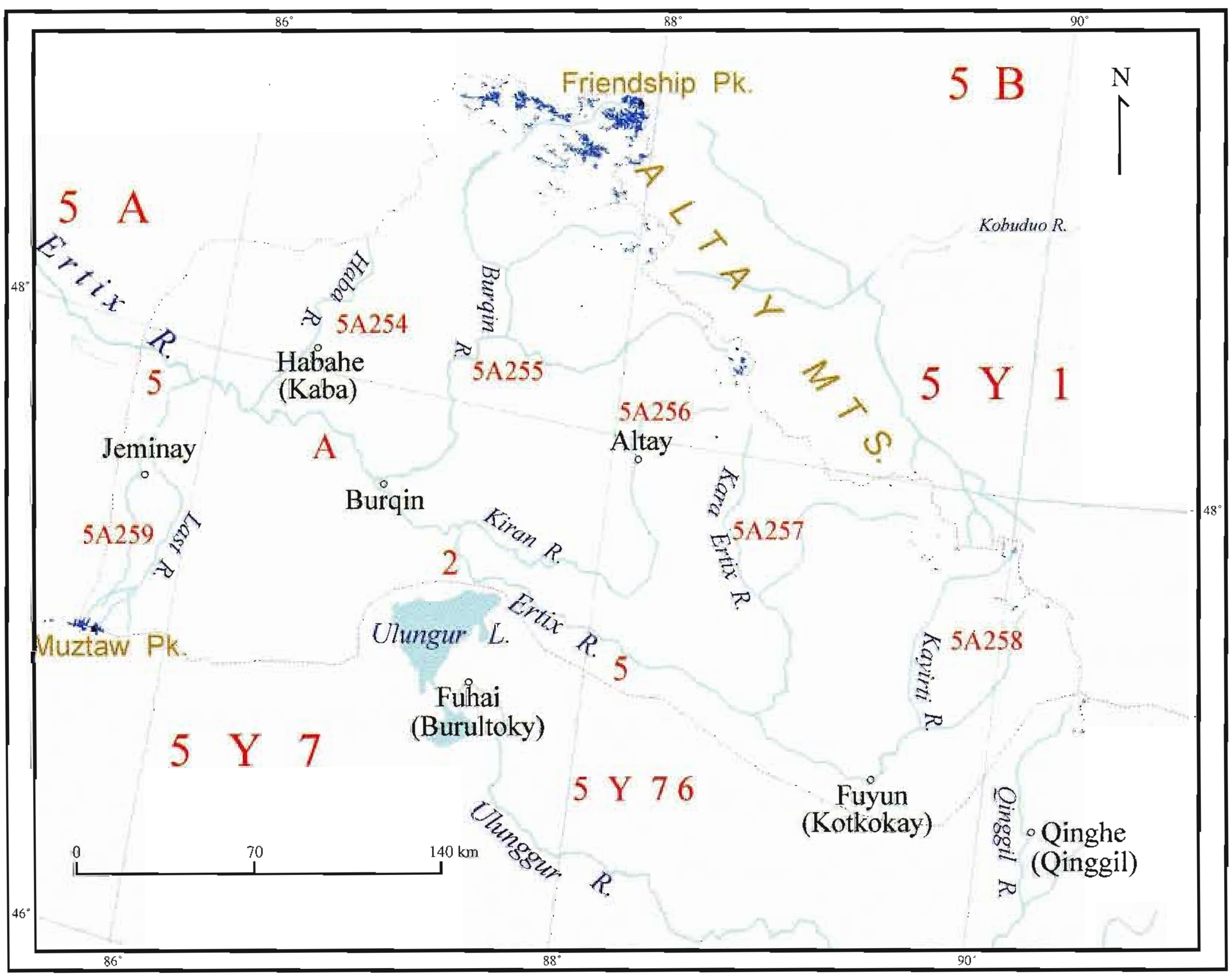


Figure 6-1 Glacier distribution in the Ertix River basin

* This subsection is prepared by Liu Chaohai.

Table 6-1 Glaciers in the Ertix River (5A25)

Tributary	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Haba.	5A254	35	8.68	19.48	6.73	0.83	5.06	0.56	2800~2900	4.40	2.8
Burqin	5A255	302	74.94	247.55	85.57	14.79	90.18	0.82	2950~3300	30.13	10.8
Kiran	5A256	1	0.25	0.26	0.09	0.01	0.06	0.25	—	0.26	0.7
Kara Ertix	5A257	11	2.73	1.19	0.41	0.02	0.12	0.11	—	0.24	0.9
Kayirti	5A258	41	10.17	7.52	2.60	0.15	0.92	0.18	3350	1.03	2.0
Others	5A259	13	3.23	13.29	4.60	0.60	3.66	1.02	3310~3350	4.27	3.9
Total	5A25	403	100.00	289.29	100.00	16.40	100.00	0.72	2800~3350	30.13	10.8

snowfall. Such climatic settings make the river basin one of the regions with the richest precipitation in the northwest China. Annual precipitation is usually higher than 150 mm in the foothills, and as high as 700~800 mm above the middle part of the mountains, according to snow pit observation at 3380 m a.s.l. on the Kanas Glacier (Wang Lilun *et al.*, 1983). About 45%~50% of the annual precipitation falls in the cold season (October to April of next year). The abundant precipitation and especially the snowfalls in winter together with low temperature promote the growth of Taiga Forests and glaciers in the region.

There are 403 glaciers in the Ertix River with a total area of 289.29 km^2 and ice volume of 16.40 km^3 (Table 6-1), measured from 1 : 100,000 topographical maps produced in 1964. The total glacier area here only accounts for 0.5% of the total in China. Most of the glaciers (85.6% area and 90.2% ice volume) distribute in the Burqin River, with an average glacier area as high as 0.82 km^2 and three glaciers larger than 10 km^2. Glacier number and size reduce eastward due to low altitude and precipitation decrease in the eastern Altay Mountains.

In the river basin, 83.6% glaciers are smaller than 1 km^2, which account only for 31.7% of the area and 13.0% of the ice volume of those in the Ertix River basin. The rest 16.4% glaciers larger than 1 km^2 cover 68.3% of area and 87.0% of ice volume in this basin (Table 6-2). Only six glaciers larger than 5.0 km^2 in the Altay Mountains in the Chinese side are located in the Burqin, Kanas and Budikanas Rivers, with three glaciers larger than 10.0 km^2 in the Kanas River. The Kanas Glacier is the largest one composed of two ice streams (Figure 6-2). The glacier is 10.8 km in length, 30.13 km^2 in area and 3.93 km^3 in volume, which terminates at an elevation of 2416 m

Table 6-2 Glacier distribution in different area classes in the Ertix River (5A25)

Area classes (km²)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km²)
	Number	(%)	(km²)	(%)	(km³)	(%)	
≤ 0.50	283	70.22	51.60	17.84	0.91	5.53	0.18
0.51~1.00	54	13.40	40.11	13.87	1.23	7.50	0.74
1.01~2.00	38	9.43	54.08	18.69	2.22	13.51	1.42
2.01~5.00	22	5.46	69.77	24.11	4.14	25.25	3.17
5.01~10.00	3	0.74	19.49	6.74	1.57	9.61	6.50
10.01~15.00	2	0.50	24.11	8.33	2.41	14.71	12.06
> 30.0	1	0.25	30.13	10.42	3.92	23.89	30.13
Total	403	100.00	289.29	100.00	16.40	100.00	0.72

a.s.l., the lowest glacier terminus in China. The Lanzhou Institute of Glaciology and Geocryology, CAS carried out an investigation on glaciers in the Altay Mountains in 1980, when observations on accumulation, ablation, movement, and ice temperature were conducted on the Ganas Glacier. The glaciological research in the region displayed that glaciers here are similar to those in the western Tianshan in China, which is characterized by the cold seasonal accumulation, warm seasonal ablation, high ice temperature and surface velocity, which shows glaciers in the region belong to the sub-continental type glaciers.

Small glaciers (< 1 km²), especially small hanging glaciers, are dominant in the river basin, which amount to 64.5% of total number (Table 6-3), higher than the percentage in the Qilian Mountains (50.9%) and the Alps in Switzerland (42.0%). Of all glaciers, only 18 valley glaciers account for 28.6% of the total glacier area. Cirque glaciers occupy 19.6% of glacier number and 35.3% of glacier area. Due to the narrow ranges and steep slopes of the Altay Mountains in the Chinese side, the topographical conditions are not beneficial to form large glaciers with broad firn basins and many branches, but only smaller cirque glaciers.

The glaciations were very extensive in the Altay Mountains during the Quaternary. It has been derived that the Kanas Glacier has extended down to the lower bank of the Kanas Lake in the Burqin River during the Last Glacial Maximum, when the glacier was measured 100 km in length (Liu Chaohai and Wang Lilun, 1983), 9.3 times as its current length, and the glacier terminus descended to 1400 m a.s.l. Based on the altitudes of cirque basins equivalent to this

Table 6-3 Distribution of glacier types in the Ertix River Basin (5A25)

Type	Glacier number		Glacier area		Glacier volume		Mean area per glacier
	Number	(%)	(km²)	(%)	(km³)	(%)	(km²)
Hanging glacier	260	64.52	44.54	15.40	0.78	4.76	0.17
Cirque-hanging glacier	34	8.44	20.80	7.19	0.62	3.78	0.61
Cirque glacier	79	19.60	102.15	35.31	4.75	28.96	1.29
Cirque-valley glacier	12	2.98	39.11	13.52	2.87	17.50	3.26
Valley glacier	18	4.46	82.69	28.58	7.38	45.00	4.59
Total	403	100.00	289.29	100.00	16.40	100.00	0.72

glaciation, the equilibrium line altitude (ELA) in the Last Glacial Maximum was between 2600~2700 m a.s.l., 600~700 m lower than the present ELAs. During the Little Ice Age, glaciers in the Altay Mountains were 72.65 km^2 or 20.0% larger than the present glacier area. Glaciers have been retreating under climate warming in the past several decades. Comparing with aerial photographs in 1959 and the field survey in 1980, it was found that four of five documented

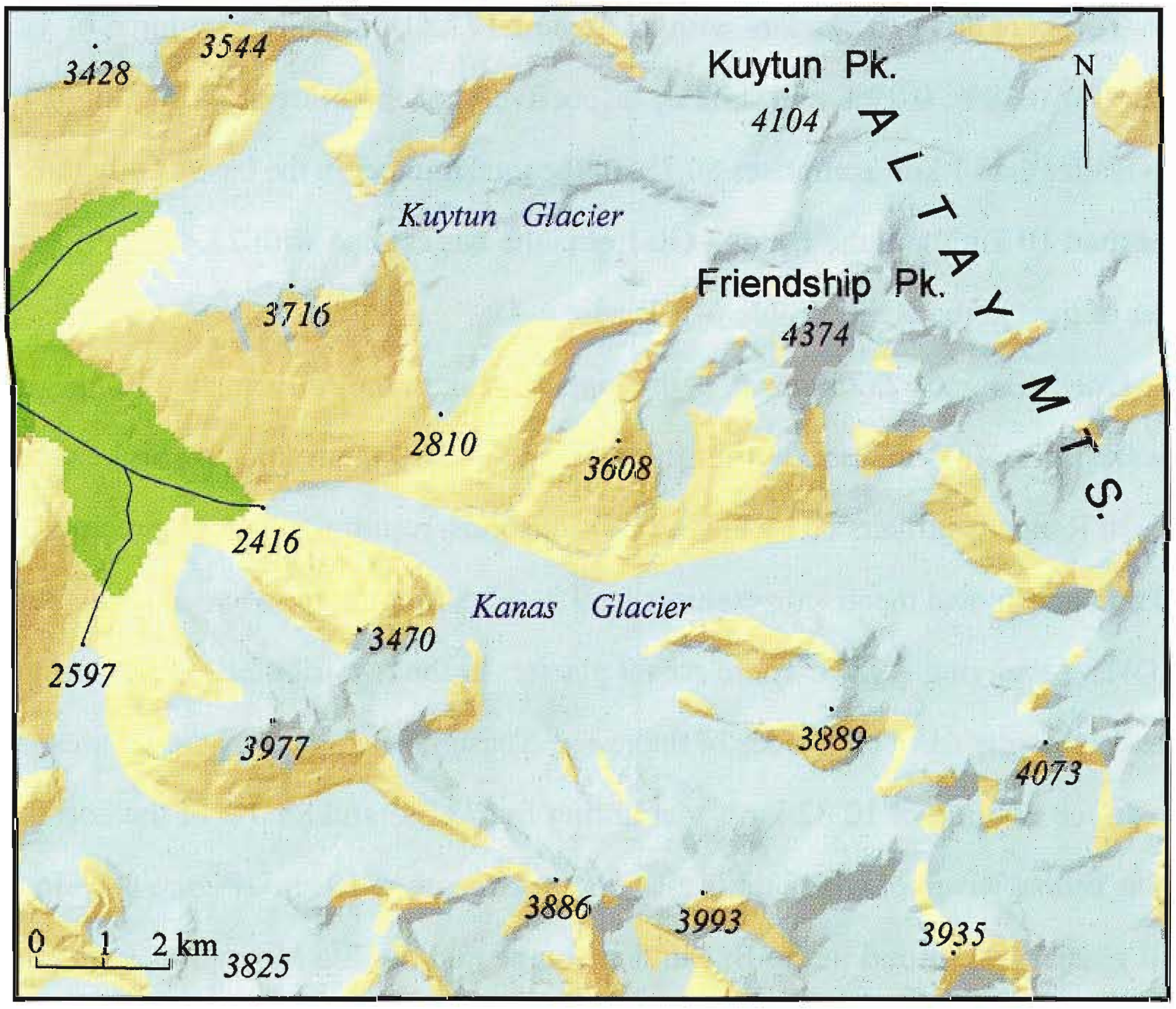


Figure 6-2 Glaciers around the Friendship Peak of the Chinese Altay Mountains

glaciers have retreated. The Kanas Glacier retreated 424 m (20 m·a^{-1}). The No. 22 Glacier at the Kanas riverhead is the only exception, having advanced a little bit (20 m).

Glacier runoff in the Altay Mountains is less abundant compared with other rivers in China. The annual average glacier runoff is only 1.2×10^8 m^3, about 1.6% of the Ertix River runoff. Plentiful snowfalls in the mid and high mountains during winter and spring make the river runoff in this season as high as 41.2% of annual runoff (Zhou Bocheng, 1983). The Ertix River has relatively abundant water resources, which is 16% of the total river runoff in Xinjiang Uygur Autonomous Region, second to that of the Ili River. The Kanas Lake, formed by end moraines blockage in the lower reaches of the Kanas Glacier and located inside the Taiga Forest, is one of the most beautiful tourism sites.

6.2 The Yellow River (5J)*

The Yellow River is not well glacierized, though it is the second longest river in China and originated from the Tibetan Plateau (Table 6-4).

Glaciers in the river are found in the source area in the A'nyemaqen Range in the east Kunlun Mountains and a tributary from the Lenglong Range in the eastern Qilian Mountains (Figure 6-3). There are 176 glaciers with an area of 172.41km^2 and ice volume of 12.29 km^3, accounting for 0.38%, 0.29% and 0.22%, respectively, of the corresponding totals in China. Glaciers smaller than 1 km^2 comprises 80.7% of the total number in the basin. Only three glaciers are larger than 10 km^2, and the Halong Glacier is the largest one with 23.49 km^2 in area at the headwater of the Qiemu River (Table 6-5, Figure 6-4).

The Maqen Kangri, 6282 m a.s.l., is the highest peak in the A'nyemaqen Range, and there are 15 peaks over 5000 m a.s.l. within the distance of 28 km around the highest peak. The A'nyemaqen Range is influenced by the Indian monsoons, resulting in a high precipitation up to 700~900 mm and annual mean temperature of −9.2~−7.5℃ at the snowline altitude (4900~5000 m a.s.l.) (Wang Wenying, 1987). There are 59 glaciers in the two tributaries, the Qiemu and the Qu'ngoin, originating from both sides of the range. These glaciers occupy a total area of 126.16 km^2 with an ice volume of 10.82 km^3, accounting for 73.2% and 88.0% of the corresponding totals in the Yellow River, of which three glaciers are larger than 10 km^2 (Figure 6-4). In addition, few small glaciers are found in the Bayan Har Range and the Ela Mountains in the north and

* This subsection is prepared by Wang Zongtai.

Table 6-4 Glaciers in the Yellow River basin (5J)

Tributary		Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
			Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Yellow River trunk stream	Haqu-Nigequ	5J31	5	2.84	4.01	2.32	0.19	1.55	0.80	4860	2.35	2.2
	Qiemu	5J351	28	15.91	92.25	53.50	8.93	72.66	3.29	4900~5230	23.49	7.7
	Qu'ngoin.	5J352	31	17.62	33.91	19.67	1.89	15.38	1.09	5150~5180	5.57	4.0
	Daheba.	5J353	4	2.27	1.27	0.74	0.03	0.24	0.32	4950	0.58	1.0
	Sub-total	5J3	68	38.64	131.44	76.23	11.04	89.83	1.93	4900~5230	23.49	7.7
Datong tributary	Tangmoer	5J425	5	2.84	2.77	1.61	0.09	0.73	0.55	4710	1.67	2.3
	Laohugou	5J428	103	58.52	38.20	22.16	1.16	9.44	0.27	4360~4660	2.51	3.2
	Sub-total	5J42	108	61.36	40.97	23.77	1.25	10.17	0.38	4360~4710	2.51	3.2
Total		5J	176	100.00	172.41	100.00	12.29	100.00	0.98	4360~5230	23.49	7.7

south of the A'nyemaqen Range.

There are 108 glaciers with a total area of 40.97km² and ice volume of 1.2501 km³ in the Datong River from the Qilian Mountains, they only account for 23.8% and 10.2% of the total area and ice volume in the Yellow River, respectively. The mean glacier area of these glaciers is only 0.57 km² with the largest glacier of 2.51 km² in area.

The source region of the Yellow River suffered from extensive glaciations in the Quaternary. Wang Jingtai (1987) found that the glacier area during the Last Glacial Maximum (LGM) was 405 km², 3.2 times larger than the present glacier area in the Maqen Kangri and the glacier

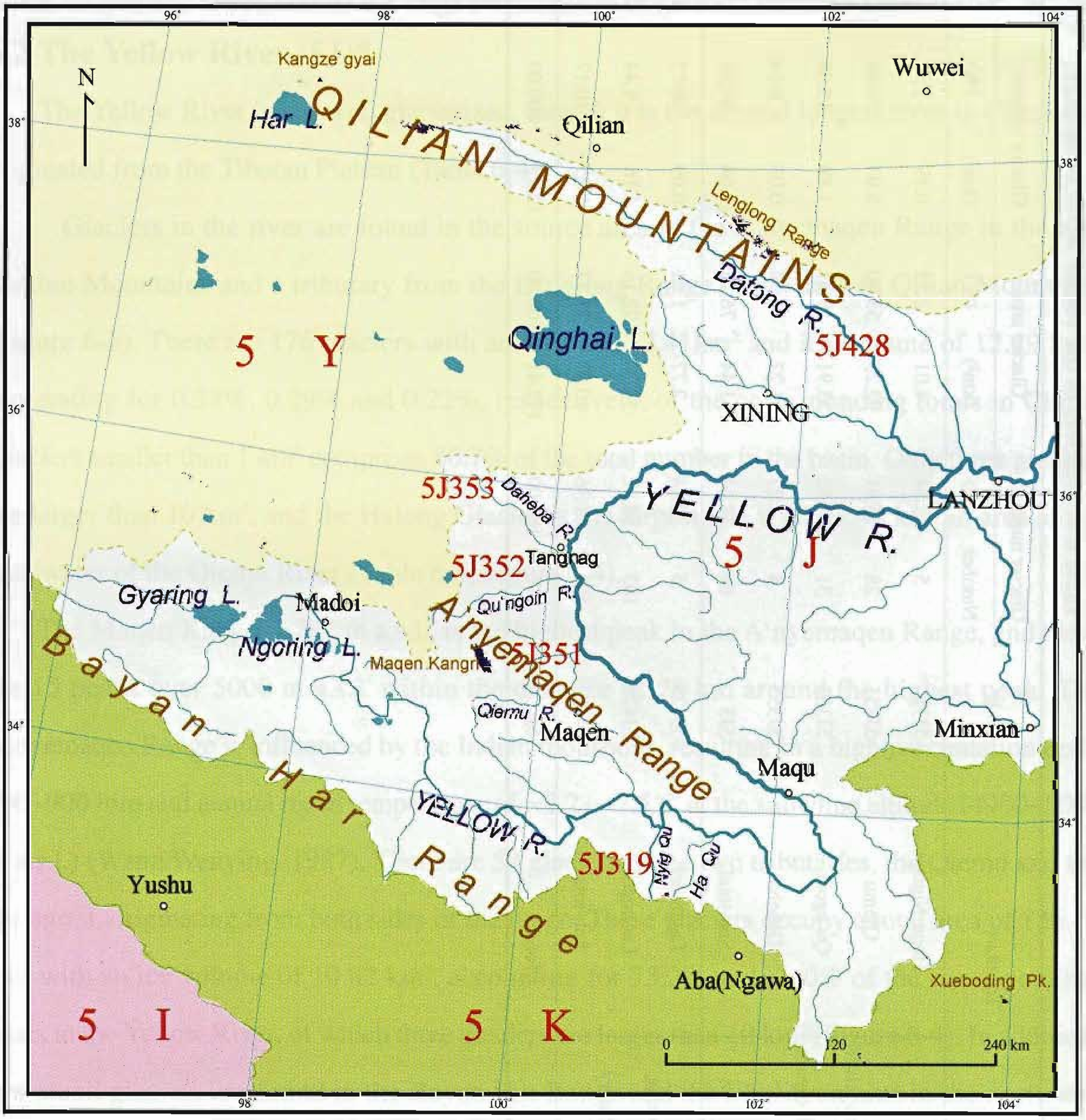


Figure 6-3 Glacier distribution in the Yellow River basin

Table 6-5 Distribution of glaciers in different area classes in the Yellow River basin (5J)

Area classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier
(km^2)	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
≤ 0.50	118	67.05	25.47	14.77	0.53	4.31	0.22
0.51~1.00	24	13.64	16.73	9.70	0.54	4.39	0.70
1.01~2.00	18	10.23	28.80	16.70	1.38	11.23	1.60
2.01~5.00	11	6.25	30.74	17.83	1.88	15.30	2.79
5.01~10.00	2	1.13	11.79	6.84	0.94	7.65	5.90
15.01~20.00	2	1.13	35.39	20.53	4.06	33.04	17.70
20.01~30.00	1	0.57	23.49	13.63	2.96	24.08	23.49
Total	176	100.00	172.41	100.00	12.29	100.00	0.98

terminus altitude was 400~600 m lower than that of the present. The Mount Nianbaoyeze in the east end of the Bayan Har Range is an oval shape with 50 km long in the south-north direction and 30 km wide in the east-west direction and is averagely 300~1000 m above the surrounding

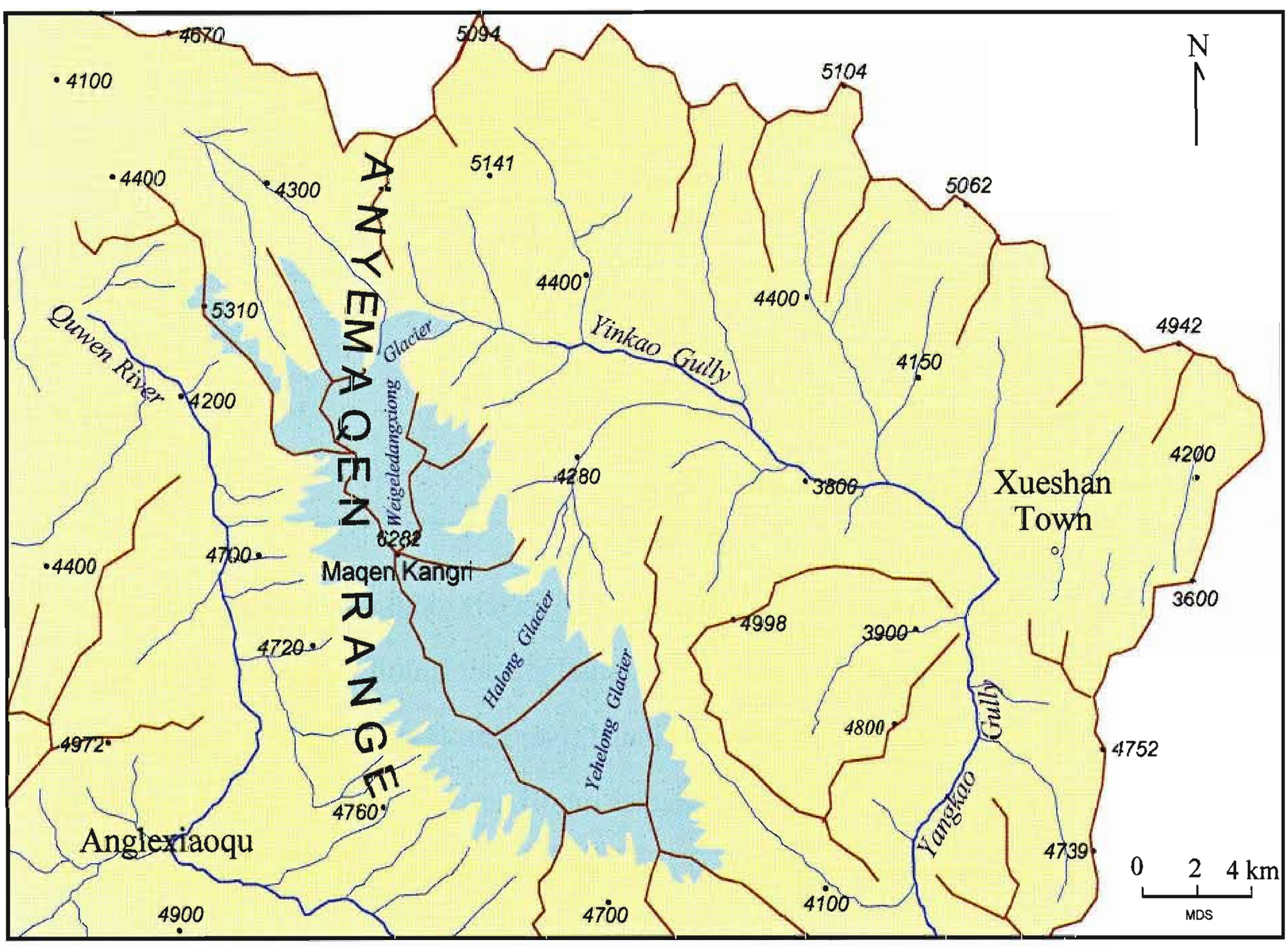


Figure 6-4 Glacier distribution in the A'nyemaqen Range

foothills. The Mount Nianbaoyeze area was covered by an ice cap with an area of at least 1028 km^2 during the Last Glacial Maximum, about 200 times as the area of its modern one. The glacier terminus in LGM was between 3860~4060 m a.s.l., 500~940 m lower than that of the present (Yang Huian and An Ruizhen, 1992).

Glaciers were also quite large in the A'nyemaqen Range during the Little Ice Age (LIA), about 1.4 times as the glacier area in 2000. Glaciers have been generally retreating since the LIA. However, 16 of 40 surveyed glaciers (40%) advanced by 50~790 m during 1966~1981, while 22 glaciers (55%) were stable, and only two glaciers (5%) retreated by 150 and 220 m during that period (Wang Wenying, 1987). The fact that many glaciers in the A'nyemaqen Range are in a state of advance is probably a reflection of the cooling and increased precipitation since the end of the 1960s. In response to the climate warming since the 1980s, most glaciers retreated again and the speed has accelerated. Among the 57 monitored glaciers (Table 6-6), only three glaciers advanced and two had no obvious change, and the rest of them (91%) were retreating during 1966~2000 (Liu Shiyin *et al.*, 2002c). The total glacier area decreased by 17% during this period. The Yehelong glacier with a length of 9.4 km experienced the obvious retreat of 1950 m, 23.2% of the length in 1966 during 1966~2000.

Table 6-6 Glacier area change in the A'nyemaqen Range since the LGM

Time	Glacier area (km^2)	Glacier area change (km^2)	Relative change in glacier area (%)
LGM	391.6	391.6	100
LIA	147.8	−243.8	−62
1966	125.5	−22.3	−15
2000	103.8	−21.7	−17

Due to the low glacierization in the Yellow River, glaciers exhibit an insignificant regulation to the river discharge. It was estimated that the annual glacier runoff is around 3.94×10^8 m^3 in the Yellow River, approximately 1.9% of the annual river runoff at the Tangnaihai Hydrological Station (Yang Zhenniang, 1991). However, glacier runoff accounts for 74.0% of the river runoff in the Qiemu and Qu'ngoin Rivers, and is obviously quite important in regulating river runoff and stabilizing the ecosystem.

6.3 The Yangtze River (5K)*

Traversing China from the west to east, the Yangtze River with a total length of 6300 km is the longest river in China. The headstream of the Yangtze River is located in the center of the Qinghai-Xizang (Tibet) Plateau. Glaciers in the Yangtze River are mainly found in the four large tributaries, the Jinsha, Yalong , Minjiang and Jialing Rivers (Figure 6-5).

The upstream of the Jinsha River, called as Tongtian River, is located in a series of mountain ranges with broad valleys lying northwest to southeast. The sub-tributaries, the Kouqian, Dangqu, Garqu, Togton (Photo 6-1) and Qumar Rivers, lie in the fan-shape arrangement (Figure 6-5). Many large glaciers are developed around the Mount Geladaindong at an altitude of 6621 m

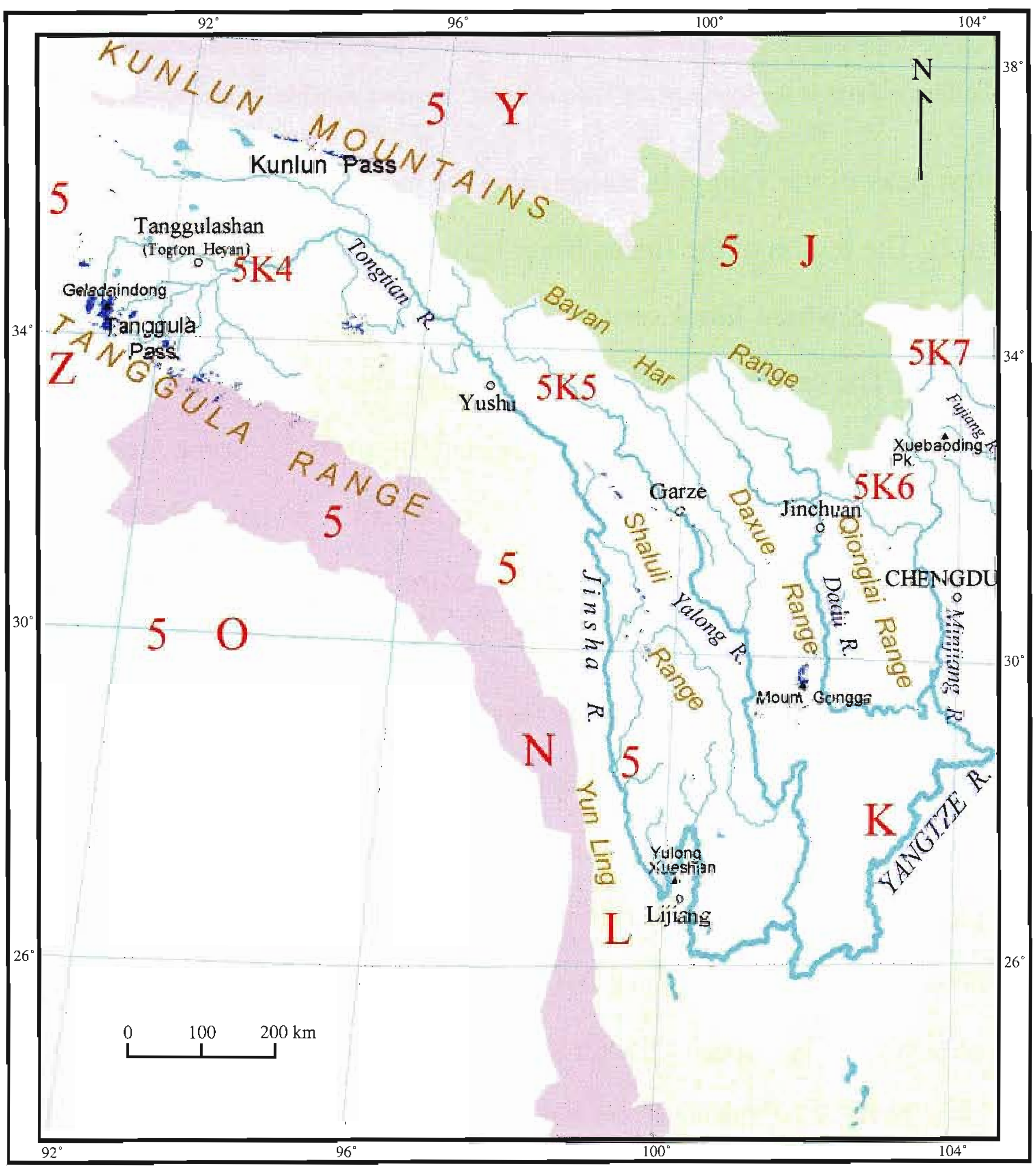


Figure 6-5 Rivers, mountains and glaciers in the upper reaches of the Yangtze River

* This subsection is prepared by Pu Jianchen.

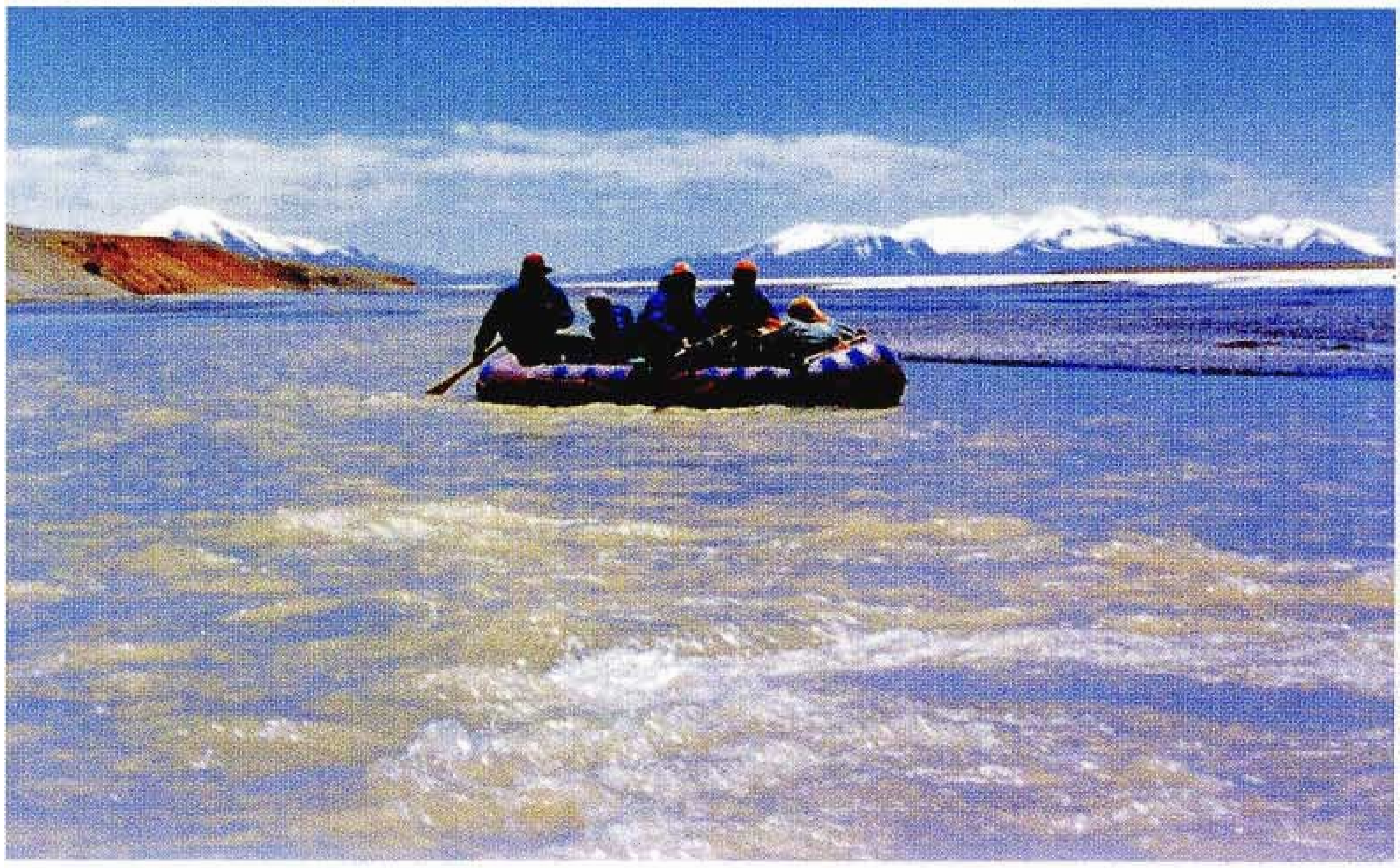


Photo 6-1 The Togton River in the source of the Yangtze River - the river with glacier meltwater supply (Pu Jianchen)

a.s.l., the highest peak of the Tanggula Range, also the highest peak in the source of the Yangtze River (Photo 6-2). The region of the Jinsha River between Yushu county and the western Sichuan Province is a vast area where lies a series of famous north-south mountains and valleys with large altitude spans. The easternmost glacierized region, Xuebaoding and the southernmost one, Yulong Xueshan are located in the drainage region (Figure 6-5). Some steep, long and large glaciers are developed in the Mount Gongga (7756 m a.s.l.), which is the highest peak of the Daxue Mountains in West Sichuan, and is referred to as the "King of Jokuls" where the surrounding 28 peaks are above 6000 m a.s.l.

According to *Glacier Inventory of China* for the Yangtze River, there are 1332 glaciers with a total glacier area of 1895.0 km^2 and ice volume of 147.26 km^3 in the basin (Table 6-7), accounting for 2.9%, 3.2% and 2.6% of the total glacier number, area and volume in China. More than two-thirds of the glaciers in the Yangtze River are found in the Jinsha River, 81.6% of the glacier number and 89.8% of the glacier area of the Jinsha River basin are concentrated in the source area and the Mount Geladaindong. Glacier sizes in the Minjiang River are much smaller than those in the Jinsha River. The Yalong River basin has fewer glaciers with much smaller sizes, and its glaciers are sparsely distributed. Only one small glacier with 0.15 km^2 in area is in the source region of the Fujiang River, a tributary of the Jialing River. This is Chinese easternmost glacier.

Table 6-7 Glaciers in the tributaries of the Yangtze River (5K)

Tributary	Sub-tributary	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
			Number	(%)	(km²)	(%)	(km³)	(%)	(km²)	(m)	Area (km²)	Length (km)
Jinsha River	Yanggongjiang	5K41	21	1.58	11.89	0.63	0.47	0.32	0.57	4620~4900	1.90	2.3
	Nieqia Qu	5K42	136	10.21	112.70	5.95	6.28	4.26	0.83	5000~5400	10.35	6.9
	Kouqian Qu	5K43	20	1.50	13.33	0.70	0.56	0.38	0.67	5280~5320	3.45	2.6
	Dang Qu	5K44	468	35.14	718.67	37.92	53.18	36.11	1.54	5360~5880	37.44	10.8
	Togton R.	5K45	92	6.91	389.09	20.53	42.15	28.62	4.23	5500~5930	52.92	9.9
	Qumar R.	5K46	47	3.53	47.09	2.49	2.41	1.64	1.00	5250~5440	6.75	5.9
	Zhen Qu	5K47	42	3.15	49.13	2.59	3.30	2.24	1.17	4960~5240	14.67	6.6
	Ding Qu	5K48	99	7.43	76.83	4.05	3.47	2.36	0.78	5020~5280	5.27	3.9
	Chongtian R.	5K49	10	0.75	7.94	0.42	0.35	0.24	0.79	4800~4880	2.20	1.7
	Sub-total	5K4	935	70.20	1426.67	75.28	112.17	76.17	1.53	4620~5930	52.92	9.9
Yalong River	Xiaojin R. Upstream	5K51	24	1.80	13.70	0.72	0.52	0.35	0.57	5080~5280	1.96	2.0
	of Yalongjiang	5K52	75	5.63	86.26	4.55	5.82	3.95	1.15	4560~5400	17.03	6.8
	Xianshui R.	5K53	7	0.53	3.93	0.21	0.14	0.10	0.56	—	1.09	1.6
	Liqi R.	5K54	44	3.30	26.04	1.38	0.96	0.65	0.59	4880~5300	2.28	1.8
	Sub-total	5K5	150	11.26	129.93	6.86	7.44	5.05	0.87	4560~5400	17.03	6.8
Minjiang	Dadu R.	5K61	175	13.14	312.36	16.48	26.85	18.23	1.78	4400~5240	32.15	10.5
	Minjiang	5K62	71	5.33	25.89	1.37	0.80	0.54	0.36	4920~4960	1.89	3.2
	Sub-total	5K6	246	18.47	338.25	17.85	27.65	18.77	1.38	4400~5240	32.15	10.5
Jialing	Fujiang	5K71	1	0.07	0.15	0.01	< 0.01	0.01	0.15	—	0.15	0.6
	Sub-total	5K7	1	0.07	0.15	0.01	< 0.01	0.01	0.15	—	0.15	0.6
Total		5K	1332	100.00	1895.00	100.00	147.26	100.00	1.42	4400~5930	52.92	9.9

Photo 6-2 Glacier groups on the northern slope of the Mount Geladaindong in the Yangtze River source (Cited from *Chinese Glaciers*, 1980)

Glaciers in the Yangtze River are developed in various terrains from the flat plateaus and wide valleys in the river source area to the high mountains with deep valleys in the Hengduan Mountains. As a result, they have distinct regional characteristics. There are few hanging or cirque-hanging glaciers, but lot of valley or cirque-valley glaciers in the river source areas (Table 6-8). This is obviously related to the well-preserved planation surfaces. Large-sized valley glaciers and cirque-valley glaciers are mainly concentrated around high peaks such as the Geladaindong, the Gaqiadirugang Xueshan, the Longyala, the Mount Gongga and the Chola. Hanging glaciers and cirque-hanging glaciers are found mainly in narrow and low mountains with steep slopes aside of some long and large glaciers. Flat-topped glaciers are mostly located on the mountains with flat top in the river source area, while canyon glaciers are mainly found on high mountainous area with deep valleys along the Jinsha River and the Minjiang River.

In the Yangtze River, glaciers smaller than 1.0 km^2 account for 71.5% of glaciers in the basin, while their area and ice volume only comprise 20.1% and 7.7% of the corresponding totals. Although glaciers larger than 10.0 km^2 only account for 2.3% of the glacier number, their total glacier area and ice volume comprise 33.1% and 53.5% of the corresponding totals, respectively (Figure 6-6, Table 6-9, Table 6-10). There are seven large glaciers with areas greater

Table 6-8 Distribution of various glacier types in the Yangtze River (5K)

Type	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging glacier	544	40.84	139.47	7.36	2.85	1.93	0.26
Cirque-hanging glacier	188	14.11	96.29	5.08	3.22	2.19	0.51
Cirque glacier	278	20.87	287.43	15.17	13.29	9.02	1.03
Cirque-valley glacier	179	13.44	392.68	20.72	24.65	16.74	2.19
Valley glacier	108	8.11	941.28	49.67	101.55	68.96	8.72
Canyon glacier	10	0.75	7.57	0.40	0.31	0.21	0.78
Mountain slope glacier	18	1.35	16.44	0.87	0.60	0.41	0.91
Flat-topped glacier	7	0.53	13.84	0.73	0.79	0.54	1.98
Total	1332	100.00	1895.00	100.00	147.26	100.00	1.42

than 30 km^2 (Table 6-11), of which five are located in the west Tanggula Range, one is located in the Zu'erken Wula Range, and another on the eastern slope of the Mount Gongga. The proportion of small glacier number gradually increases from the west area in river source to the lower reach eastward, while that of large glaciers decreases from west to east. Glacier dimensions and shapes are strongly affected or controlled by terrains. The valley glaciers in the mountains in the east part are usually narrow, long and steep with large altitude span due to strong erosive mountain terrain with narrow and deep valleys. Moreover, the high temperature in the east limits glacier growth and favors the development of the small glaciers like hanging glaciers and cirque-hanging glaciers. The Plateau-type amphitheater glaciers and flat-topped glaciers are favored in the flat and less steep mountains with wider valleys in the west part of river basin.

The altitudinal differences of glaciers decrease from northwest to southeast. Glaciers in the river source area have small altitude spans with a maximum altitude difference about 1000~1260 m due to flat plateau surfaces with gentle and wide valleys. The ice surface slopes are usually 6°~13° for valley glaciers and 21°~29° for hanging glaciers, so snow avalanches and icefalls are rare and glacier surfaces are clean with little debris cover. Due to different ablation rate, seracs can be found on the frontal of some large glaciers facing to the west-east. However, glaciers flow within a large altitude range in the Mount Gongga. For example, the vertical span of the Hailuogou Glacier, on the eastern slope of the Mount Gongga, reaches 4576 m. This glacier is

Table 6-9 Distribution of glaciers in different length classes in the Yangtze River (5K)

Length classes (km)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.5	147	11.04	21.73	1.15	0.36	0.25	0.15
0.6~1.0	560	42.04	209.44	11.05	5.74	3.90	0.37
1.1~2.0	382	28.68	362.55	19.13	15.85	10.76	0.95
2.1~5.0	193	14.49	559.75	29.54	37.33	25.35	2.90
5.1~10.0	43	3.22	533.09	28.13	59.47	40.38	12.40
10.1~15.0	7	0.53	208.44	11.00	28.51	19.36	29.78
Total	1332	100.00	1895.00	100.00	147.26	100.00	1.42

characterized by very steep surfaces on the upper reach, so with the development of snow avalanches, icefalls and cracked ice mass with numerous and interlaced crevasses in the middle reach and the thick surface debris on glacier tongues.

The snowline altitudes (SLA) of glaciers in the Yangtze River vary from 4620 to 5880 m a.s.l. The highest SLA appears at the Mount Geladaindong while the lowest SLA is at the Yulong Xueshan. The obvious regional difference in SLA is mainly owing to the great difference

Table 6-10 Distribution of glaciers in different area classes in the Yangtze River (5K)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.50	662	49.70	177.41	9.36	3.94	2.68	0.27
0.51~1.00	291	21.85	203.45	10.74	7.34	4.98	0.70
1.01~2.00	186	13.96	260.23	13.73	12.38	8.41	1.40
2.01~5.00	128	9.61	394.11	20.80	25.29	17.17	3.08
5.01~10.00	34	2.55	232.01	12.24	19.52	13.26	6.82
10.01~15.00	12	0.90	145.35	7.67	14.76	10.02	12.11
15.01~20.00	8	0.60	135.11	7.13	15.27	10.37	16.89
20.01~30.00	4	0.30	96.55	5.10	12.30	8.35	24.14
30.01~40.00	6	0.45	197.86	10.44	27.78	18.87	32.98
40.01~50.00	—	—	—	—	—	—	—
50.01~60.00	1	0.08	52.92	2.79	8.68	5.89	52.92
Total	1332	100.00	1895.00	100.00	147.26	100.00	1.42

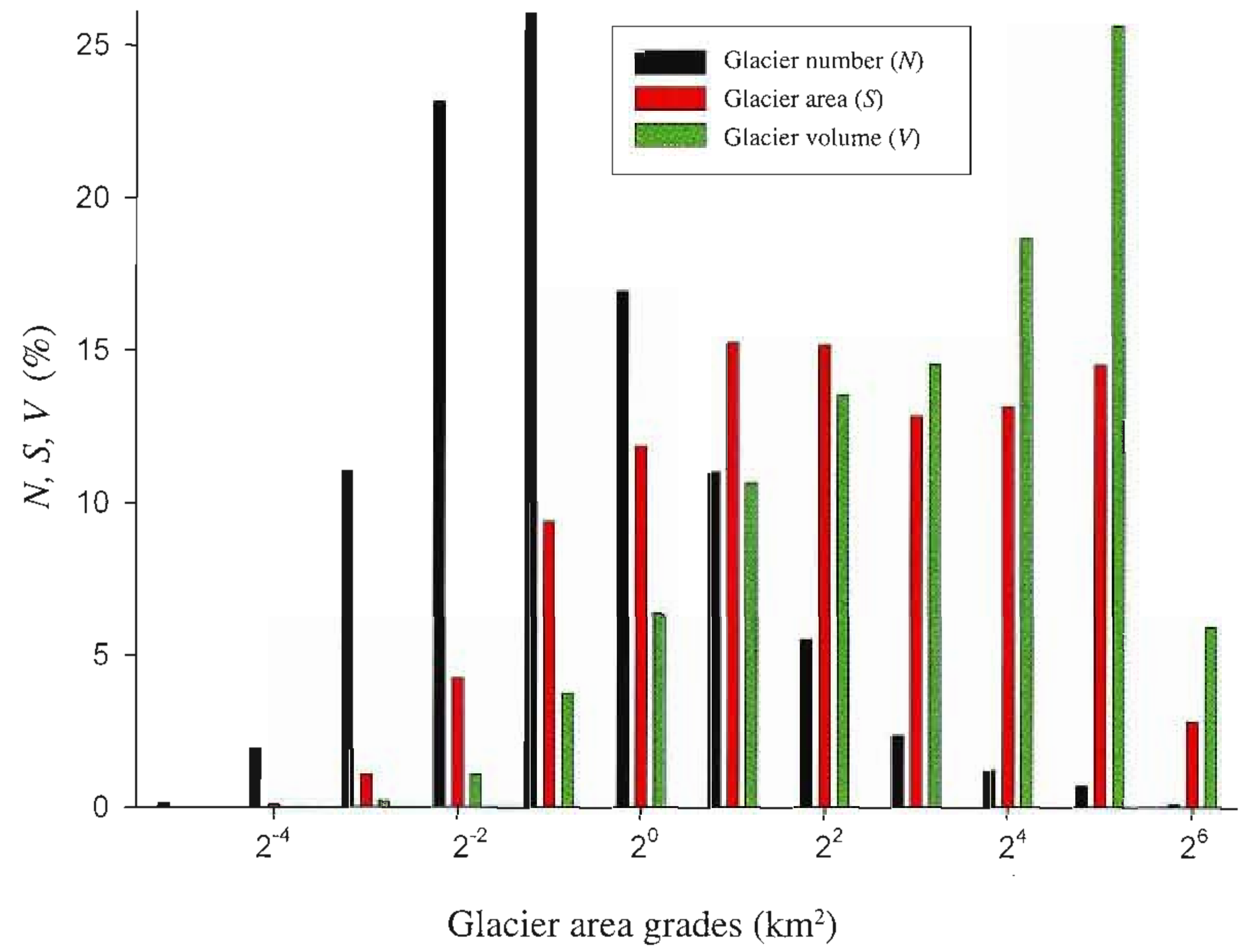


Figure 6-6 Distribution of glacier resources (*N*, *S*, *V*) versus area grades in the Yangtze River

in precipitation. Similar to SLA, median altitudes of glaciers also indicate the hydrothermal conditions of glacier development. The median altitudes of glaciers in the Yangtze River vary between 4320 and 6000 m a.s.l., higher than SLAs. The greater the altitudes difference between SLA and median altitude, the larger the glacier accumulation area, and the higher the corresponding glacier accumulation area ratio (AAR), indicating the glaciers are comparatively more stable. The AAR values for 457 glaciers in the Yangtze River demonstrate that the maximum AAR values occur on mountains in river source areas, and the minimum values appear in the Yulong Xueshan in the south, and the Qionglai Range and the Xuebaoding Range in the east.

Table 6-11 Large glaciers (>30 km²) in the Yangtze River (5K)

Glacier name	Code	Glacier area (km³)	Glacier length (km³)	Glacier Direction	Height of glacier (m)				Glacier volume (km³)	Glacier type
					Max.	Mid	SLA	Terminus		
Qiesumeiqu	5K451F8	52..92	9.9	NW	6621	5760	5680	5360	8.68	Dendritic valley
Gangjiaquba	5K444B64	37.44	10.8	E	6543	5840	5820	5300	5.47	Complex valley
Jianggudiru (S)	5K451F33	34.77	12.4	SW	6543	5860	5840	5395	4.97	Valley glacier
Jianggudiru (N)	5K451F30	31.40	10.1	W	6543	5820	5820	5400	4.33	Valley glacier
—	5K444B41	31.34	8.6	SE	6338	5800	5780	5380	4.32	Valley glacier
—	5K451F69	30.76	8.4	N	6012	5640	5660	5320	4.21	Valley glacier
Yanzigou	5K612F13	32.15	10.5	N	7556	5200	4840	3680	4.47	Valley glacier

The Xuebaoding Range with peak altitude of 5588 m a.s.l. is China's easternmost glaciated mountains where eight glaciers with a total area of 2.64 km^2 are scattered. Glaciers there are smaller in size and are mainly hanging glacier types, with median altitudes between 4800 and 5220 m a.s.l. The largest Xuebaoding Glacier No.7 has an area of 1.20 km^2 (Photo 6-3). There are three terminal moraines from the Little Ice Age roughly 150~700 m down to the modern glacier as shown in a 1982 map. This means the glacier retreated 150 m from the end of the Little Ice Age to 1982, meanwhile some small moraine-dammed lakes have been formed.

The Shanzidou, the main peak of the Yulong Xueshan, with an altitude of 5596 m a.s.l., is the southernmost region with modern glaciers in China (Figure 6-7). Along both sides of the ridges are 19 glaciers with a total area of 11.61 km^2 and mean glacier area of 0.61 km^2. The SLAs are between 4620 and 4900 m a.s.l.. The largest glacier, Baishuihe No.1 Glacier (2.7 km long with an area of 1.52 km^2) in the Yulong Xueshan, has been monitored recently. Snow avalanches frequently happen in its steep back wall and icefalls often occur in its steep front of the glacier (Photo 6-4). Observation at 4200 m a.s.l. on the glacier tongue showed that its daily ablation was 44.1 mm water equivalent from June 22 to July 11, 1982 when it was overcast (Su Zhen *et al.*, 1987), so the melting rate might be larger on fine days. The glacier's maximum thickness is 120~130 m near the altitude of 4700 m a.s.l. From this point, the glacier gradually thins while

Photo 6-3 Xuebaoding Glacier No.7 —— the easternmost glacier in China (Su Zhen)

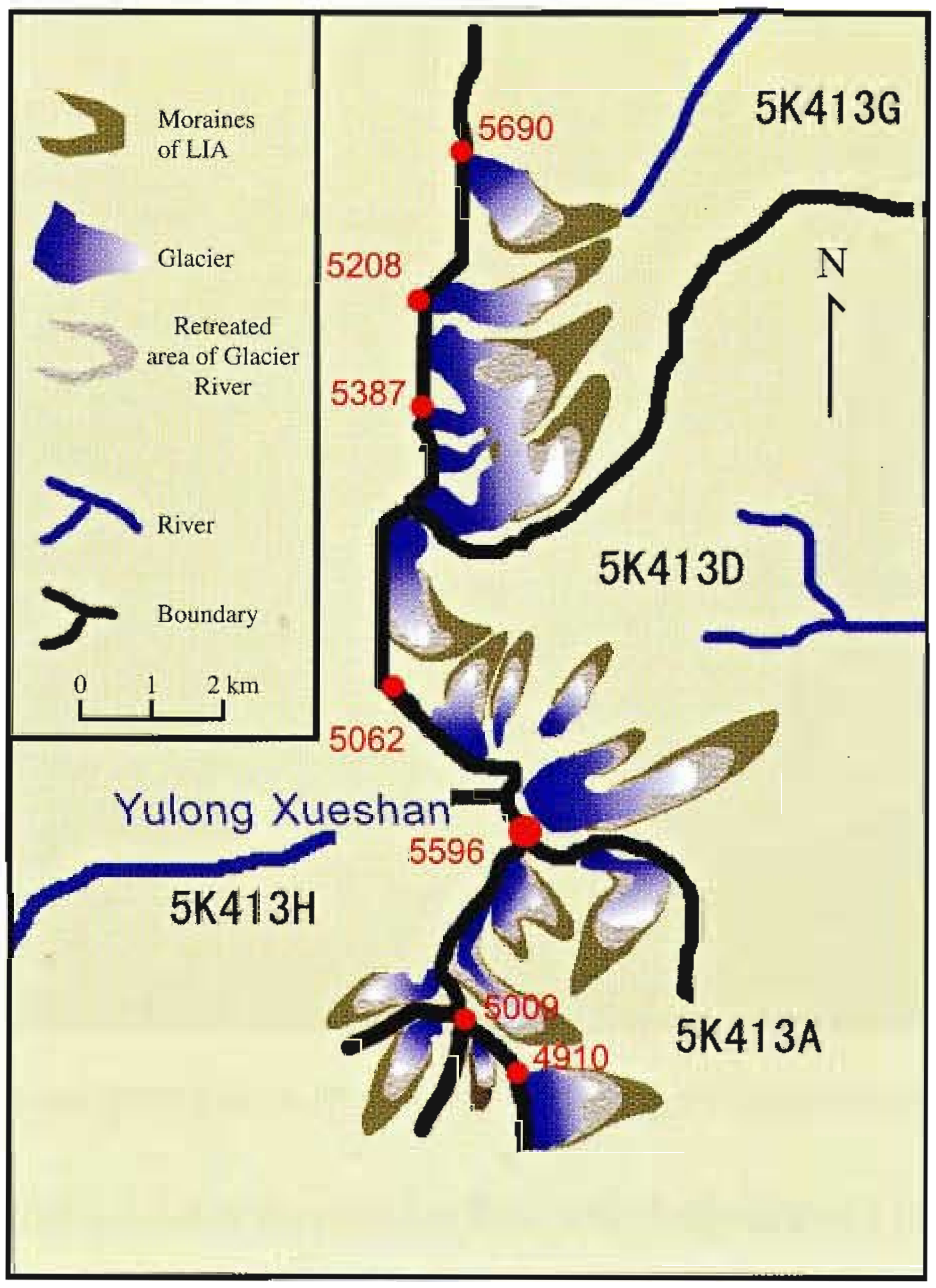


Figure 6-7 Modern glaciers and their changes since the Little Ice Age in the Yulong Xueshan, the China's southernmost glacierized region (Su Zhen and Shi Yafeng, 2002, edited by Pu Jianchen)

going upward or downward. Measurements in a borehole drilled through snow layers at the center of the firn basin indicate that the upper snow layers are in the melting point. However, in the ablation area the lowest ice temperature was measured as −0.8℃ at 4~5 m depth. Measurements on glacier strain deduce that the surface velocity within 4560~4650 m a.s.l. show the velocity reaches 1.06~1.07m·d^{-1}, making it a high-moving glacier. At the Little Ice Age Maximum (LIAM), the glacier terminus had extended down to 3800 m a.s.l., 300 m lower than the position in 1982. An aerial photographs taken in 1957 indicated that the terminus was at 4535 m a.s.l., while it was down to 4100 m a.s.l. in June 1982, showing that this glacier has advanced by 800 m during 1957~1982. Further observation on July 13, 1998 displayed that the terminus has receded by 100~150 m again during 1982~1998.

There are 92 modern glaciers with a total area of 267.27 km^2 in the Mount Gongga and its surrounding areas, the largest glaciation region in the western Sichuan (Figure 6-8). The Hailuogou, Mozigou, Yanzigou (Photo 6-5) and Nanmenguan Glaciers are the largest glaciers on the eastern slopes while the Da Gongba and Xiao Gongba Glaciers are the largest ones on the western

Photo 6-4 The terminus of the Baishuihe No.1 Glacier in the Yulong Xueshan (Su Zhen)

slopes. The Hailuogou and Da Gongba Glaciers have been investigated. The Hailuogou Glacier is 13.1 km long with an area of 25.71 km^2, and the terminus at 2980 m a.s.l. into the forest. The glacier has a steep back wall, so ice falls and avalanches occur all year round on the glacier. A huge icefall with an altitudinal span larger than 1000 m exists at the central section of the glacier. It may be the tallest icefall known in China (Pu Jianchen, 1995). Magnificent black-and-white act-structures are formed in the ablation area. It is deduced that channels in ice may be well developed as indicated by a huge ice tunnel at the snout, called as "city gate". The maximum annual ablation on the Hailuogou Glacier could be as high as 10 m water equivalent as observed during 1990~1994 and increased to 11 m water equivalent during 1994~1998 (Zhang Wenjing *et al.*, 2002). Based on water balance method, the mass balance of the glacier was negative during 1960~1993 (Xie Zichu *et al.*, 1998). The maximum annual ablation was 5.3 m (at 4386 m a.s.l.) on the Da Gongba Glacier on the western slope of the Mount Gongga (Photo 6-6), while it was 3.9 m (at 4550 m a.s.l.) on the Xiao Gongba Glacier. Radar echo sounding measurements on 4 glaciers in the Mount Gongga showed the maximum ice thickness was 263 m at 4380 m a.s.l. on the Da Gongba Glacier; 163 m at 4500 m a.s.l. on the Xiao Gongba Glacier; 218 m at 3530 m a.s.l. on the Hailuogou Glacier and 148 m at 4015 m a.s.l. on the Yanzigou Glacier, respectively. Borehole measurements displayed that ice temperature was as high as −0.48~0.85℃ at depth of

13~14 m between 4120 and 4540 m a.s.l. on the Da Gongba Glacier. It was also observed that the annual mean surface velocities varied within 164.81~184.57m · a^{-1} on the Hailuogou and Da Gongba Glaciers. Studies showed that the Hailuogou Glacier has been retreating by 1150 m during 1930~1966, 177.8 m during 1966~1981, 255 m during 1981~1995; 55 m during 1996-1998 (Su Zhen *et al.*, 2002; Zhang Wenjing *et al.*, 2002). The results clearly show the remarkable acceleration of glacier retreat since the end of the 1960s.

To the northeast of the Tanggula Pass, the Dongkemadi glacier and adjacent 30 glaciers, with a total area of 87.63 km^2, crowd around the highest peak of 6104 m a.s.l. in the Yangtze River source area. The largest glacier, Longxia Zailongba Glacier, is a valley glacier facing west (Photo 6-7), 7 km in length and 19.35 km^2 in area. Ice cores drilled at an altitude of 5900 m a.s.l. on the glacier in 2004 identified that the ice thickness at this site is larger than 200 m. The Dongkemadi Glacier (Photo 6-8) is a valley glacier facing south converged with two branches, the Da and Xiao Dongkemadi Glaciers. It is 5.3 km long with an area of 16.52 km^2, and the SLA and terminus altitude are 5600 m and 5280 m a.s.l., respectively. The annual precipitation is

Figure 6-8 Glacier distribution in the Mount Gongga

about 302 mm, and the annual mean temperature is −9.8℃ at the equilibrium line altitude on the Xiao Dongkemadi Glacier. The highest temperature is 3.5℃ with 21 days of mean daily air temperatures higher than 0℃. The climatic setting implies that the ablation is weak and the ablation period is short on glaciers in the Tanggula Range. The maximum ablation is 1095.8 mm water equivalent at 5490 m on the glacier tongue during 1990~1991 (Pu Jianchen and Yao Tandong, 2002). Ice core record indicates that the mass balance of the Dongkemadi Glacier was mainly positive, and the cumulated mass balance was 5214.4 mm (104.4 mm$\cdot$a^{-1}) during 1944~1993 (Pu Jianchen and Yao Tandong, 1996). However, the monitored mass balance in recent years indicated that it has become negative since the mid 1990s, which was mainly the consequence of obvious climate warming (Pu Jianchen, *et al.*, 2004). The ice temperature is about −2.5℃ in the surface layer of 1~3 m depth, varying between −7.5~−4.0℃ below 4 m depth (Pu Jianchen, 1995). The glaciers in the Tanggula Range have shrunk by about 13% of the area since the Little Ice Age maximum. During 1969~1986, the Chawuqu No.3 and No.4 Glaciers in the Dangqu River on the east Tanggula Range have retreated 168 m and 140 m, respectively, and the south and north branches of the Jianggudiru glaciers on the west Tanggula Range have also retreated 154 m and 125 m, respectively. Monitoring on the terminus change at the Dongkemadi Glacier

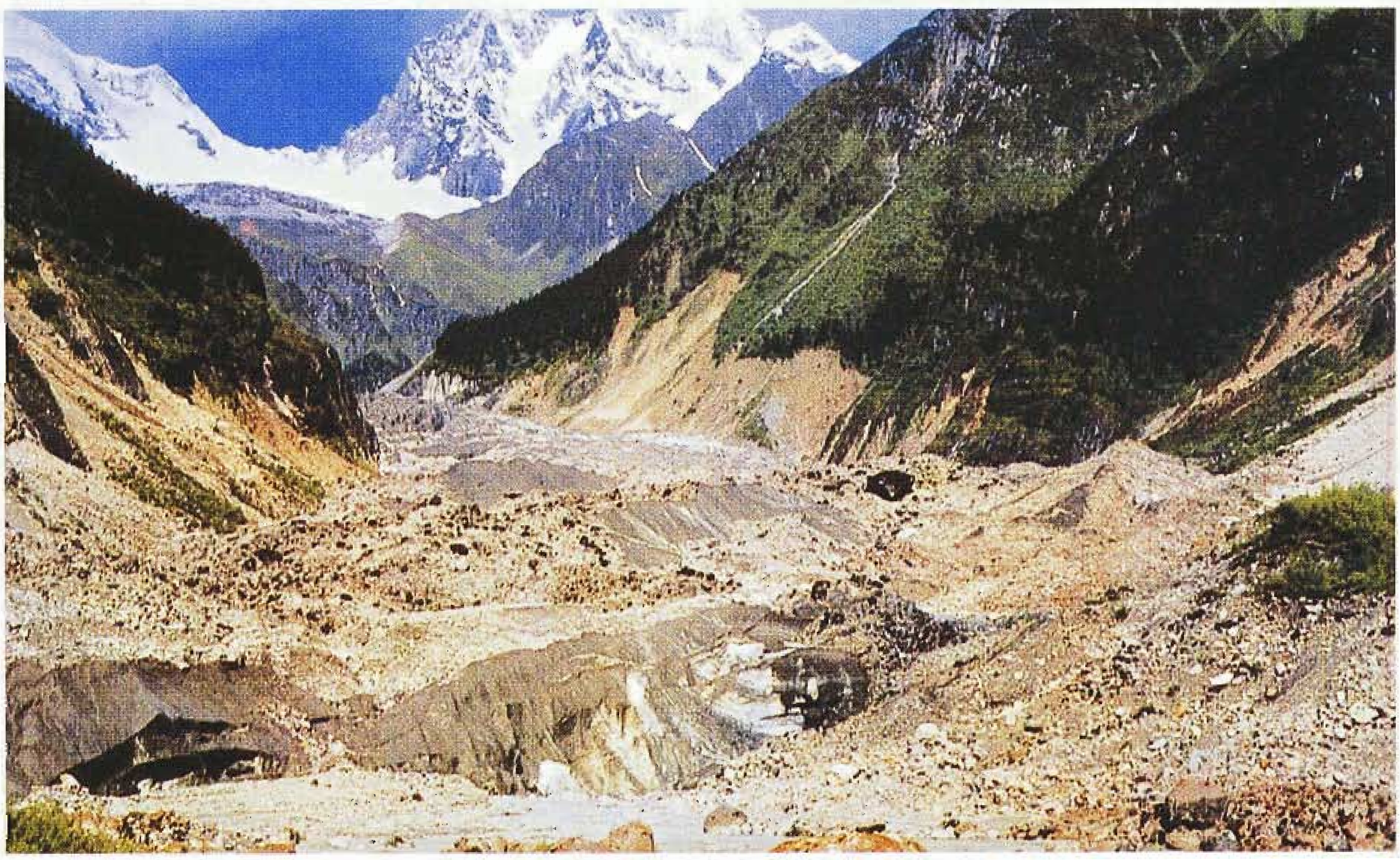


Photo 6-5 The Yangzigou Glacier in the Mount Gongga (Su Zhen)

Photo 6-6 The Da Gongba Glacier on the western slope of the Mount Gongga (Su Zhen)

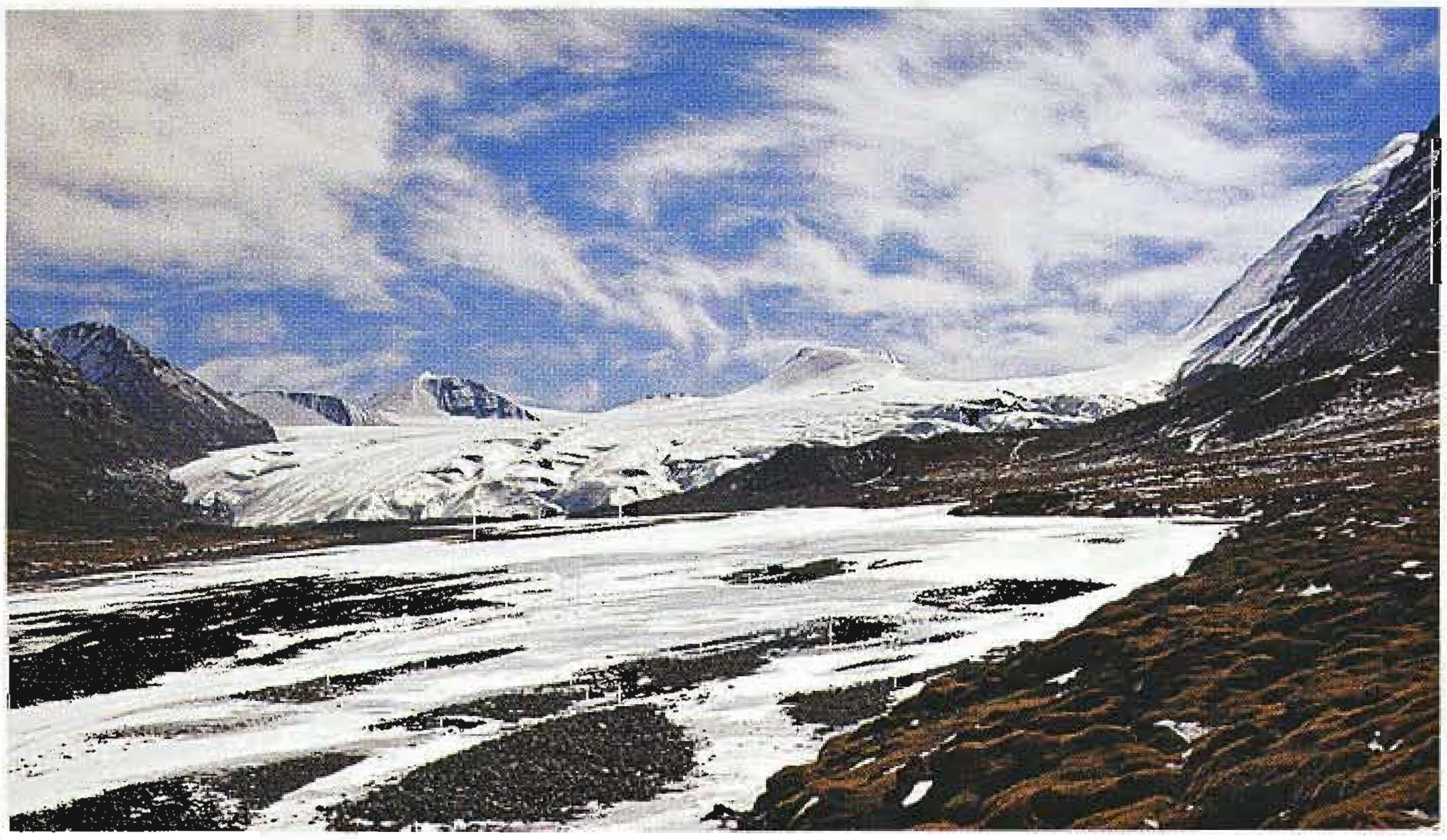


Photo 6-7 The Longxia Zailongba Glacier in the Tanggula Range (Pu Jianchen)

found that the glacier advanced 2.1~9.4 m during 1969~1989, and advanced another 14.14 m during 1989~1992, then became stable by 1994. After that, the glacier retreated $4.56m \cdot a^{-1}$ during 1994~2001 (Pu Jianchen *et al.*, 2004; Yao Tandong *et al.*, 2004).

The Mount Geladaindong is the highly glaciated area in the Yangtze River. There are 74 glaciers in the Yangtze River, mainly belonging to valley glaciers, with an area of 384.08 km^2 in the northern part of the mountain. The south and north branches of the Jianggudiru Glacier on the western slope of the mountain (Figure 6-9) consist of the headstream of the Yangtze River. Unique seracs develop on its tongue. The Gangjiaquba Glacier, the largest glacier on the eastern slope of

Photo 6-8 The Dongkemadi Glacier in the Tanggula Range (Pu Jianchen)

the mountain, is 37.44 km^2 with its terminus altitude at 5300 m a.s.l. Seracs can also be found at the end of its tongue. The southern part of the Mount Geladaindong contains 29 glaciers with 182.1 km^2 area that flow into the interior drainage area of the Qinghai-Tibetan Plateau.

In the Yangtze source region, less rainfall and glacier accumulation, high terrain and low air temperature result in weak glacier ablation, low level of mass balance, small change of glaciers and slow water cycles. Glaciers in the region are all located in flat and wide valleys which is better for glacier development. Physically, these glaciers all belong to extremely continental glaciers. However, glaciers in regions below the Tongtian River and its east are the maritime or temperate types of glaciers.

70.9% of glacier resources in the Yangtze River are concentrated in the river source area above the Tongtian River where ice volume is 1004.14×10^8 m^3 (887.52×10^8 m^3 water equivalent), five times as the annual runoff at the Zhimenda station on the Jinsha River (182×10^8 m^3). Glacier runoff has little effect on the runoff at the upper reach of the Yangtze River (Yang Zhenniang, 1991), but glacier runoff can amount to 25% of the river runoff in the source area above the Tongtian River. In the region below the Tongtian River, glacier meltwater takes a little proportion of stream flow. However, intensive glacier ablation combined with high precipitation always bring about debris flows, blockage and outburst of glacier lakes, as well as casualties of local people in the Hengduan Mountains.

In the glaciated Hengduan Mountains, such as the Mount Gongga, Chola and Yulong Xueshan, many glaciers extend down into the forests. The beautiful scenery and the moderate climate make it suitable for development as mountain glacier parks. For example, the Baishuihe No.1 Glacier on the Yulong Xueshan has already been developed as a glacier tourist site. A cable car up to 4746 m a.s.l. on the upper part of the glacier tongue has been used, and many tourists swim into this glacier park every year. The mysterious Hailuogou Glacier with its unique vertical distribution of vegetation cover has also become a top scene for tourists. Glaciers around the Mount Geladaindong in the Yangtze River source area are even more attractive. At present, only a few explorers visit this site, but it will probably become a popular scene for tourism and exploration following the operation of Qinghai-Xizang railway.

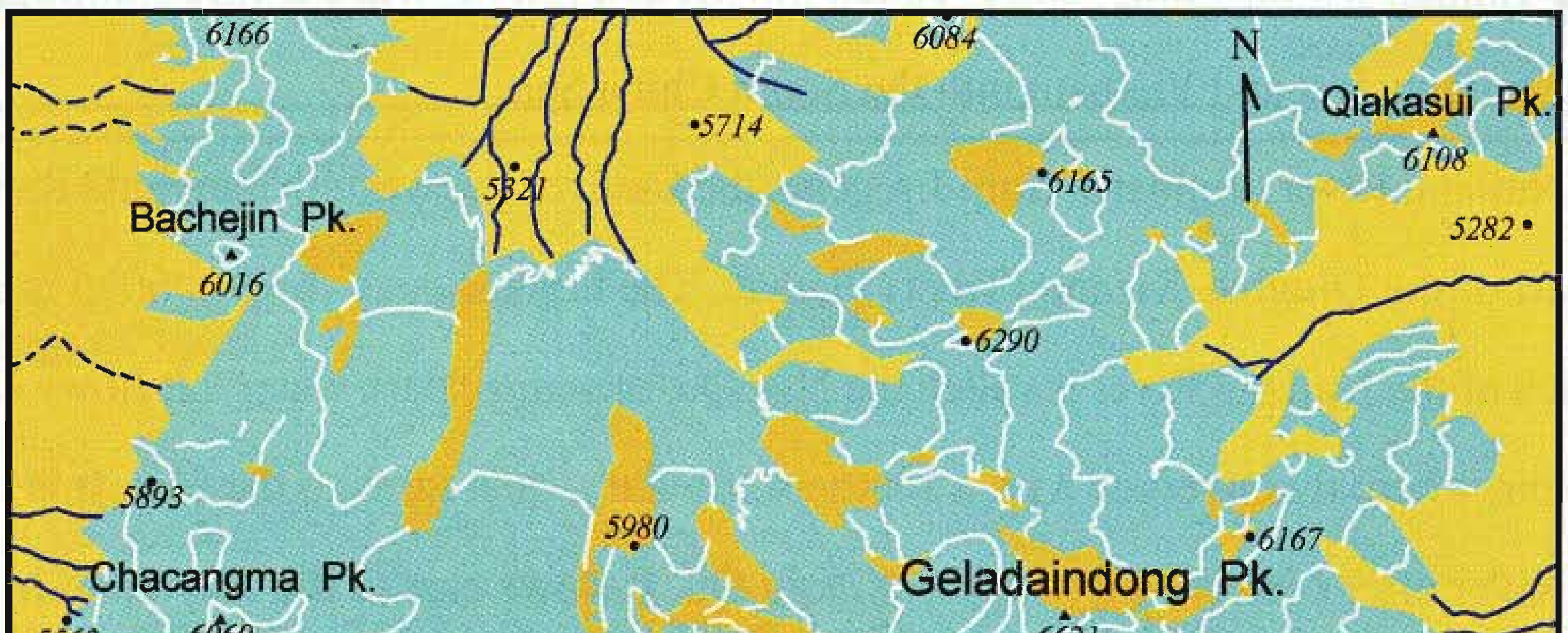


Figure 6-9 Glaciers at the source region of the Yangtze River

6.4 The Lancang River (5L) and the Nujiang River (5N)*

The Lancang River, the upper reach of the Mekong, and the Nujiang River, the upstream of the Salween River originate from the eastern and western Tanggula Range in the central part of the Qinghai-Xizang (Tibet) Plateau.

The Lancang River is 81.0 $\times 10^4$ km^2 drainage area with a total length of 4880 km, ranking the sixth among the world's great rivers. The Lancang River source lies in the Plateau surface with wide and shallow valley, where it is converged by two tributaries: the east one is the Za Qu, and the west one is the Ngom Qu. Starting from Qamdo, the river valley becomes gradually narrow and deep in the Hengduan Mountains. The river flows through three provinces, Qinghai, Tibet and Yunnan within China, and is called the Mekong River when it flows through Burma, Thailand, Kampuchea and Vietnam into the South China Sea.

The Nujiang River originates from Jiregepa, the south of the western Tanggula Range in the central part of the Qinghai-Xizang (Tibet) Plateau. The highest peak there is 6096 m a.s.l. The upper reach of the Nujiang River is called the Nag Qu, meaning "dark water". It flows southward to Monason, where it converges with a southern tributary, then turns to the east. It is called the Nujiang River after converging with the Xiaqiu Qu. It flows east to the Jiayuqiao in Luolong County, through the lake basins and the wide valleys on the Plateau. The river becomes narrower after Luolong, where it flows in parallel along with the Lancang River to the southeast. After merging with its longest tributary, the Yu Qu, it flows southward parallel together with the Lancang River into a deep gorge where its rapid, howling and roaring characteristics give it the Chinese name Nujiang meaning "Roaring River". The Nujiang River valley becomes wider and wider after passing Baoshan city in Yunnan Province, and it is called the Salween River after entering Burma. Across the borders of Burma and Thailand, it divides into north and south tributaries flowing into Andaman Sea of the Indian Ocean at the Gulf of Motama. The whole watershed area is 32.5 $\times 10^4$ km^2, with 38.4% within the territory of China. The total length of the mainstream is 3763 km, with 2013 km within the Chinese territory.

Also coded the same 5N as the Nujiang River, a relatively small river basin, the Daying River, in the west of the Nujiang, originates from the east of the Boshula Range in the southeast

* This subsection is prepared by Pu Jianchen.

Tibet. It is called the Ridong River within Tibetan region, and the Daying River after entering Yunnan Province, then called the Enmeikai River after merging with the Dibule tributary in Burma, and becomes the Irrawaddy River after converging with the Mailikai River, near Mizhina where it flows southward into the Andaman Sea of the Indian Ocean.

It is relatively highly glacierized in the upper and middle reaches of the Lancang River and the Nujiang River because of high elevations and cold climate on the plateau areas of the rivers (Figure 6-10). Based on the photogrammetrical maps published in the 1970s and 1980s, 380 glaciers were identified with a total area of 316.32 km^2 and ice volume of 17.88 km^3 in the Lancang River (Table 6-12) and 2021 glaciers with a total area of 1730.20 km^2 and ice volume of 114.97 km^3 in the Nujiang River (Table 6-13).

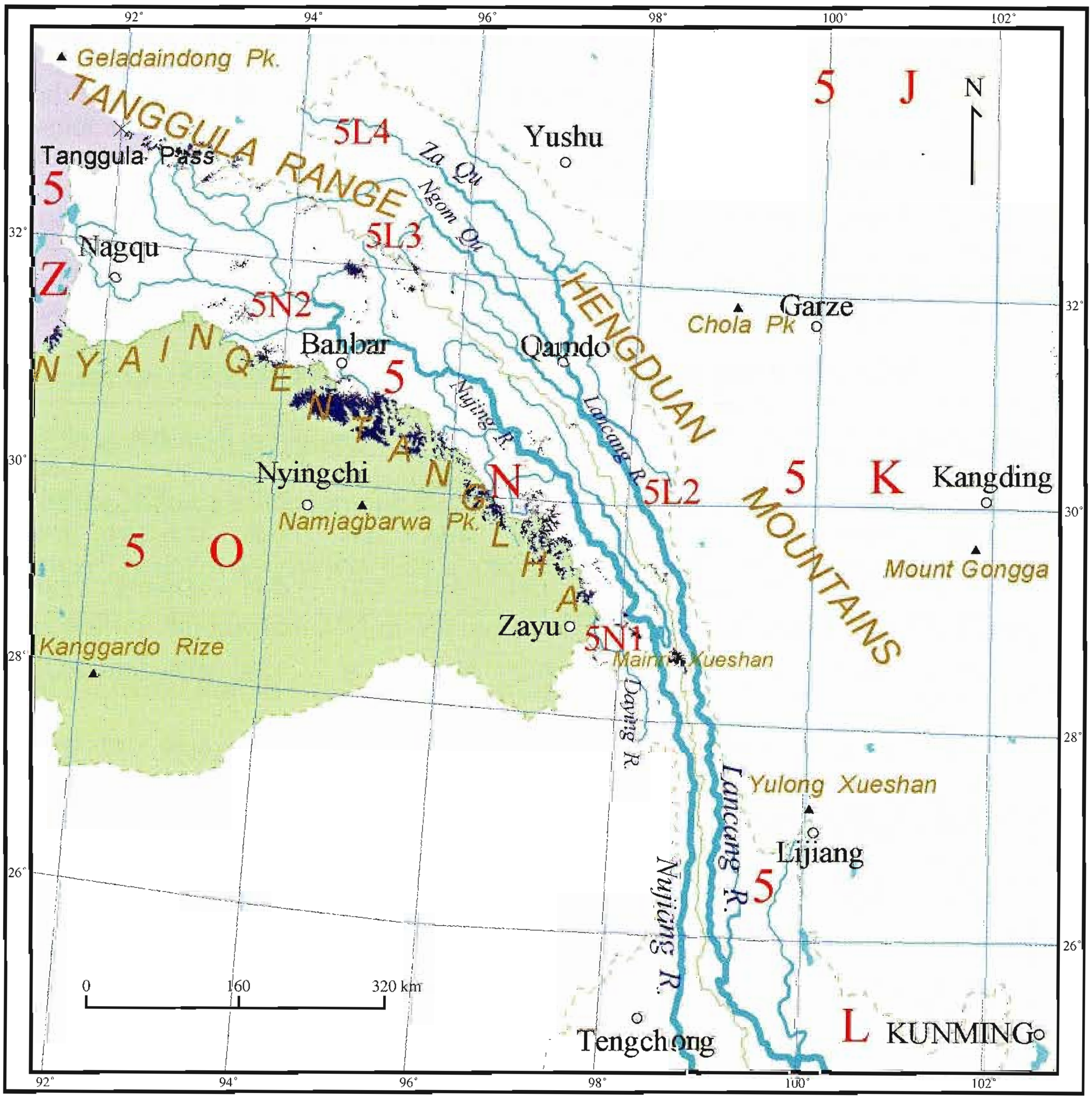


Figure 6-10 Glacier distribution in the Lancang River and the Nujiang River

Table 6-12 Glaciers in the tributaries of the Lancang River (5L)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km²)	(%)	(km³)	(%)	(km²)	(m)	Area (km²)	Length (km)
West bank of middle reaches	5L22	39	10.26	83.04	26.25	6.61	36.97	2.13	4600~5160	15.80	4.7
Se Qu	5L31	40	10.53	22.70	7.18	1.06	5.93	0.57	5240	5.47	3.6
Ngom Qu	5L32	123	32.37	69.17	21.87	2.88	16.11	0.56	5240~5360	6.13	4.2
Za Qu	5L41	164	43.16	133.53	42.21	7.00	39.15	0.81	5240~5460	8.80	4.8
Zi Qu	5L42	14	3.68	7.88	2.49	0.33	1.84	0.56	5200	2.92	1.8
Total	5L	380	100.00	316.32	100.00	17.88	100.00	0.83	4600~5460	15.80	4.7

Glaciers are relatively bigger (mean glacier area of 2.13 km^2) at the west bank of the middle reaches than that in other tributaries of the Lancang River, so that the mean glacier area in the whole basin is only 0.83 km^2. Glaciers are concentrated in two major source regions of the Ngom Qu and the Za Qu, the most highly glacierized tributaries, and no glaciers are found in the south of 32° N. In the Za Qu there are 164 glaciers, 43.2% of total glacier number in the Lancang River basin with an average glacier area of 0.81 km^2. In the Ngom Qu basin, there are 123 glaciers

Table 6-13 Glaciers in the tributaries of the Nujiang River 5N

Basin	River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
			Number	(%)	(km²)	(%)	(km³)	(%)	(km²)	(m)	Area (km²)	Length (km)
Irrawaddy	Enmeikai R.	5N123	54	2.67	24.84	1.44	0.95	0.83	0.46	4720~5100	2.48	3.4
	Sub-total	5N12	54	2.67	24.84	1.44	0.95	0.83	0.46	4720~5100	2.48	3.4
Salween	Right bank of middle and lower reaches	5N22	730	36.12	869.20	50.23	64.32	55.94	1.19	4720~5520	40.71	13.5
	Nag Qu	5N23	878	43.45	541.57	31.30	30.57	26.59	0.62	5160~5560	35.12	11.8
	Left bank of middle reaches	5N24	244	12.07	183.38	10.60	11.85	10.31	0.75	5200~5420	18.83	8.0
	Yu Qu	5N25	91	4.50	72.80	4.21	4.51	3.92	0.80	4580~5280	16.02	9.6
	Left bank of lower reaches	5N26	24	1.19	38.41	2.22	2.77	2.41	1.60	4700~5160	14.06	8.8
	Sub-total	5N2	1967	97.33	1705.36	98.56	114.02	99.17	0.87	4580~5560	40.71	13.5
	Total		2021	100.00	1730.20	100.00	114.97	100.00	0.86	4700~5560	40.71	13.5

(32.4%) with an average glacier area of 0.56 km^2. The largest glacier (Glacier 5L222B13) in the Lancang River is 15.80 km^2. Both the largest area and the mean area of glacier in the river are much smaller than those in the Yangtze River. The equilibrium line altitude varies between 4600~5460 m a.s.l., rising from the south to the north. So the lowest altitude of glacier terminus is as low as 2700 m a.s.l in the southern region, while the highest one can be found as 5480 m a.s.l. to the north of the river.

A series of mountain ranges, such as the Tanggula, the Taniantaweng, the Nushan, the Nyainqentanglha, the Boshula, the Gaoligong, the Yonglonglinan, and the Dandanglika lies along two banks of the Nujiang River where glaciers can be found. Because of the influence of the Indian monsoon, glaciers developed in the river basin are mainly the maritime type with a glacierization increase from the southwest to the northeast. The southern Boshula Range and the Nyainqentanglha Range are mostly glacierized, where glaciers account for over 60.0% of the total glacier area in the whole basin. The northern Tanggula Range is the second highly glacierized area in the basin, accounting for 24.6% and 22.6%, respectively, of the glacier numbers and total glacier area in the basin. Glacier sizes are the smallest with mean area of only 0.45 km^2 in the Irrawaddy River basin. The SLAs vary from 4700m a.s.l. to 5560 m a.s.l., rising from the midstream and downstream toward the source area.

The Mainri Xueshan with peak of 6740 m a.s.l. (Figure 6-11) is located between the Lancang River and the Nujiang River, forming the largest glacier center in the southern part of the Hengduan Mountains. There are 48 glaciers with a total area of 146.87 km^2 in the mountain, with three of the five glaciers larger than 10 km^2 on the eastern slope. The largest glacier, Gongsenlongba (5N253I10), 16.02 km^2 in area is on the northwest side of the mountain, with various thickness of debris cover on the ablation area due to avalanches. The Nainuogeru Glacier (also called the Mingyong, Photo 6-9), 12.55 km^2 in area and 11.5 km in length on the eastern slope extends to 2700 m a.s.l., the lowest terminus in the Henduan Mountains. Because of the steep backwall and frequent ice avalanches on the glacier, over 10 people of the Sino-Japanese joint mountaineering team died in an avalanche event at their camp site at 5300 m a.s.l. in the firn basin on January 3, 1991, and their bodies were found at the glacier ablation area at an altitude of 4000 m a.s.l. on July 18, 1998. This means the glacier surface velocity was 533 $m \cdot a^{-1}$ during 1991~1998. This is than those in the northern slope.

The Lancang and Nujiang River basins are characterized by dense river channel networks, narrow river valleys with high mountains, rich precipitation and high temperature, short and small tributaries with large altitude spans. These topography and climate factors make the glacier types (Table 6-14, Table 6-15) different from the neighboring Yangtze River and other basins. There are much more hanging glaciers and cirque-hanging glaciers, but much less valley glaciers and cirque-valley glaciers. Their valley glacier number and area are 10% and 22%~26%, respectively, less than those in the Yangtze River basin. Most of the valley and cirque-valley glaciers are located in mountains such as the northern slopes of the Nyainqentanglha Range, south of the Nujiang River, the northeastern slopes of the Boshula Range, and both sides of the Mainri Xueshan and the Bujia Kangri while other glacier types, such as mountain slope glaciers, flat-topped glaciers and canyon glaciers, are rather few and sparse.

81.1% are small glaciers less than 1.0 km^2 in area and 62.9% glaciers are shorter than 1.0 km

Photo 6-9 The Mingyong (or Nainuogeru) Glacier (Zheng Benxing)

Table 6-14 Distribution of glacier types in the Lancang River (5L)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging	180	47.37	38.34	12.12	0.72	4.03	0.21
Cirque-hanging	63	16.58	29.79	9.42	1.00	5.59	0.47
Cirque	88	23.16	91.59	28.95	4.49	25.11	1.04
Cirque-valley	28	7.37	80.52	25.45	5.76	32.22	2.88
Valley	17	4.47	71.93	22.75	5.74	32.10	4.23
Canyon	3	0.79	2.87	0.91	0.12	0.67	0.96
Mountain slope	1	0.26	1.28	0.40	0.05	0.28	1.28
Total	380	100.00	316.32	100.00	17.88	100.00	0.83

in length in the Lancang River, but they only account for 33.9% (for glaciers <1.0 km^2) and 20.7% (for glaciers <1.0 km), respectively, of the total area in the basin (Table 6-16, Table 6-17). However, large glaciers with areas greater than 10.0 km^2 and lengths longer than 5.0 km are few, accounting for 12.3% and 9.0%, respectively, of its total area indicating that the glacier size is much smaller in the Lancang River basin.

Similar to the Lancang River, small glaciers are dominant, of which 82.1% glaciers are less than 1.0 km^2 and 65.3% glaciers are shorter than 1.0 km in the Nujiang River (Table 6-18, Table 6-19), but large glaciers with areas larger than 10.0 km^2 and lengths longer than 5.0 km in Nujiang

Table 6-15 Distribution of glacier types in the Nujiang River (5N)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging	1018	50.37	203.69	11.77	3.93	3.42	0.20
Cirque-hanging	321	15.88	167.04	9.66	6.05	5.26	0.52
Cirque	492	24.34	562.15	32.49	28.21	24.54	1.14
Cirque-valley	97	4.80	172.23	9.95	9.56	8.31	1.78
Valley	66	3.27	593.75	34.32	65.12	56.64	9.00
Canyon	11	0.54	9.09	0.53	0.40	0.35	0.83
Mountain slope	9	0.45	5.22	0.30	0.15	0.13	0.58
Flat-topped	7	0.35	17.03	0.98	1.55	1.35	2.43
Total	2021	100.00	1730.20	100.00	114.97	100.00	0.86

River are more than those in the Lancang River basin, which account for 24.2% and 27.4% of the basin's total glacier area, respectively.

Glacier runoff accounts for only 6.6% and 8.8% of river runoff in the Lancang River and the Nujiang River, respectively. High mountains and deep valley topography limit the utilization of glacier runoff. However, the glacier runoff plays an important role in the agricultural irrigation and alpine animal husbandry in the dry and heated midstream and downstream of the two rivers.

In the Lancang and Nujiang River exist not only the unique Tibetan cultural customs and sights, but also graceful landscapes such as mountain gorges, glacier- and snow-covered mountains, sighting winds wafting through pine forests, deep blue lakes, surging rivers, cattle, sheep and meadows —— a quiet and elegant environment with pure and fresh air, which attract more and

Table 6-16 Distribution of glaciers in various length classes in the Lancang River (5L)

Length classes (km)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.5	68	17.89	9.51	3.01	0.14	0.78	0.14
0.6~1.0	171	45.00	56.06	17.72	1.47	8.22	0.33
1.1~2.0	95	25.00	82.96	26.23	3.54	19.80	0.87
2.1~5.0	43	11.32	139.48	44.09	10.03	56.10	3.24
5.1~10.0	2	0.53	15.76	4.98	1.42	7.94	7.88
10.1~15.0	1	0.26	12.55	3.97	1.28	7.16	12.55
Total	380	100.00	316.32	100.00	17.88	100.00	0.83

Table 6-17 Distribution of glaciers in various area classes in the Lancang River (5L)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.50	238	62.63	58.65	18.54	1.31	7.33	0.25
0.51~1.00	70	18.42	48.45	15.32	1.74	9.73	0.69
1.01~2.00	39	10.26	56.65	17.91	2.74	15.32	1.45
2.01~5.00	23	6.05	70.61	22.32	4.56	25.50	3.07
5.01~10.00	7	1.84	42.94	13.57	3.47	19.41	6.13
10.01~15.00	2	0.53	23.22	7.34	2.32	12.98	11.61
15.01~20.00	1	0.27	15.80	5.00	1.74	9.73	15.80
Total	380	100.00	316.32	100.00	17.88	100.00	0.83

Table 6-18 Distribution of glaciers in various length classes in the Nujiang River (5N)

Length classes (km)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.5	494	24.44	60.80	3.51	0.90	0.78	0.12
0.6~1.0	826	40.87	275.70	15.93	7.44	6.47	0.33
1.1~2.0	514	25.43	487.69	28.19	21.40	18.61	0.95
2.1~5.0	158	7.82	432.42	24.99	28.26	24.58	2.74
5.1~10.0	23	1.14	268.61	15.53	27.67	24.07	11.68
10.1~15.0	6	0.30	204.98	11.85	29.30	25.49	34.16
Total	2021	100.00	1730.20	100.00	114.97	100.00	0.86

Table 6-19 Distribution of glaciers in various area classes in the Nujiang River (5N)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
≤ 0.50	1297	64.18	290.63	16.80	6.30	5.48	0.22
0.51~1.00	362	17.91	257.92	14.91	9.40	8.18	0.71
1.01~2.00	211	10.44	295.11	17.06	14.08	12.25	1.40
2.01~5.00	109	5.39	321.00	18.55	20.54	17.86	2.94
5.01~10.00	21	1.04	146.70	8.48	12.47	10.85	6.99
10.01~15.00	10	0.49	122.28	7.07	12.52	10.89	12.23
15.01~20.00	4	0.20	69.56	4.02	7.94	6.91	17.39
20.01~30.00	2	0.10	44.67	2.58	5.52	4.80	22.34
30.01~40.00	4	0.20	141.62	8.18	20.09	17.47	35.41
40.01~50.00	1	0.05	40.71	2.35	6.11	5.31	40.71
Total	2021	100.00	1730.20	100.00	114.97	100.00	0.86

more people to spend holidays and carry out exploration. An eco-tour "Shangrila" scenic spot has been established by Yunnan Province and Tibet Autonomous Region. Moreover, the Mainri Xueshan hiding in the clouds and curling mist all year round is a sight full of mystery and illusion. Its mountain streams and large glaciers zigzag through the landscape, and a relatively convenient transportation is making it an ideal place for glacier tourism.

However, the river basins are basins with lot of disasters, like frequent snow avalanches, landslides and debris flows relating to glaciers, which threaten the agricultural production and local residents. The landslide and debris flow resulted from an huge outburst of the Yiong Lake in April, 2000 caused an immense calamity in the upper reach of the river due to the combined effect of intensive melt of ice and snow, ice and snow avalanches.

6.5 The Upper Reach of the Ganges Rivers (5O)*

The upper reach of the Ganges is located in the south and southeast parts of Tibetan Autonomous Region within the region between 27°40′N~31°30′N and 78°30′E~ 98°00′E. It can be divided into two sub-regions: 5O1 converged by many small tributaries flowing into the Ganges through the Himalayas and the Yarlung Zangbo (5O2) (or the upper reach of the Brahmaputra River) in the northern Himalayas.

The Bajilati and Nanda Rivers, the upper reaches of the Jiazhagangge and Daoli Rivers are the westernmost tributaries of the Ganges (5O1). Then the Mabjia Zangbo, Gyirong Zangbo, Mazang Zangbo, Rongxar Zangbo and Pumqu Rivers lie orderly eastward (Figure 6-13). All these rivers cut through the main Himalayas. The Pumqu is the biggest among these rivers and originates from the Dasuopu Glacier on the northern slope of the Mount Xixabangma. It circumambulates the Himalayas summits to the north, including the Mount Qomolangma (Everest) (Figure 6-14), then turns south to traverse the main mountain ridge near Chengtang and flows out of China. Its downstream inside Nepal is called the Arun River.

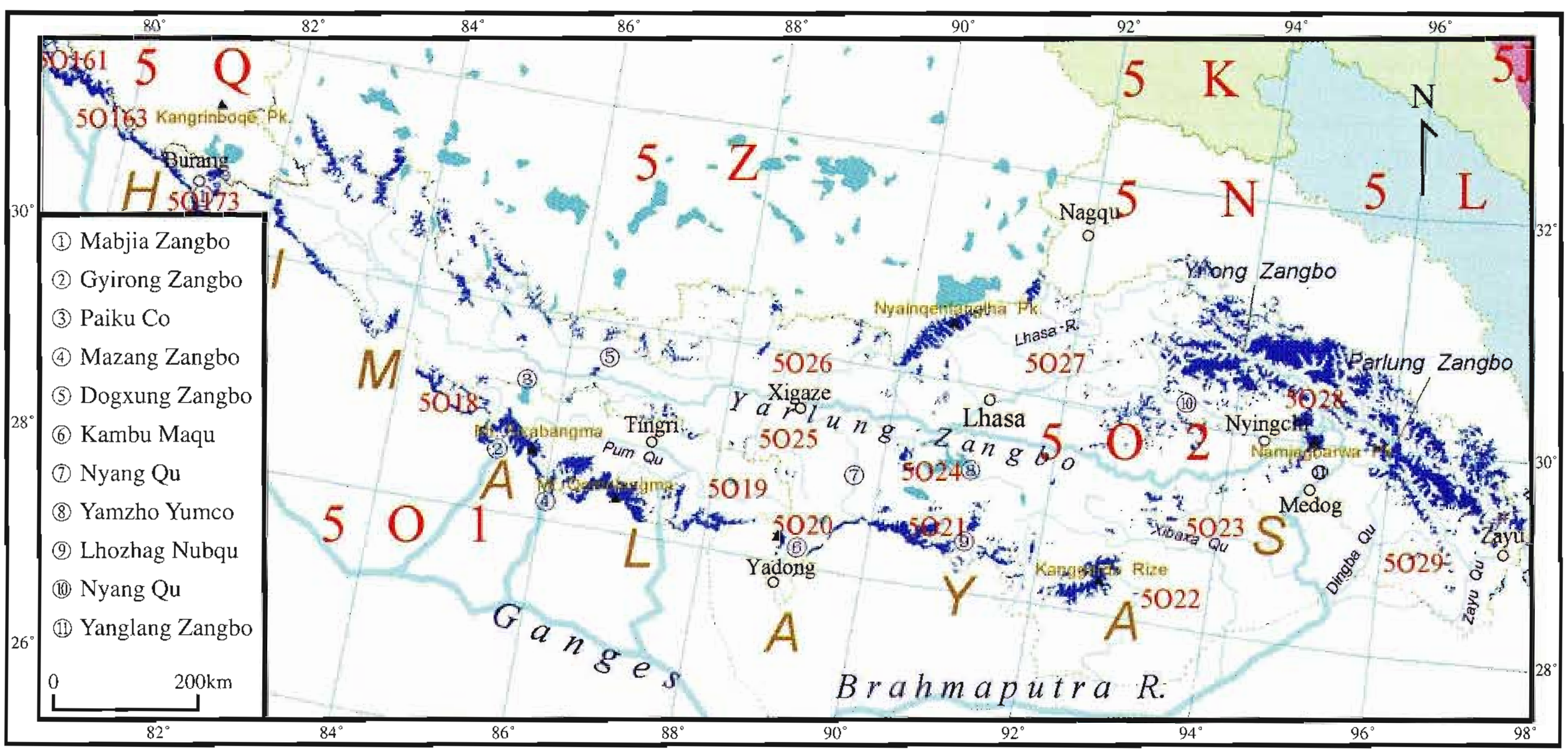


Figure 6-13 Glacier distribution in the Ganges-Yarlung Zangbo (5O)

* This subsection is prepared by Liu Chaohai.

Table 6-20 Glaciers in the tributaries of the Ganges (5O1)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Jiazhagangge	5O16	165	7.53	342.29	9.48	31.29	9.49	2.07	4980~5500	58.90	13.1
Mabjia Zangbo	5O17	184	8.39	318.02	8.81	23.63	7.16	1.73	5010~6080	18.23	12.4
Gyirong Zangbo	5O18	443	20.21	713.20	19.76	60.14	18.24	1.61	4690~6040	44.21	13.3
Pumqu and others	5O19	1400	63.87	2235.77	61.95	214.70	65.11	1.60	4611~6278	85.40	22.4
Total	5O1	2192	100.00	3609.28	100.00	329.76	100.00	1.65	4611~6278	85.40	22.4

In the Ganges coded as 5O1, there are 2192 glaciers with a total glacier area of 3609.28 km^2 and an ice volume of 329.76 km^3, which are 11.3%, 15.1% and 16.3%, respectively, of the corresponding totals of glaciers in the exterior rivers in China (Table 6-20). The mean area of glaciers is 1.65 km^2, the largest mean glacier among the external rivers. Of all the rivers in this region (5O1), the Pumqu is highly glacierized, occupying 65.1% of total ice volume in the river system (5O1). Interestingly, about 80% of the ice volume in the Pumqu is distributed mountainous slopes in the river right bank, including the northern slope of the Himalayas, such as those mountains of the Xixabangma, the Qowowuyag, the Qomolangma, the Luozi and the Makalu. This region is also characterized by center-like glacierization in the Himalayas due to the high precipitation of 2000~2500 mm at the altitude of 4900~5100 m a.s.l. during June and September

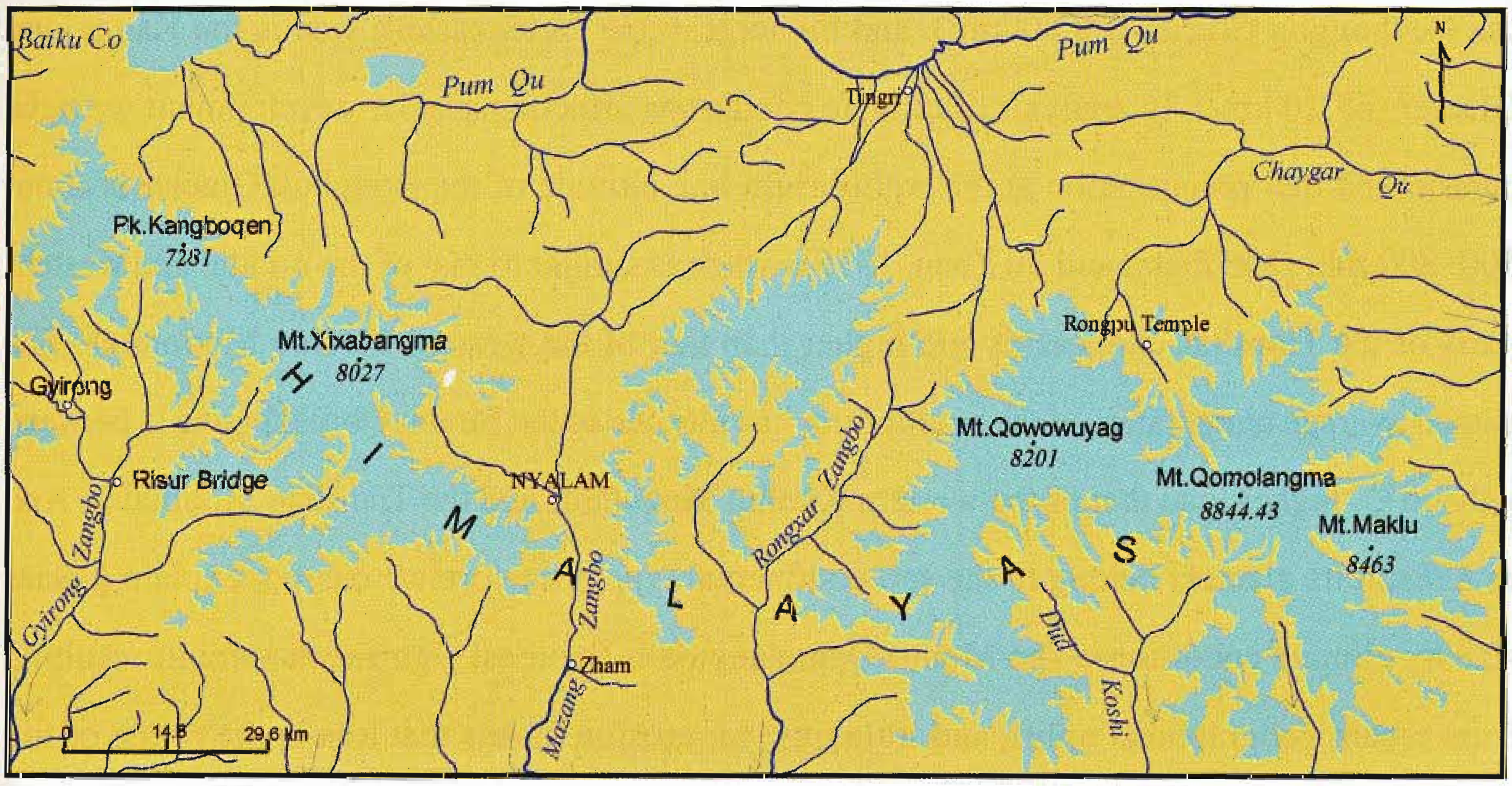


Figure 6-14 Glacier distribution in the Mounts Qomolangma and Xixabangma

on the southern side, as well as numerous high peaks over 7000 m a.s.l., like the Badelinasi, the Kameite and the Nandadewei. Glaciers in the Jiazhagangge and Daoli Rivers, the source of the Ganges, exhibit the largest mean length (2.73 km) and area (2.07 km^2) in China (Xie Zichu and Feng Qinghua, 2002).

It was found that the distribution of glacier area with area classes in the Ganges (5O1) is similar to that of most mountain glaciers (Table 6-21, Figure 6-15). The cumulated curves of glaciers (number, area and volume) show that the cumulated glacier number increases more slowly than that of area and volume of glaciers (Figure 6-16), meaning that the glacier area, especially glacier volume, but not the glacier number dominates the glacier source. These can be represented by median area $S_{\mathrm{med}(N)}$, $S_{\mathrm{med}(S)}$, $S_{\mathrm{med}(V)}$, which is the glacier area at 50% of cumulated curve for glacier number, area and volume. They are different in various tributaries of the Ganges (5O1), reflecting the different distributions of glacier sizes. For example, the ratio of $S_{\mathrm{med}(V)}$ / $S_{\mathrm{med}(N)}$ is as high as 120 for the Ganma Zangbo (5O193) in the Pumqu, indicating a wide difference of the size of its glaciers. Glaciers of the Ganges (5O1) are generally larger (an average area of 1.65 km^2), but no glaciers larger than 100 km^2 even though there are world's highest peaks in the region. None of the 33 largest glaciers larger than 100km^2 in West China exists in the area of the Mount Qomolangma. The largest glacier on the Mount Qomolangma's northern side is the Rongbuk Glacier (85.40 km^2) (Figure 6-17, Photo 6-10), the largest one on its southern side is the Gechongba Glacier (80.80 km^2), and the largest one on its eastern side is the Kangxiong Glacier (67.20 km^2). In analysis of climate conditions affecting glacier development we have determined that precipitation at the equilibrium line altitude of the Rongbuk Glacier is about 500~800 mm (Xie Zichu and Su Zhen, 1975), which is similar to that of the middle and western parts of the Tianshan Mountains and higher than that of the western Kunlun Mountains. The annual average temperature at the equilibrium line altitude of the Mount Qomolangma is between −9~−6℃, higher than that of the western Kunlun Mountains and the Tianshan Mountains. And as a result its glaciers belong to the sub-continental type, therefore we can not explain glacier size by climate conditions. The Mount Qomolangma is the most significant summit resulting from recent geographical uplift, and little time for erosion means that it is in the prime of life with gaunt, high and precipitous ridges (Zhang Xiangsong, 1975). The Mount Qomolangma is not like the high, broad, ancient, and smooth surfaces of the Tianshan and western Kunlun Mountains, nor is it like the high and deep vertical valleys of the Karakorum Mountains, all of which continuously develop firn basins whose many glaciers join together and flow downwards to become large glaciers with areas greater than 100 km^2.

Most types of glaciers can be found, like hanging glaciers, ice-cap glaciers, valley glaciers,

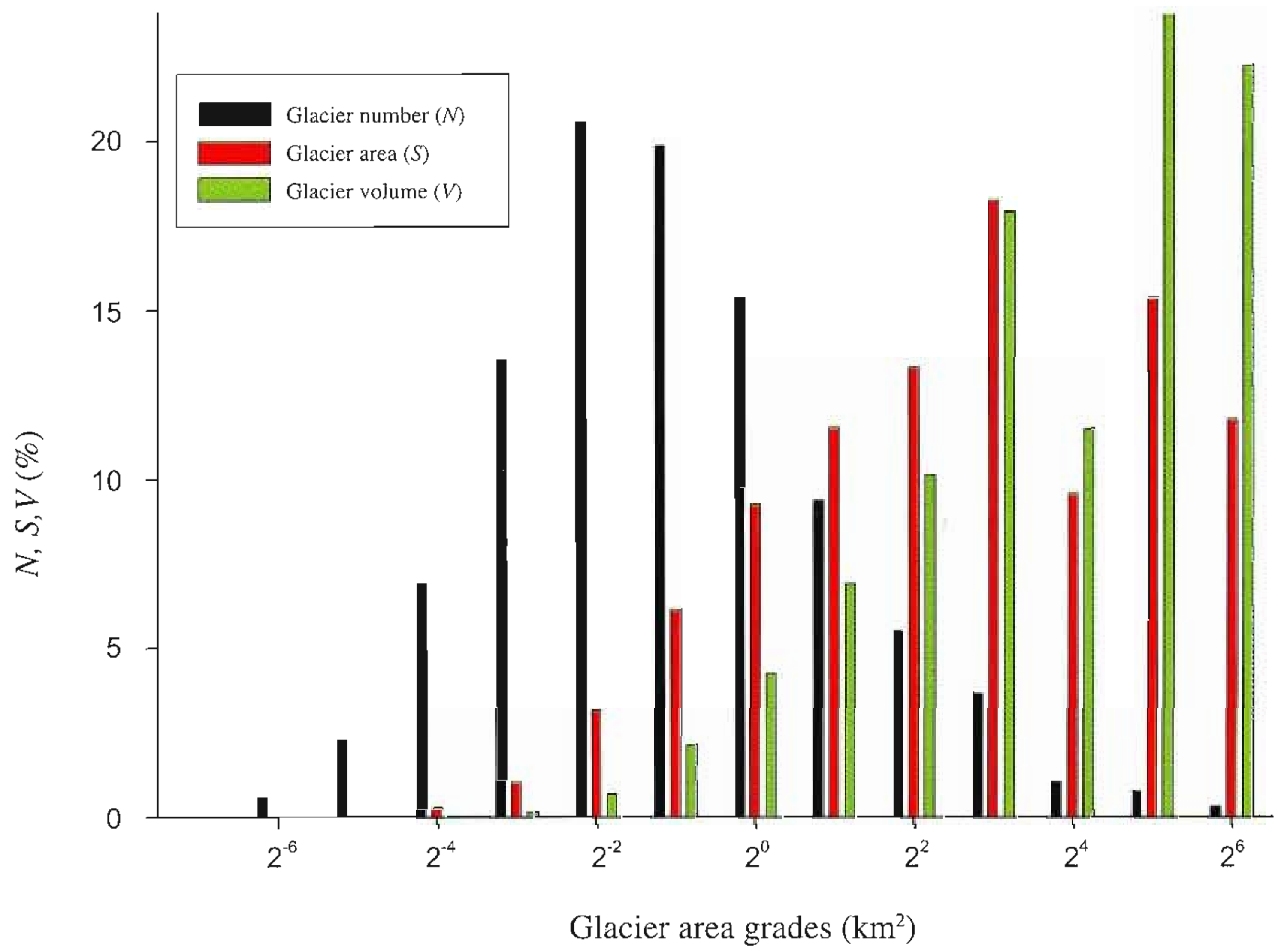


Figure 6-15 Distribution of glacier resources (*N, S, V*) versus area grades in the Ganges (5O1)

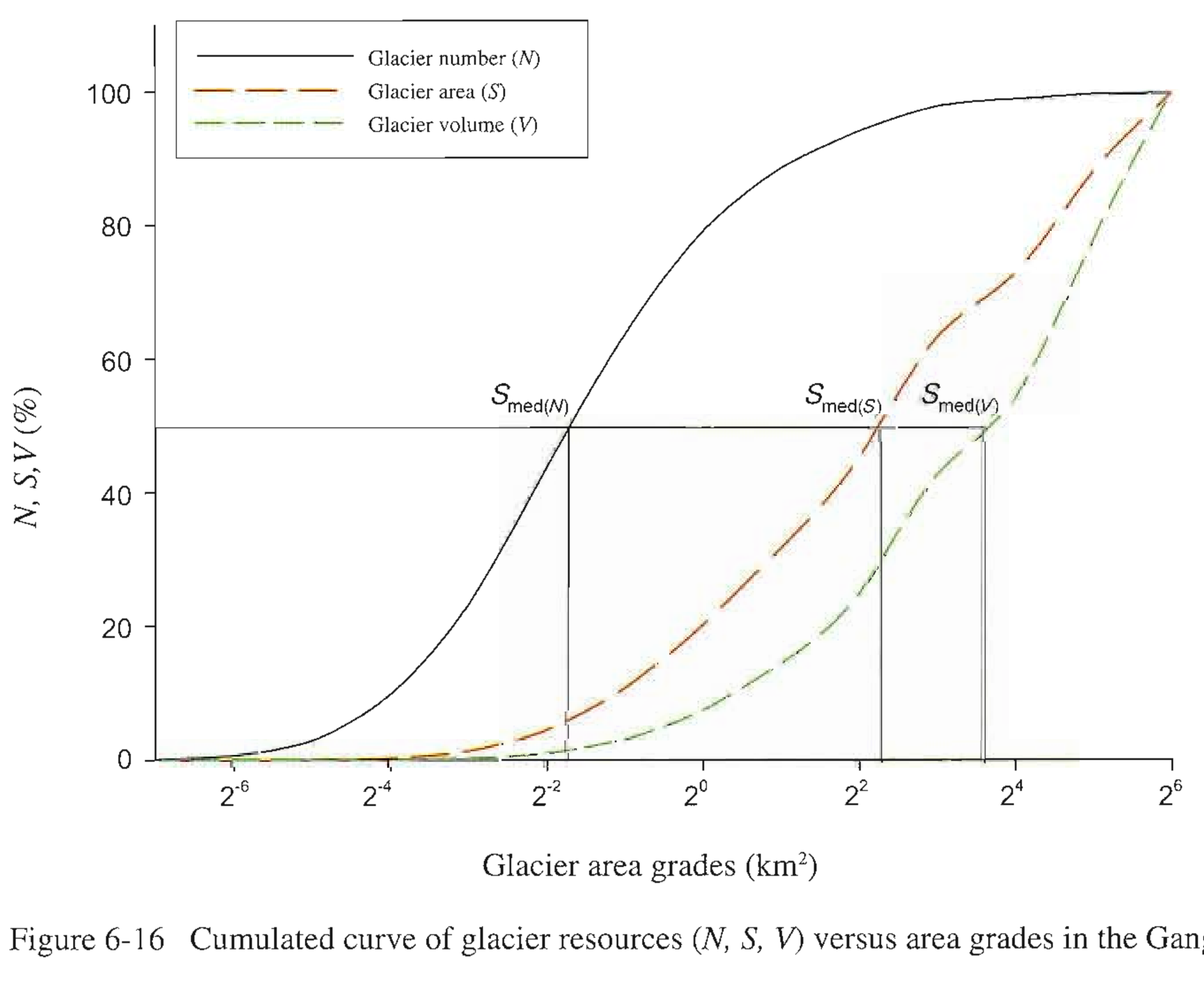


Figure 6-16 Cumulated curve of glacier resources (*N, S, V*) versus area grades in the Ganges (5O1)

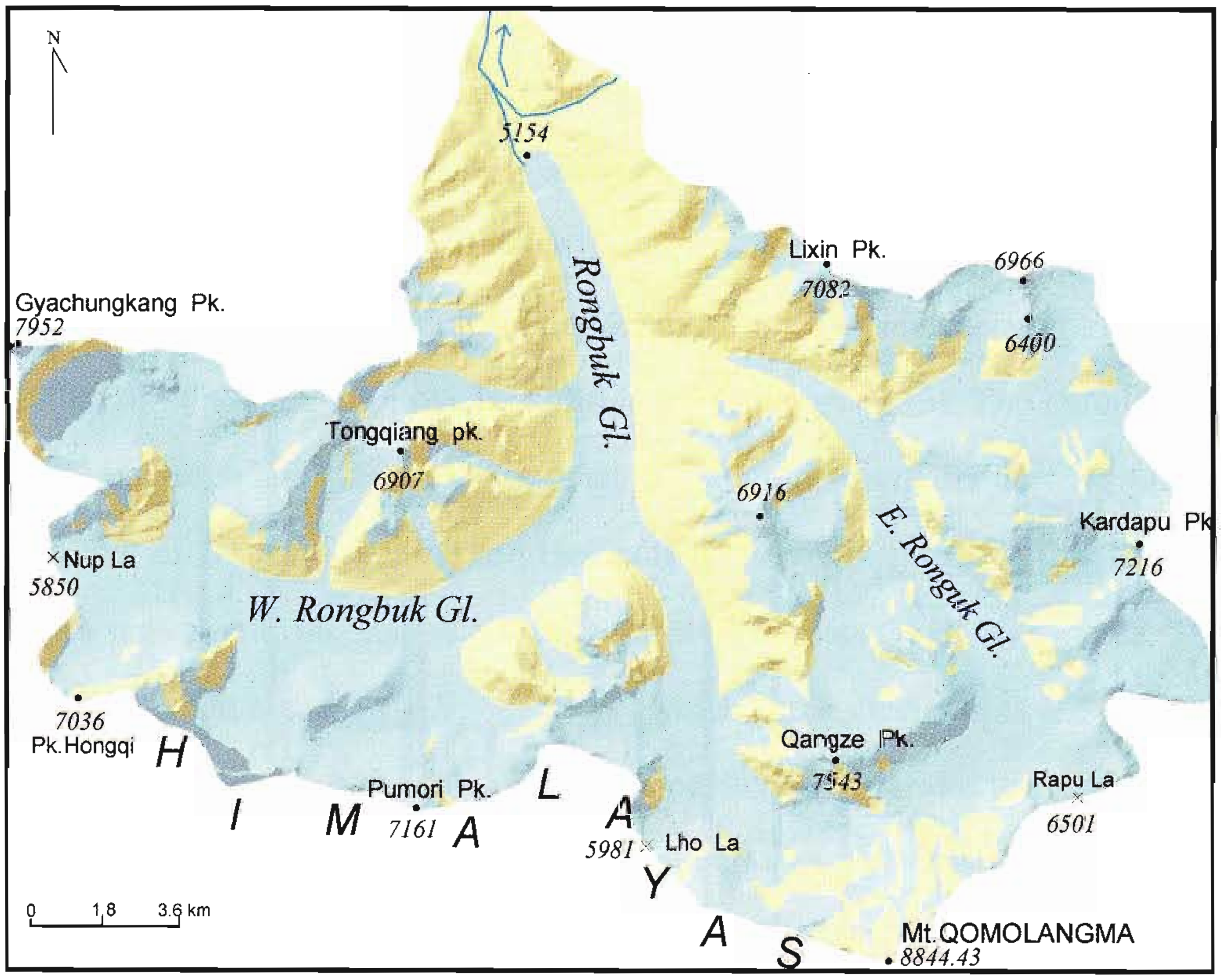


Figure 6-17 The Rongbuk Glacier, the largest glacier in the Mount Qomolangma

flat-topped glaciers and transitional types in the Ganges (5O1) (Table 6-22). The primary type of hanging and cirque-hanging glaciers comprises approximately 63.2% of all glacier number in the whole basin. Their area and ice volume, however, are only 14.9% and 6.0% of the corresponding totals. On the other hand, large glaciers (valley glaciers and cirque-valley glaciers), only 20.1%

Table 6-21 Distribution of glaciers in various area classes in the Ganges (5O1)

Area classes	Glacier number		Glacier area		Glacier volume		Mean area per glacier
(km^2)	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
⩽ 0.50	1200	54.74	265.13	7.35	5.82	1.77	0.22
0.51~1.00	397	18.11	288.73	8.00	10.72	3.25	0.73
1.01~5.00	451	20.58	982.97	27.23	57.57	17.46	2.18
5.01~10.00	81	3.70	576.49	15.97	49.43	14.99	7.12
10.01~30.00	47	2.14	729.76	20.22	82.53	25.02	15.53
30.01~50.00	11	0.50	434.99	12.05	65.15	19.76	39.54
50.01~80.00	4	0.18	245.81	6.81	42.25	12.81	61.45
80.01~90.00	1	0.05	85.40	2.37	16.29	4.94	85.40
Total	2192	100.00	3609.28	100.00	329.76	100.00	1.65

Table 6-22 Glacier type in the Ganges (5O1)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier
	Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)
Hanging	1202	54.84	342.33	9.49	10.27	3.12	0.28
Cirque-hanging	184	8.40	193.86	5.37	9.32	2.83	1.05
Cirque	360	16.42	529.99	14.68	29.12	8.83	1.47
Cirque-valley	251	11.45	567.12	15.71	42.58	12.91	2.25
Valley	189	8.62	1968.00	54.53	238.10	72.20	10.41
Flat-topped	6	0.27	7.98	0.22	0.37	0.11	1.33
Total	2192	100.00	3609.28	100.00	329.76	100.00	1.65

of the total number, occupy 70.2% and 85.1% of the total area and volume, respectively in the basin.

The Yarlung Zangbo (5O2), 2057 km in length and 240,480 km^2 in area, originates from the Jiemayangzong Glacier on the northern side of the Himalayas, flows southeast, turns to

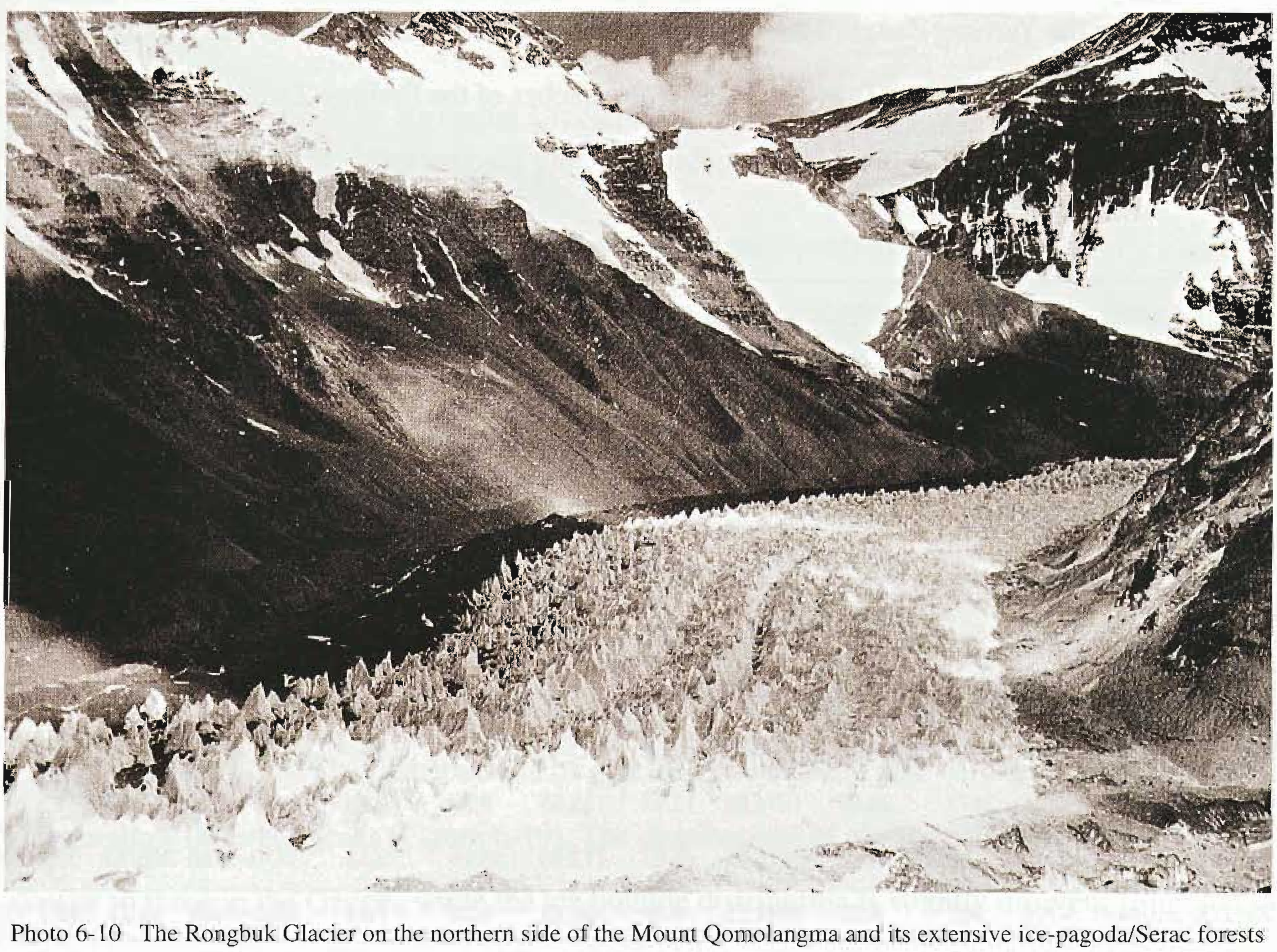


Photo 6-10 The Rongbuk Glacier on the northern side of the Mount Qomolangma and its extensive ice-pagoda/Serac forests (Wang Zongtai)

south and forms the famous "U-shape" turn and the biggest canyon in the world, then enters into India and joins the Ganges near Geerlongduo, Bangladesh, where it is called the Brahmaputra River inside India. All tributaries on its right originate from the northern slope of the Himalayas, while the tributaries on its left originate from the southern slope of the Gangdise Range, the Nyainqentanglha Range and the Gangrigabu Range from west to east. Within the watershed of the Ganges and the Yarlung Zangbo, there are some interior basins, such as the Paiku Co, the Yamzho Yumco and others. Since these interior basins were once exterior rivers in the late Quaternary, they are also included into the Ganges- Yarlung Zangbo River System.

In the Yarlung Zangbo, there are 10,816 glaciers with a total area of 14,492.86 km^2 and ice volume of 1293.07 km^3, which are about 55.9%, 60.5% and 63.9%, respectively, of the corresponding total number, area and volume in the exterior drainage basins, and 23.3%, 24.4% and 23.1%, respectively, of corresponding totals in China (Table 6-23). The Yarlung Zangbo is the second with intensive glacierization to the Tarim River over China and the first in the exterior rivers. Within the Yarlung Zangbo, greater part of glaciers are concentrated in two tributaries, the Yiong Zangbo and the Boduo Zangbo, in the upper reaches of the Parlung Zangbo, which account for 55.1% of the ice volume in the Yarlung Zangbo. Four glaciers larger than 100 km^2 are located

Table 6-23 Glaciers in the tributaries of the Yarlung Zangbo (5O2)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Kambu Maqu	5O20	25	0.23	47.30	0.33	4.00	0.31	1.89	5330~5630	18.92	7.5
Lhozhag Nubqu	5O21	853	7.89	1083.26	7.47	84.56	6.54	1.27	4850~6323	62.88	20.1
Xibaxa Qu	5O22	649	6.00	768.70	5.30	57.69	4.46	1.18	5040~5950	52.30	17.9
Yanglang Zangbo	5O23	418	3.86	531.23	3.67	45.04	3.48	1.27	3390~5610	55.38	16.4
Yamzho Yumco	5O24	144	1.33	229.85	1.59	26.02	2.01	1.60	5480~6300	86.16	19.5
Nyang Qu and others	5O25	932	8.62	1154.98	7.97	97.58	7.55	1.24	5170~6460	43.40	8.5
Dogxung Zangbo	5O26	1615	14.93	788.84	5.44	35.08	2.71	0.49	5510~6070	10.30	5.2
Lhasa R. and others	5O27	2173	20.09	1876.02	12.94	123.85	9.58	0.86	4420~6040	49.35	12.5
Yiong Zangbo	5O28	3102	28.68	6613.43	45.63	712.40	55.10	2.13	3370~5980	206.70	35.3
Zayu Qu and others	5O29	905	8.37	1399.25	9.66	106.85	8.26	1.55	3800~5480	54.27	15.1
Total	5O2	10,816	100.00	14,492.86	100.00	1293.07	100.00	1.34	3370~6460	206.70	35.3

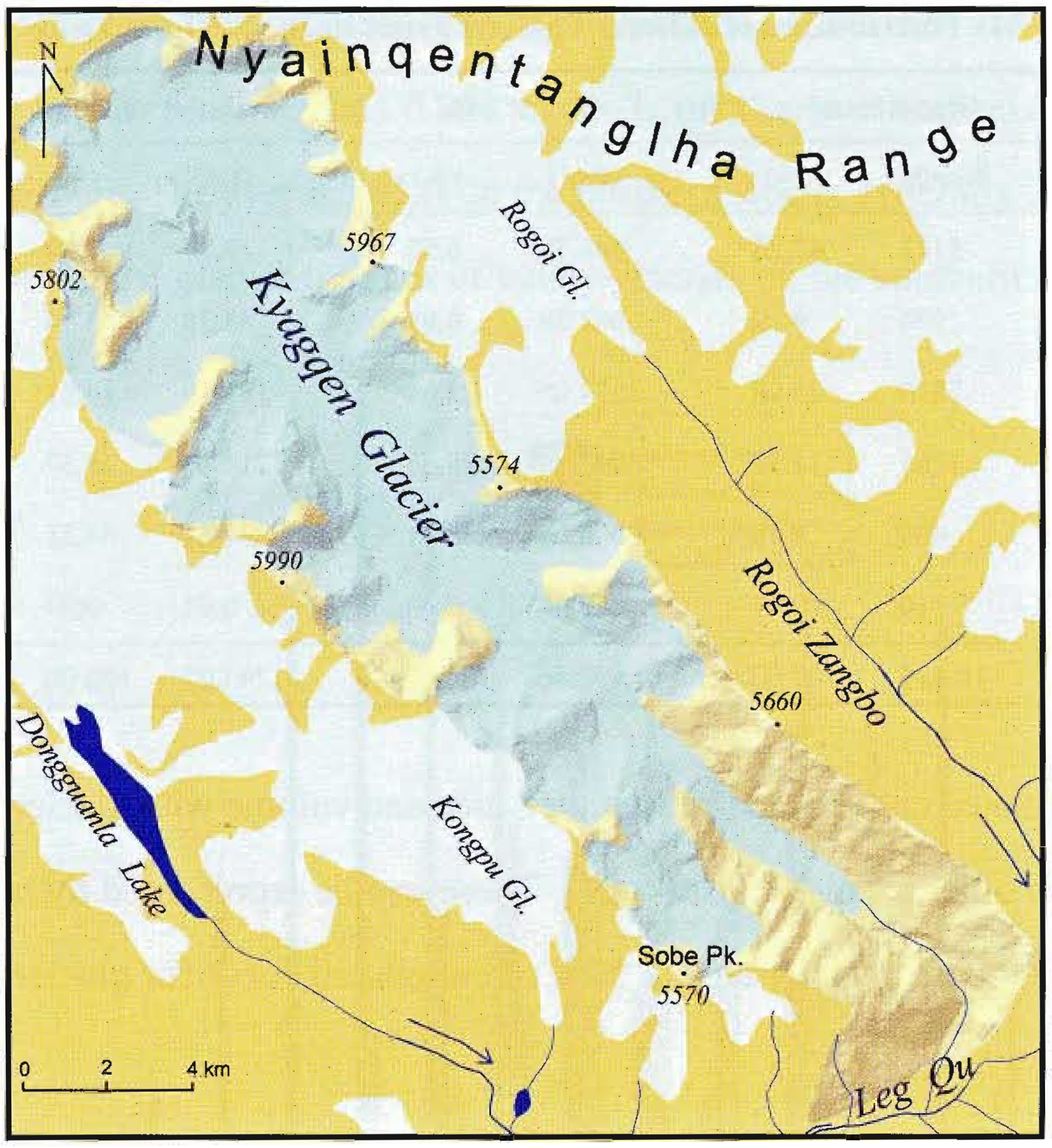


Figure 6-18 The Kyagqen Glacier, the largest valley glacier in Tibet

in the Parlung Zangbo. The Kyagqen Glacier is the largest valley glacier, 35.3 km in length, 206.70 km^2 in area in Tibet (Figure 6-18).

Hanging and cirque-hanging glaciers hold the most proportion in the Yarlung Zangbo, accounting for 56.5% of total glacier number in the whole basin. However, their glacier area and ice volume are only 13.3% and 5.1% of the corresponding totals, respectively. Although the number of valley glaciers (including valley glaciers and cirque-valley glaciers) is only 17.5% of all glaciers in this basin, their glacier area and ice volume are 64.2% and 80.9% of the corresponding totals, respectively (Table 6-24), smaller than those of the Ganges (5O1).

The glaciers smaller than 1 km^2 account for 75.7% of total glacier number in the Yarlung Zangbo (Table 6-25). The distributions of glacier number, area and volume with glacier area classes show different peaks (Figure 6-19). The distributions of glacier number and area are very similar to those in the Ganges while the ice volume distribution is slightly different from that in the Ganges. As shown earlier, most of the glacier volume are contributed by larger glaciers in the

Table 6-24 Distribution of different glacier types in the Yarlung Zangbo (5O2)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging	5112	47.26	944.79	6.52	19.85	1.54	0.18
Cirque-hanging	994	9.19	962.78	6.65	45.78	3.54	0.97
Cirque	2810	25.98	3277.05	22.61	181.19	14.01	1.17
Cirque-valley	1265	11.70	2993.12	20.65	214.23	16.57	2.37
Valley	625	5.78	6306.06	43.51	831.61	64.31	10.09
Flat-topped	10	0.09	9.06	0.06	0.41	0.03	0.91
Total	10,816	100.00	14,492.86	100.00	1293.07	100.00	1.34

Ganges. The cumulated curve of glacier number, area and volume with glacier area classes show similar patterns to other basins (Figure 6-20). These can be represented by median area $S_{med(N)}$, $S_{med(S)}$, $S_{med(V)}$, which is the glacier area at 50% of cumulated curve for glacier number, area and volume, respectively.

The ratio of median area for glacier volume $S_{med(V)}$ to median area for glacier number $S_{med(N)}$ is different among rivers. For example, $S_{med(V)} / S_{med(N)}$ for the Yiong Zangbo (5O281) is as high as 112, reflecting the great variation in glacier areas there, while the ratio for the Caiqu River (5O253) is only 2.5, indicating a nearly equal distribution of large and small glaciers.

Larger glaciers often develop within a large altitudinal span. A study (Xie Zichu and Feng Qinghua, 2002) shows that there is a good relationship between the mean glacier area ($\bar{S}$) and the glacier altitudinal span ($\triangle H$). For the Ganges (5O1) (eq. 6-1) and the Yarlung Zangbo River (5O2) (eq. 6-2) the equations have been established:

$$\triangle \overline{H}=789.47\overline{S}^{\,0.3378} \qquad (6\text{-}1)$$

$$\triangle \overline{H}=657.79\overline{S}^{\,0.362} \qquad (6\text{-}2)$$

In the Yarlung Zangbo, about 5/6 of the glacier number and 9/10 of the glacier area are concentrated on the southern slopes of the Nyainqentanglha Range while small glaciers are distributed on the northern slopes due to more precipitation on the southern slope. This is different from other mountains in the Northern Hemisphere where there are usually more glaciers on the northern slopes than those on the southern slope. The distributions of the SLA and terminus altitude are also abnormal which are related to such glacier distribution. The SLA rises from the south to the north. For example, it is 4300 m a.s.l. near the Tongmai in the south, then rises to the north, and reaches 5100 m a.s.l. on the northern side of the eastern Nyainqentanglha Range. The average SLA on the northern side is generally 200~400 m higher than that on the south. The glacier tongues of valley glaciers on the southern side of the eastern

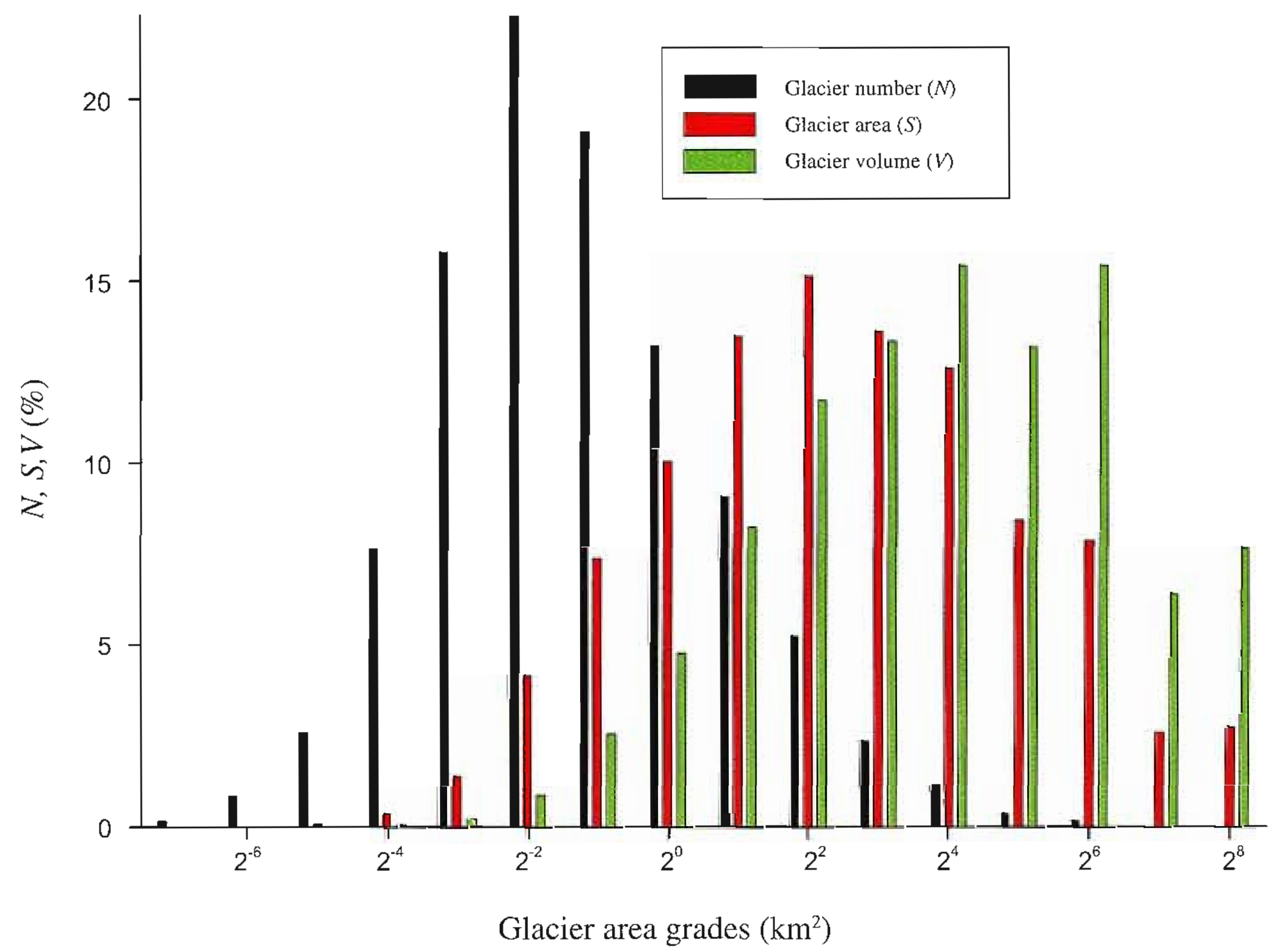


Figure 6-19 Distribution of glacier resources (*N, S, V*) versus area grades in the Yarlung Zangbo

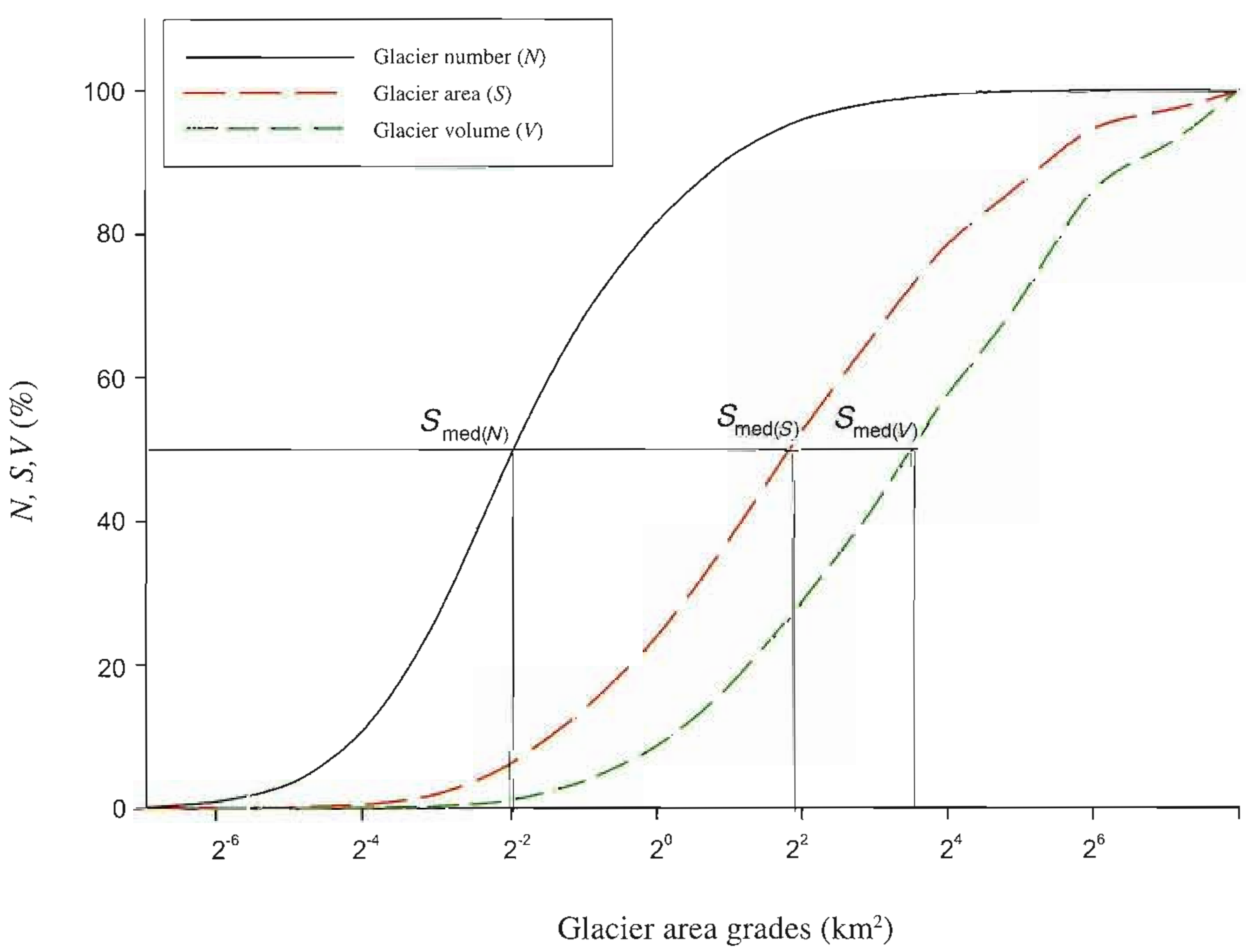


Figure 6-20 Cumulated curve of glacier resources (*N, S, V*) versus area grades in the Yarlung Zangbo

Table 6-25 Glaciers in different area classes in the Yarlung Zangbo (5O2)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
⩽ 0.50	6552	60.58	1410.93	9.74	29.74	2.30	0.22
0.51~1.00	1640	15.16	1221.57	8.43	45.82	3.54	0.74
1.01~5.00	2109	19.50	4522.56	31.20	262.75	20.32	2.14
5.01~10.00	296	2.73	1998.82	13.79	167.34	12.94	6.75
10.01~30.00	173	1.60	2605.95	17.98	288.41	22.30	15.06
30.01~50.00	26	0.24	956.41	6.60	139.97	10.83	36.79
50.01~80.00	13	0.12	823.53	5.68	143.35	11.09	63.35
80.01~100.00	3	0.03	273.54	1.89	53.28	4.12	91.18
⩾ 100.00	4	0.04	679.55	4.69	162.41	12.56	169.89
Total	10,816	100.00	14,492.86	100.00	1293.07	100.00	1.34

Nyainqentanglha Range cross the sub-alpine shrubbery and grassy zone, as well as the mountainous dark conifer zone and conifer-broadleaved forest zone to close to the semi-tropical cultivated areas (crops such as tea and Chinese flowering guince, etc.); whereas the glacier terminus on the northern slopes lies in high altitudes and generally extends only into high mountain meadows zone. Those glaciers developed on the southern slopes of the eastern Nyainqentanglha Range, such as in the Parlung Zangbo, Zayu Qu and Dingba Qu basins, belong to the monsoon-temperate/maritime type. Besides, the glaciers in some tributaries on the southern Himalayas that directly enter the Brahmaputra River, including the Kelu River and the Kameng Qu of the Xibaxa Qu, also belong to the monsoon-temperate/maritime type. Altogether, there are monsoon-temperate/maritime glaciers with an area of 10,067.4 km^2 and an ice volume of 969.84 km^3 in the Yarlung Zangbo, accounting for 69.5% and 75.0% of the corresponding totals for the whole basin, respectively. The rest glaciers are the sub-continental type. Consequently, the Yarlung Zangbo is a major center for monsoon-temperate/marine glaciers in China.

The mountaineering expedition on the Mount Qomolangma during 1959~1960 initiated the first glaciological researches in the Mount Qomolangma (Everest) in China. A comprehensive expedition to the Qinghai-Xizang (Tibet) Plateau from CAS (the Chinese Academy of Sciences) once again investigated glaciers in this region during 1966~1968. In the 1980s, a cooperative research expedition from three countries, including China, Nepal and Canada, initiated a joint investigation on glacier lake outburst floods in the Himalayans region. Since the 1990s, glaciological researches focused on ice cores and environmental change were carried out in the region with the highest peaks in the world, linking to the international programs about the global climate change. The glacial studies conducted by scientists from China, Russia and USA in the Xixabangma region in the 1990s obtained ice cores at an altitude of 7000 m a.s.l. (Photo 6-11) and discovered evidence of re-recrystallization on mid-latitude mountain glaciers and advanced a theory of ice formation (Yao Tandong, 1998).

Glacier investigations in the Yarlung Zangbo have mainly focused on temperate glaciers in the Parlung Zangbo. Initial research on glacier debris-flow of the Parlung Zangbo and the Yiong Zangbo in the mid 1960s also revealed the basic characteristics of temperate glaciers. In the mid 1970s, the Multidisciplinary Expedition to the Qinghai-Xizang (Tibet) Plateau from CAS conducted a more comprehensive investigation on glaciers on the plateau, and later this team drew the distinction between continental and maritime glaciers.

Photo 6-11 Ice core drilling in the Xixabangma region

The temperate glaciers in the Yarlung Zangbo and others have shrunk by 3921.2 km^2 since the Little Ice Age (LIA), which is about 23% of glacier area in the LIA, much greater than that of continental type glaciers in the same period (Su Zhen and Shi Yafeng, 2000). The glaciers in the Ganges-Yarlung Zangbo basins generally have continued to shrink in recent decades due to climate warming. For example, the Middle Rongbuk, Eastern Rongbuk and Far Eastern Rongbuk Glaciers on the Mount Qomolangma retreated 270 m (8.7 $m \cdot a^{-1}$), 170 m (5.5 $m \cdot a^{-1}$) and 230 m (7.4 $m \cdot a^{-1}$) during 1966~1997, respectively (Ren Jiawen *et al.*, 1998). The mass balance of the Kangwure flat-topped glacier on the northern slope of the Mount Xixabangma also showed negative in recent decades, −250 mm in 1991~1992 and −640 mm in 1992~1993 while the glacier terminus retreated about 6.3 $m \cdot a^{-1}$ (Su Zhen and Pu Jianchen, 1998). Several glaciers in the upper reaches of the Yiong Zangbo tributary in the Yarlung Zangbo retreated faster in 1970s than in 1930s. The Rogoi Glacier has retreated about 1.2 km during 1959~1975, and the Azha Glacier retreated 700 m during 1933~1973 and then retreated 195 m during 1973~1976 and 100 m between 1976 and 1980.

The glacier runoff in the Ganges-Yarlung Zangbo basins is very abundant with a total amount of 280×10^8 m^3, about 9.1% of the river runoff (Kang Ersi *et al.*, 2000). The Yarlung Zangbo and its tributaries with higher glacier runoff contribution own a potential hydropower theoretically about 1.13×10^8 kW, which is 1/6 of the total hydropower reserves and in the second place in China. An estimate showed that the hydropower generation can be 1.66×10^7 kW if constructing a tunnel at the big turn of the Yarlung Zangbo by using the altitude span of 2250 m (Xie Zichu and Feng Qinghua, 2002). A hydropower station has been built in the Yamzho Yumco, a lake with glacier runoff supply. Many huge glaciers supply and regulate the river discharge in the Yarlung Zangbo in the southeastern Tibet while these glaciers are also the sources of huge glacial debris-flows that seriously jeopardize highway traffic and result in serious casualties. There are a lot of moraine dammed lakes, which are also the origin of outburst floods and debris flows both in the Himalayas and in the Nyainqentanglha Range. In addition, snow and ice avalanches happen frequently due to the high and steep mountainous slopes in these regions. Therefore, much attention should be paid to glacier lake outburst floods, glacial debris-flow and snow/ice avalanches.

6.6 The Upper Reach of the Indus River (5Q)*

The upper reach of the Indus River mainly consists of three tributaries: the Sengge Zangbo (the Shiquan River), the Langqen Zangbo (the Xiangquan River) and the Shyak River (Figure 6-21). The Sengge Zangbo is the main headstream of the Indus River, with its longest tributary originated from the Kangriboqe Peak. The Langqen Zangbo is the upper stream of the Sutlej River —— the largest tributary of the Indus River. The Shyak River, an important tributary on the right side of the Indus River, originates from the famous the Lümo Glacier. Some tributaries on its left side originate from the Karakorum Mountains in the Xinjiang Uygur Autonomous Region. Within the Tibetan Autonomous Region, the Indus River originates from the north of the Aling Mountian (the Anglong Kangri, 6708 m a.s.l.) between the west of the Gangdise Range and the south of the Bangong Co. The Gangriboqe Peak (the highest peak of the Gangdise Range at 6638 m a.s.l.) lies in the east of the river. The south and southwest boundaries of the Indus River in the Tibetan Autonomous Region are the Great Himalayas with the highest peak, Kameite, of 7342 m a.s.l. The drainage area of the Indus River in China is 52,960 km^2, all of which lies within Ali Prefecture of the Tibetan Autonomous Region.

In the upper reach of the Indus River, there are 2033 glaciers with a total area of 1451.26 km^2, accounting for 2.7% of the total surface area in the Indus River. Surface debris cover is 26.62 km^2 on the glaciers, accounting for 1.8% of the glacier area. The total ice volume is 93.87 km^3. The glacier number, area and ice volume of the upper reach of the Indus River account for 10.5%, 6.1% and 4.6% (Table 6-26) of the corresponding totals of the exterior rivers in China. Comparing with

Table 6-26 Glaciers in the upper reach of the Indus River (5Q)

River name	Code	Glacier number		Glacier area		Glacier volume		Mean area per glacier	SLA	Largest glacier	
		Number	(%)	(km^2)	(%)	(km^3)	(%)	(km^2)	(m)	Area (km^2)	Length (km)
Shyak R.	5Q14	488	24.00	492.15	33.91	31.32	33.36	1.01	5370~6100	23.80	18.2
Sengge Zangbo	5Q15	756	37.19	286.79	19.76	12.55	13.37	0.38	5590~6020	11.55	8.4
Sangbo R.	5Q21	175	8.61	121.64	8.38	6.84	7.29	0.70	5100~5800	13.60	8.5
Langqen Zangbo	5Q22	614	30.20	550.68	37.95	43.16	45.98	0.90	5230~6120	52.40	17.2
Total	5Q	2033	100.00	1451.26	100.00	93.87	100.00	0.71	5100~6120	52.40	17.2

* This subsection is prepared by Liu Chaohai.

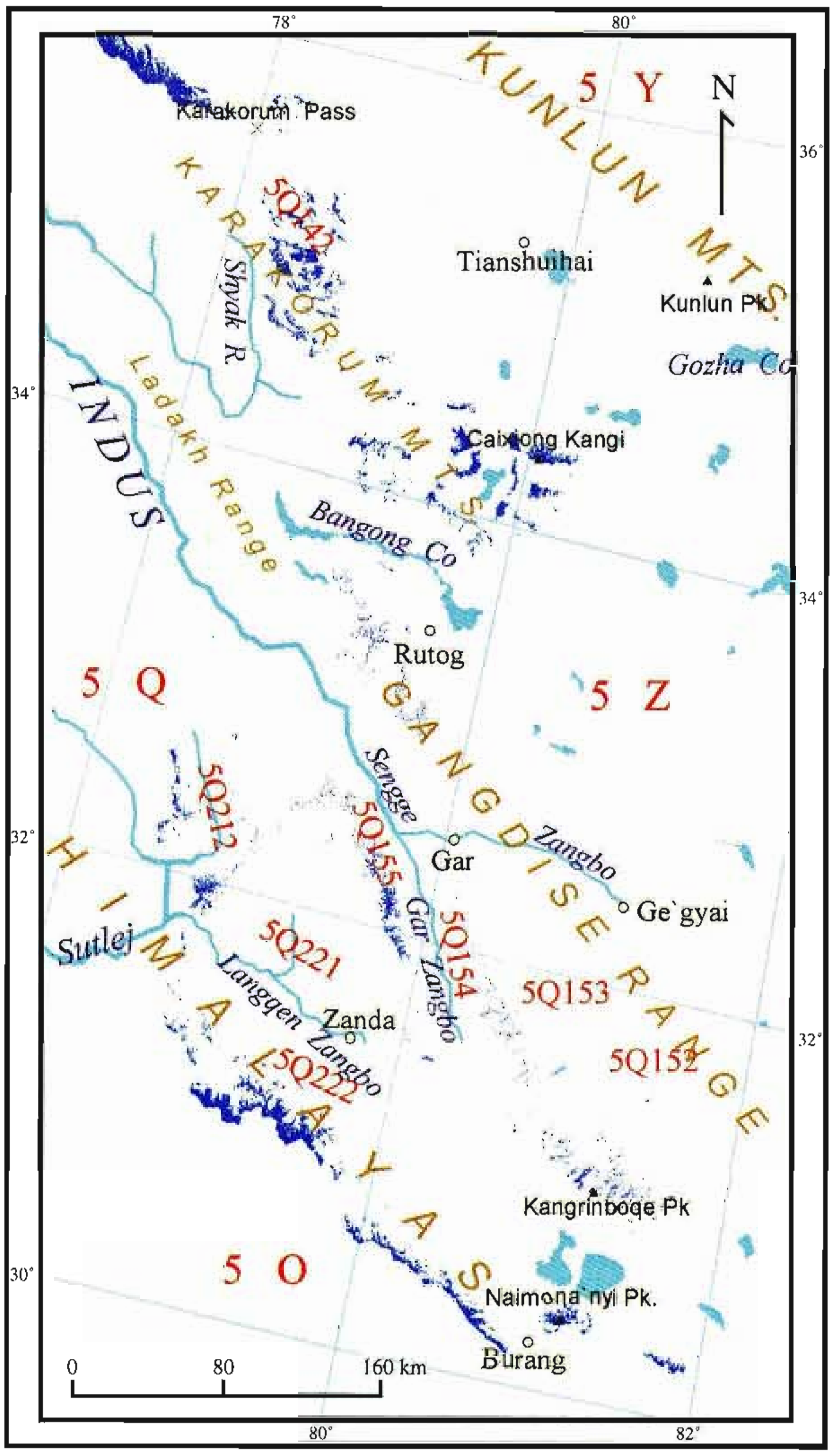


Figure 6-21 Glacier distribution in the upper reach of the Indus River

other exterior rivers in West China, the Indus River is less glacierized, but still higher than the Yellow River and the Ertix River. Of all the tributaries in the upper reach of the Indus River, the Langqen Zangbo (the Xiangquan River) and the Shyak River are the most glacierized basins, whereas the Sengge Zangbo is less although there are a lot of small glaciers in the tributary.

Glaciers smaller than 1 km^2 in the upper reach of the Indus River account for 85.9% of the total number, second only to the Ertix River (83.4%). There are only 18 glaciers with an area greater than 10 km^2, but their total area and ice volume are 22.1% and 41.4% of the basin's totals, respectively (Table 6-27). The largest glacier is the Menbari Glacier (5Q222B91) with an area of 52.4 km^2 in the Langqen Zangbo. Similar to the small average glacier area in the Ertix River (0.72km^2), glaciers in the upper reach of the Indus River is averaged as 0.71km^2 in area. The distribution of glaciers (glacier number, area and ice volume), as well as the cumulated curve for glacier number, area and volume with glacier area classes in this region are similar to those in other rivers in China (Figure 6-22, Figure 6-23). The median area $S_{med(N)}$, $S_{med(S)}$, $S_{med(V)}$ changed as: $S_{med(N)} < S_{med(S)} < S_{med(V)}$ and $S_{med(S)} > 1$.

$S_{med(S)} / \bar{S}$ tends to increase with the total glacier area in the tributaries of the Indus River. There is a statistical relationship between mean glacier altitudinal span ($\triangle\bar{H}$) and mean glacier area ($\bar{S}$):

$$\triangle \bar{H} = 552.86\bar{S}^{0.3444} \quad (6\text{-}3)$$

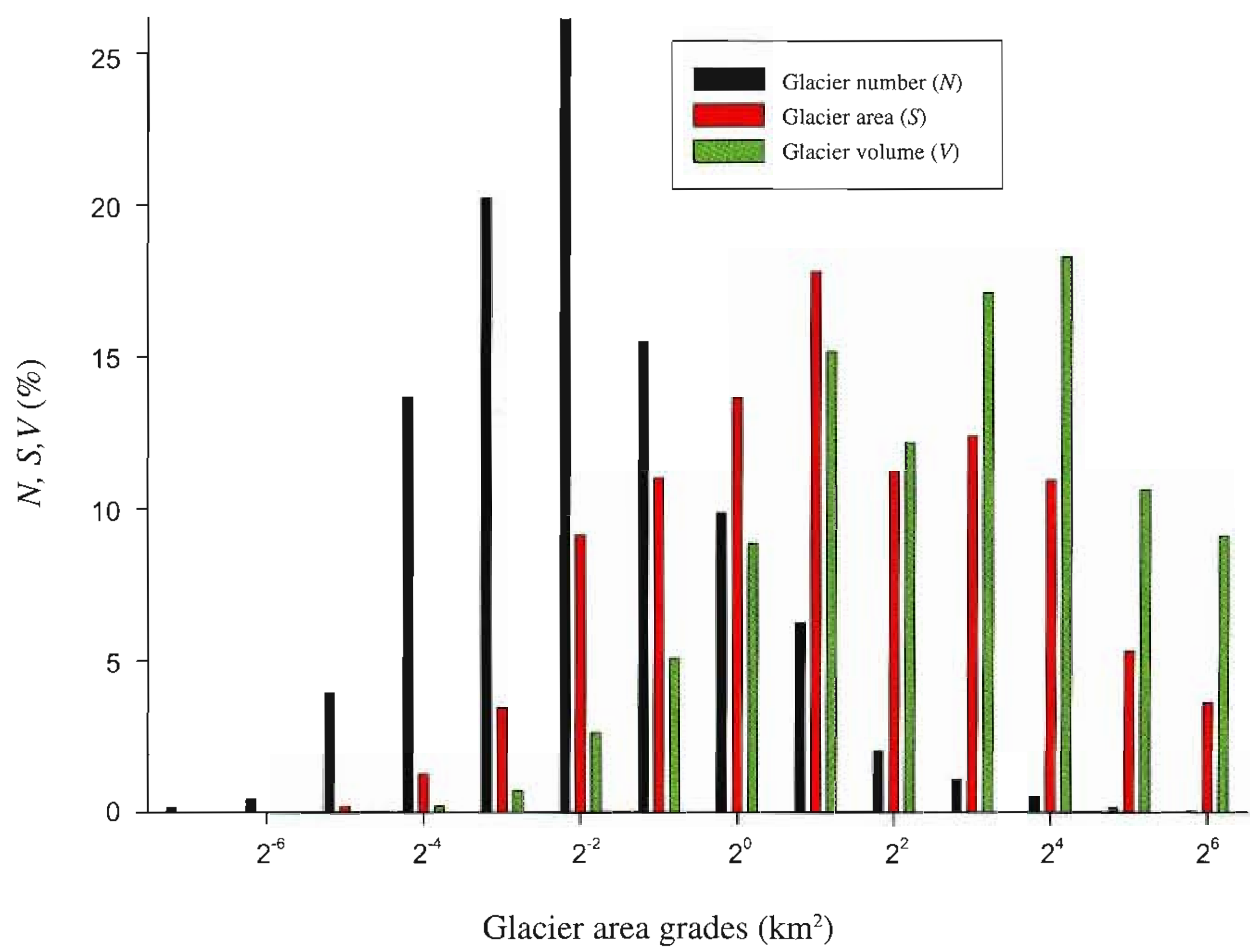


Figure 6-22 Distribution of glacier resources (*N, S, V*) versus area grades in the upper reach of the Indus River

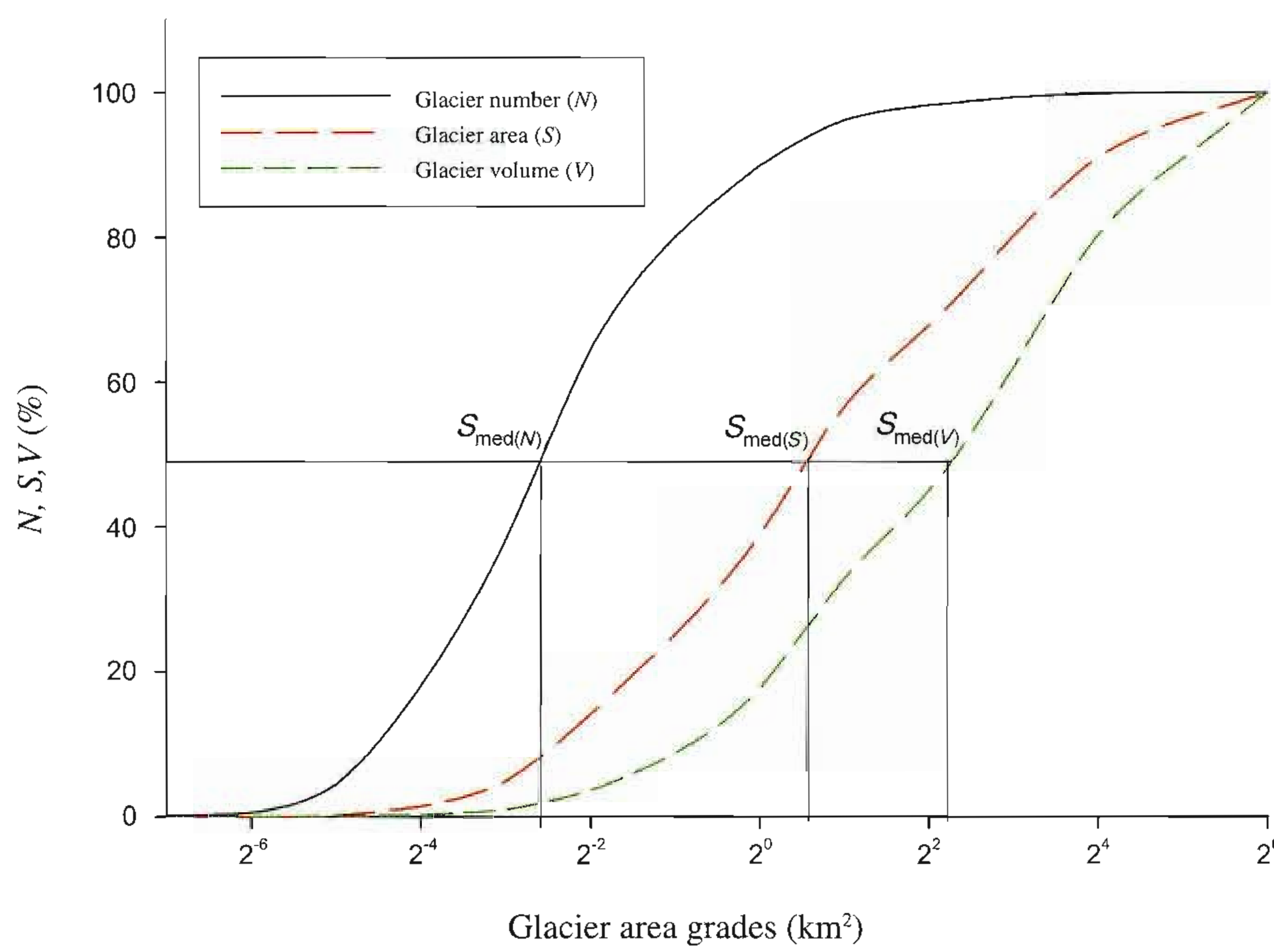


Figure 6-23 Cumulated curve of glacier resources (*N, S, V*) versus area grades in the upper reach of the Indus River

Table 6-27 Distribution of glacier in various glacier area classes in the upper reach of the Indus River (5Q)

Area classes (km^2)	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
⩽ 0.50	1503	73.93	287.30	19.80	5.51	5.87	0.19
0.51~1.00	244	12.00	177.63	12.24	6.61	7.04	0.73
1.01~2.00	139	6.84	193.79	13.35	9.27	9.88	1.39
2.01~5.00	103	5.06	287.80	19.83	17.89	19.06	2.79
5.01~10.00	26	1.28	184.53	12.72	15.75	16.78	7.10
10.01~15.00	11	0.54	133.47	9.20	13.55	14.43	12.13
15.01~20.00	2	0.10	35.19	2.42	4.03	4.29	17.60
20.01~30.00	4	0.20	99.15	6.83	12.72	13.55	24.79
50.01~60.00	1	0.05	52.40	3.61	8.54	9.10	52.40
Total	2033	100.00	1451.26	100.00	93.87	100.00	0.71

Most glaciers are hanging glaciers in the upper reach of the Indus River. Hanging and cirque-hanging glaciers account for 83.0% of the glaciers, meanwhile, their area and ice volume account for only 32.9% and 15.3% of the relevant totals in the whole basin (within China), respectively (Table 6-28). Valley glaciers are the dominant in the glacier area, accounting for 33.9% of the total. Consequently, the primary glacier types are hanging glaciers and cirque-hanging glaciers in the basin which are dispersed widely with only a considerable amount.

Table 6-28 Distribution of glacier types in the upper reach of the Indus River (5Q)

Glacier types	Glacier number		Glacier area		Glacier volume		Mean area per glacier (km^2)
	Number	(%)	(km^2)	(%)	(km^3)	(%)	
Hanging	1466	72.11	269.78	18.59	5.21	5.55	0.18
Cirque-hanging	221	10.87	207.00	14.26	9.12	9.72	0.94
Cirque	39	1.92	48.12	3.32	2.38	2.53	1.13
Cirque-valley	261	12.84	423.07	29.15	23.11	24.62	1.62
Valley	43	2.11	492.46	33.93	53.20	56.67	11.45
Flat-topped	3	0.15	10.83	0.75	0.85	0.91	3.61
Total	2033	100.00	1451.26	100.00	93.87	100.00	0.71

Glaciers in the upper Indus River in China were less observed, with only several expeditions by foreigners in the regions before 1949. The Chinese glaciologists did not do any glacier investigation in the region until the mid 1970s. Glaciers here may be attributed to the extreme-continental type of glaciers based on the dry and warm climate in the region.

It was estimated that the annual glacier runoff is 7.7×10^8 m^3 in the upper reach of the Indus River (Kang Ersi *et al.*, 2000), accounting for 44.8% of the total runoff of the river basin. In some tributaries, like the Ruxu Zangbo, glacier runoff supply can be as high as 76.5% (Xie Zichu and Feng Qinghua, 2002). So the glacial runoff is a precious water resource for the region. In the Shyak and Langqen Zangbo basins where the proportion of glacier melt runoff is great, a permanent hydraulic engineering should be built in the main watercourse to conserve glacier water resources. Most parts of the region are flat, so the disasters caused by glacial debris-flow, glacial lake outburst floods and so on, occur much less frequently here than those in the eastern and southern parts of the Qinghai-Xizang (Tibet) Plateau.

CHAPTER 7 GLACIER RUNOFF

Ye Baisheng

Glacier runoff is an important part of water resources in West China, especially in the arid northwest China. Glaciers, as "solid reservoirs", also regulate water resources through self-fluctuation. This regulation comes to two modes: short term (annual and multiannual) and long term (several decades to several centuries). In the short term, during drought years with high temperatures and less precipitation, enhanced glacial ablation leads to runoff increases; ice volume stored in glaciers melts and drains into rivers, leading runoff increasing, which meets the great need for water. On the other hand, during wet years, with low temperatures and more precipitation, glaciers store a large amount of precipitation in the form of snow or ice, making the river discharge and the amount of unused water reduced. The variation of glacier mass balance is a reflection of this regulation. In the long term, formation and fluctuation of glaciers is controlled by climate change. However, the response of glacier to climate change is not instant, but effected by the dynamics of glaciers, and the response process may take hundreds or thousands of years, or even longer. As a result, when certain climate conditions cause water stored in glaciers hundreds of years before to be released, or a portion of current precipitation to be stored in a glacier, glacier runoff then results in positive or negative trends in some later period, regulating water resources through glacial fluctuation in the long term.

In this chapter, we discuss the characteristics of glacier runoff and the glacial meltwater's contribution to and regulation of river discharge, as well as the response of glacier runoff to the global climate change.

7.1 Estimation of glacier runoff and regional change

1. Characteristics of glacier runoff

Glacier runoff is controlled by climate factors, so it has daily, seasonal and even annual variation like temperature and other climate factors (Yang Zhenniang, 1991).

Whether continental or maritime glaciers, glacier runoff always has an obvious daily cycle with one peak and one vale (Figure 7-1). The peak-vale cycle lags behind the daily air temperature change. The time of lag depends on the glacier type, glacial drainage properties, the size of the watershed, and the distance between the hydrological guage and glacial terminus. Air temperature and the duration of the higher air temperature period determine the daily peak of discharge and total amount of runoff. Runoff is greater on clear and high temperature days, and less on rainy and low temperature days. Furthermore, since maritime glaciers' base flow is much greater than

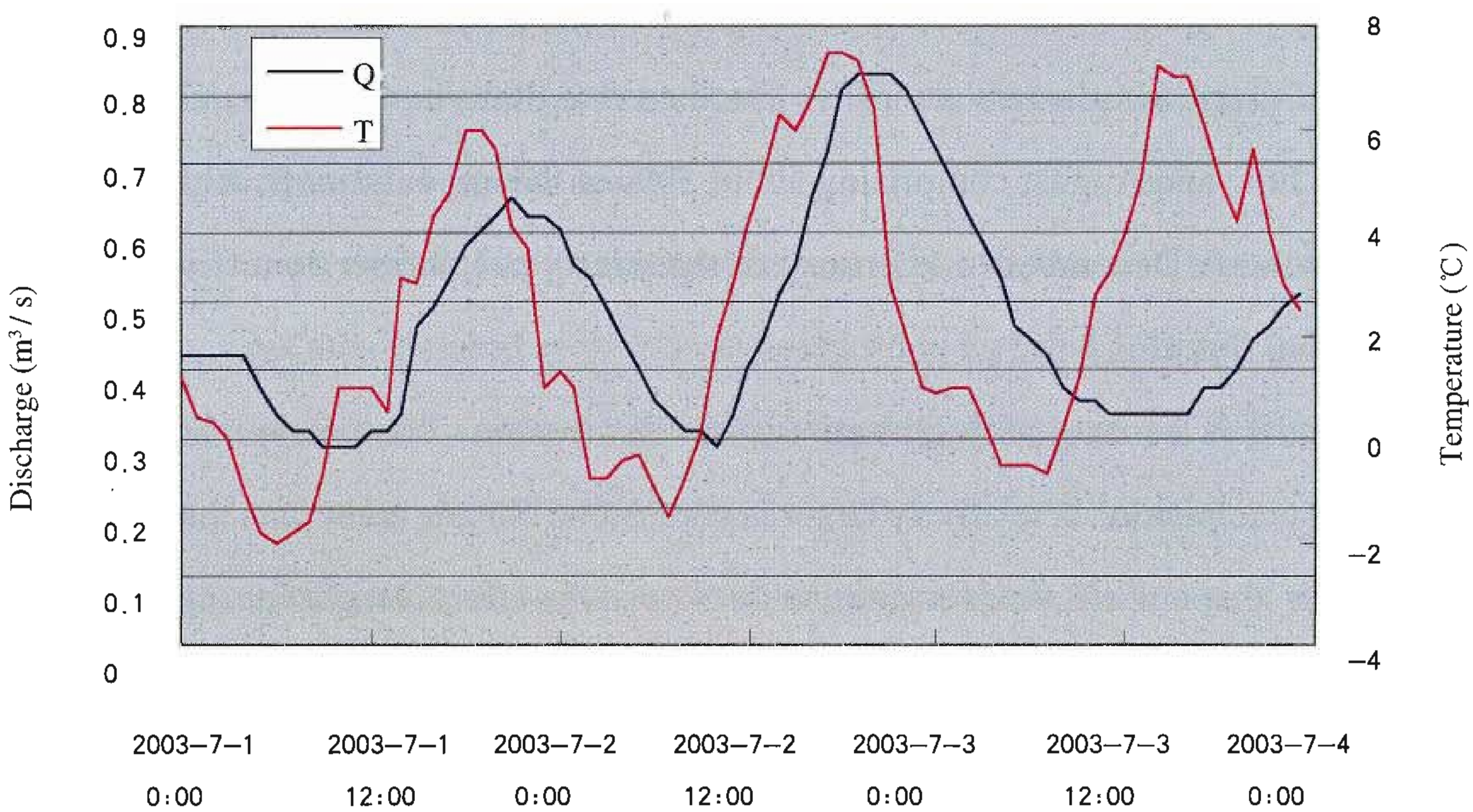


Figure 7-1 Daily discharge (Q) and air temperature (T) process at the Glacier No.1 hydrological station in the headwater of the Urumqi River

that of continental glaciers, the relative daily variation of maritime glaciers is less than that of continental glaciers.

Glacier runoff variation within one year is related to the duration of the glacial ablation period and the type of glacier. Sub-continental glaciers, which developed in high latitude areas or high altitude areas with a continental climate, such as in the Qilian Mountains and the Tianshan Mountains, have ablation periods from May to September. However maritime glaciers, which are located in the southeast part of the Qinghai-Tibetan Plateau, have ablation periods between March and November, lasting for nine months. Therefore, the hydrological year of continental glaciers in China is from October to September of the next year, while that of maritime glaciers is almost consistent with the natural year. Due to the distinctly seasonal variation in glacial meltwater, the hydrological regime is a high variation, especially for continental glaciers whose meltwater runoff is concentrated between June and August. The glacier runoff in these three months is about 85% to 95% of the runoff in the entire ablation period, with no runoff occurring in the winter season. The meltwater of continental glaciers located at low latitudes, due to their relative longer ablation period, is less concentrated between the months of June and August than that of the northwest region's continental glaciers. There is higher air temperature in the region with maritime glaciers and longer the ablation period, as well as an ability to regulate meltwater that is stored inside of glaciers. As a result, the seasonal concentration of maritime glaciers' runoff is less than that of continental glaciers, with total runoff between June and August comprising about 50% of the annual runoff. Although runoff does occur in winter (December to February of the next year), winter runoff is only about 1%~2% of annual runoff.

Glacier runoff is various with climate factors fluctuation. The yearly variation in air temperature and precipitation is relatively larger in continental climate areas than that in maritime climate areas. Air temperature and precipitation have opposite effects on glacier runoff, which is particularly apparent in continental glacier areas. In dry years with higher air temperatures and less precipitation, the heat in mountain areas intensifies, the snowline altitude rises, the ablation area of glaciers expands, and the glacier runoff increases.

2. Methods for estimating glacier runoff

(1) Estimation of glacial meltwater

We can draw a conclusion that relationship of power function exists between glacial meltwater depth and air temperature based on observation data from more than ten fixed or semi-fixed glacier stations in China. However, the coefficients in this equation vary by climate region, according to the ratio between radiation balance and the total heat balance on glacier surface for that climate region. Consequently the common equation for calculating glacial ablation (Yang Zhenniang, 1981) is:

$$\alpha = \varphi (T + 4.0)^{2.7} \qquad (7\text{-}1)$$

where, α is the average daily ablation depth during the whole ablation period ($mm \cdot d^{-1}$), φ is the climate coefficient ($\varphi = 0.382b^2$), b is the percentage of the relative value of the radiation balance(%), and T is the daily air temperature (℃). The ablation value at the glacier's middle latitude is taken as representative of average glacial ablation value. The coefficient φ can be estimated according to heat balance measured in China (Yang Zhenniang, 1991). The air temperature can be calculated according to air temperature gradients from the air temperature at meteorological stations. Furthermore, some other methods have also been adopted. One method of estimating glacial ablation is based on positive air temperature or degree-day factor deduced from the observation of single glacier or many glaciers (Liu Shiyin *et al.*, 1996, 1998; Braithwaite, 1985). In addition, when combined with a glacial area-altitude curve, glacier runoff can also be calculated using this method (Ye Baisheng *et al.*, 1996, Xie Zichu and Feng Qinghua, 2002).

(2) Basic parameters of glacier runoff

① Glacier runoff modulus: a parameter that represents the amount of glacial meltwater in the glacier coverage area, defined as the runoff produced in a glacial area unit during a time unit.

② Glacier runoff depth: a parameter that represents the yearly runoff depth in a glacial area unit.

③ Glacier runoff coefficient: a parameter that represents the ratio between yearly runoff and yearly precipitation in a glacier coverage area.

(3) Methods for estimating glacier runoff

The duration of the glacial ablation period is related to the location of glaciers, climate conditions, glacier type and altitude. The region with sub-continental glaciers ranges from 42° N to 43° N latitude, and includes the Tianshan Mountains, the Qilian Mountains, the Kunlun Mountains and other ranges. Their ablation period typically is from May to September (Figure 7-2). For extreme continental glaciers, such as the Gozha Glacier located in the West Kunlun Mountains, the ablation period is from the end of May to the beginning of September. The ablation period of continental or sub-continental glaciers located in the southern Qinghai-Tibetan Plateau commonly lasts from April to October. The ablation period of maritime glaciers, such as the Hailuogou Glacier and the Gongba Glacier in the Mount Gongga, is longer, typically from March to November.

At present the methods for calculating glacier runoff include:

① Contrasting observation method: To differentiate the runoff from a glacial surface and from that of an ice-free slope, a hydrological station is placed on the glacier terninus, and another hydrological station is placed on a neighboring ice-free basin for contrasting observation. The

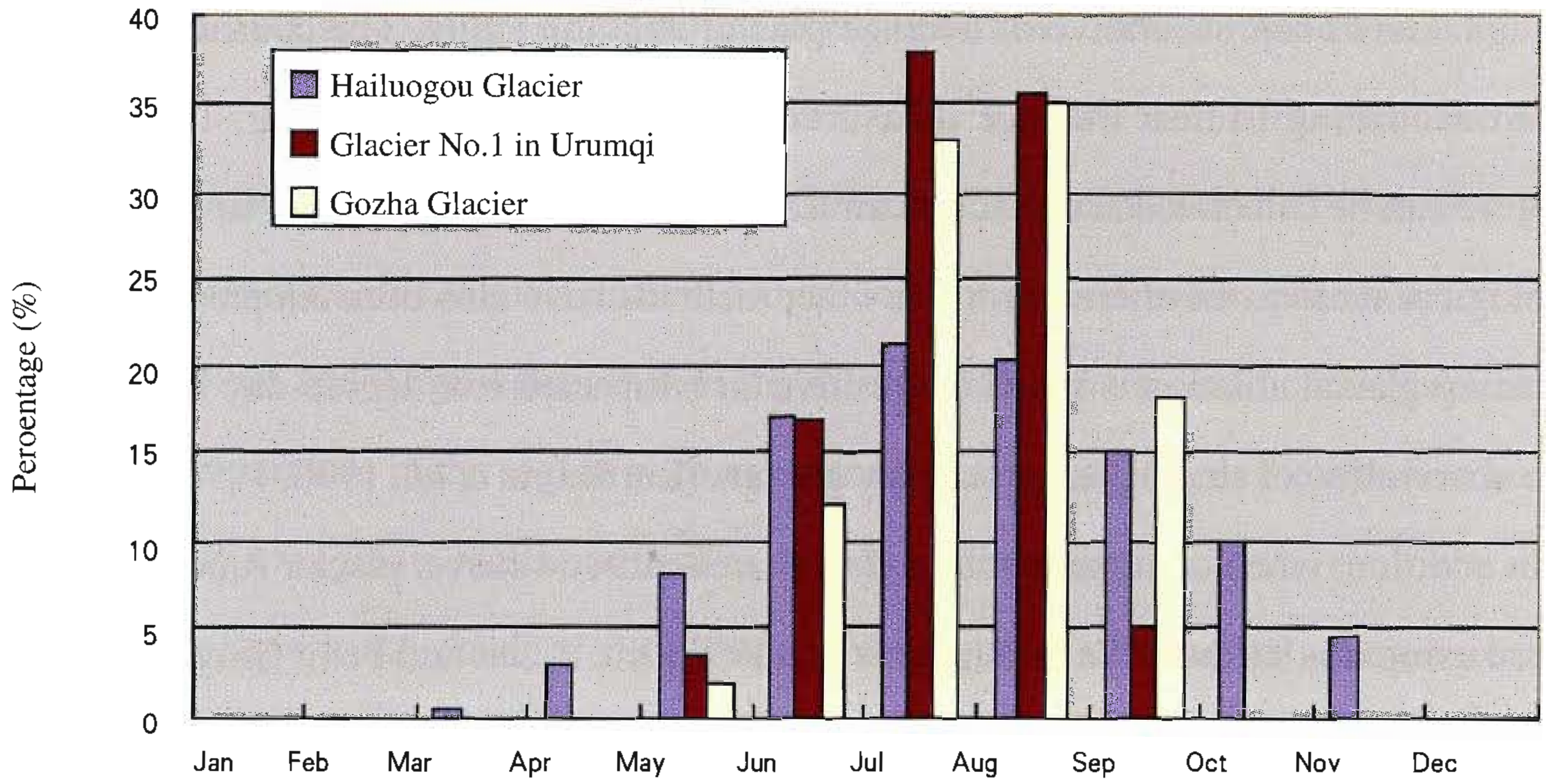


Figure 7-2 Yearly distribution of glacier meltwater runoff for different types of glacier (from Cao Zhentang, 1998)

runoff of hydrological station at glacier terminal usually includes glacier runoff and ice-free slope runoff, so the glacier runoff can be calculated by subtracting ice-free slope runoff, which is observed at constracting station with ice-free basin or estimated using another data at the similar ice-free basin where runoff is observed.

② Runoff-temperature method: a good relationship exists between the runoff at a glacial hydrological site and air temperature on days without precipitation, based on long-term field observation and research in China. The equation is an exponential or power function (Yang Zhenniang, 1991).

③ Glacier runoff modules: Because glacier runoff modules obviously have region-dependent characteristics, we can estimate runoff by the regional interpolation method.

3. The characteristics of glacier runoff distribution

The water resources from glaciers are very plentiful in mountanious areas over West China. Glacier water resources over China have been evaluated for the first time duirng 1980s~1990s. Yang Zhenniang (1991) integrated the glacier runoff modules method, runoff-temperature method, and contrasting observation method, and extended the calculated result for runoff in representative regions with observed data to mountain ranges, and even to all of China. She estimated the total glacier runoff over China to be about 563.3×10^8 m^3. Recently the figure was modified to 604.65×10^8 m^3 (Kang Ersi *et al.*, 2000). Xie Zichu *et al.* (personal correspondence, 2004), using the glacier system method, also estimated total glacier runoff over China to be about 615.75 × 10^8 m^3. This result is almost consistent with that of Kang Ersi *et al.* (2000), except for a few rivers where results are somewhat different. The total glacier runoff is about 2.2% of all river runoff in China (27,115 × 10^8 m^3) (Hydrological Bureau of the Ministry of Water Resources and Electricity, 1987). This is more than the average annual runoff of the Yellow River into the sea, and equal to 10.5% of the total river runoff of four provinces in West China (5760 × 10^8 m^3), including Gansu Province, Qinghai Province, the Xinjiang Uygur Autonomous Region and the Xizang (Tibet) Autonomous Region. Moreover, Sichuan Province and Yunnan Province also have some glacier runoff. Among mountains in West China, the Nyainqentanglha Range has the largest amount, about 35.3% of the total glacier runoff over China. In the second and the third place are the Tianshan Mountains and the Himalayas which are 12.7% and 15.9%, respectively. The Altay Mountains have the least amount, less than 1% (Table 7-1).

The Xizang Autonomous Region takes the first place for the amount of glacier runoff, about

Table 7-1 Glaciers and their runoff in mountain regions over West China*

Mountain systems	Glacier area (km^2)	Glacier runoff (× $10^8 m^3$)	Percentage of total glacier runoff in China (%)
Qilian Mountains	1930.51	11.32	1.9
Altay Mountains *	296.75	3.86	0.6
Tianshan Mountains	9224.80	96.30	15.9
Pamirs	2696.11	15.35	2.5
Karakorum Mountains	6262.21	38.47	6.4
Kunlun Mountains	12,267.19	61.87	10.2
Himalayas	8417.65	76.60	12.7
Qiangtan Plateau	1802.12	9.29	1.5
Gangdise Range	1759.52	9.41	1.6
Nyainqentanglha Range	10,700.43	213.27	35.3
Hengduan Mountains	1579.49	49.94	8.3
Tanggula Range	2213.40	17.59	2.9
Altun Mountains	275.00	1.39	0.2
Total	59,425.18	604.65	100.0

* From Kang Ersi *et al.*, 2000.

* Includes glaciers in the Sawir Range whose area is 16.84 km^2.

57.7% over China. The next is the Xinjiang Uygur Autonomous Region, about 33.3%. About 60.0% of the Chinese glacier runoff converges to external river basins, about 40.0% to internal river watersheds. However, in terms of glacier area, only 40.0% of the Chinese glaciers areas are in external river basins, 60.0% in interior river regions.

4. Glacier runoff contribution

Glacier runoff in the Xinjiang Uygur Autonomous Region has the largest contribution to river runoff supply, about 25.4% of total glacier runoff in West China. The next is in the Xizang Autonomous Region, about 8.6%, and the last is in Gansu Province, only 3.6% (Table 7-2). However, as for the Qilian Mountain region in Gansu, the proportion of its glacier runoff contribution to three interior river basins in the Hexi corridor can reach 14% to 15% (Table 7-3). Evidently in areas with rich glacial meltwater resources, the proportion of glacier runoff contribution is not always correspondingly high. As to the Tarim basin, which has almost the same amount of glacier runoff as the Yarlung Zangbo, the proportion of glacier supply is 38.5%, but only 12.3% for the latter. The proportion of glacier runoff's supply to the interior drainage areas is 22.2%, but the proportion to the exterior drainage areas is only 9.0% (Table 7-3, Table 7-4). This is mainly because precipitation is less in the interior arid regions. Water resources in these regions are mainly formed in and around relatively humid mountanious areas, especially the high glacier mountain zones with more precipitation. Consequently glacial meltwater's supply to rivers in the arid interior is more noticeable. It also indicates the significance of glacial meltwater

Table 7-2 Glaciers and their runoff in six provinces in West China*

Province	Glacier area (km^2)	Percent of glacier area in China (%)	Glacier runoff ($\times 10^8$ m^3)	Percent of Chinese meltwater runoff (%)	River runoff ($\times 10^8$ m^3)	Contribution from glacier runoff (%)
Gansu	866	1.5	10.72	1.8	299	3.6
Qinghai	3675	6.2	23.76	3.9	622	3.8
Xinjiang	25,342	42.6	201.50	33.3	793	25.4
Xizang	28,664	48.2	349.15	57.8	4064	8.6
Yunnan and Sichuan	878	1.5	19.52	3.2	—	—
Total	59,425	100.0	604.65	100.0	—	—

* From Yang Zhenniang,1991.

resources in the interior arid regions.

As a comparison of the proportion of glacier runoff supply to rivers, we provide the glacial distribution maps for mainstreams in West China based on *Glacier Inventory of China* and hydrological network data (Figure 7-3).

Table 7-3 Glacier runoff and the contribution from glacier runoff to rivers in interior rivers*

Interior river	Glacier area (km^2)	Percentage of the total area (%)	River runoff (× 10^8m^3)	Glacier runoff[1)] (× 10^8m^3)	contribution from glacier runoff[1)] (%)	Glacier runoff[2)] (× 10^8m^3)	Contribution from glacier runoff[2)] (%)
Hexi Corridor	1334.77	3.77	72.4	9.99	13.8	11.94	16.5
Junggar Basin	2254.10	6.37	125.0*	16.89	13.5	33.65	26.9
Ili River	2022.66	5.72	193.0*	26.41	13.7	37.14	19.2
Tarim Basin	19,877.65	56.20	347.0*	133.42	38.5	126.54	36.5
Qaidam Basin	1865.05	5.27	66.9	6.31	9.4	13.51	20.2
Karakul Lake	25.50	0.07	3.2	0.12	3.8	0.11	3.4
Qangtan Plateau	7836.10	21.89	246.0*	39.10	15.9	29.18	11.9
Tu-Ha Basin	252.73	0.71	—	1.90	—	3.60	—
Total	35,468.56	100.00	1053.5*	234.14	22.2	255.67	24.3

* 1) From Kang Ersi *et al.*, 2000; 2) From Xie Zichu *et al.*, 2004.

* From the Hydrological Bureau of Ministry of Water Resources and Electricity, and the Lanzhou Engineering Consulting Institute, 1986. Surface water resources in interior rivers.

Table 7-4 Glacier runoff and the percentage of its supply to rivers in exterior rivers*

Exterior rivers	Glacier area (km^2)	Percent of glacier area in China (%)	River segment	Total runoff (×10^8m^3)	Glacier runoff[1)] (×10^8m^3)	Contribution from glacier runoff[1)] (%)	Glacier runoff[2)] (× 10^8m^3)	Contribution from glacier runoff[2)] (%)
Yangtze River	1895.00	7.89	West mountain	177.0	32.71	18.5	15.52	8.8
Yellow River	172.41	0.72	West mountain	209.0	2.86	1.3	1.74	0.8
Ertix River	289.29	1.20	Mountain area	100.0	3.62	3.6	7.73	7.7
Lancang River	316.32	1.32	Qinghai-Tibet	109.0*	7.16	6.6	4.43	4.0
Nujiang River	1730.20	7.21	Tibet	409.0*	35.98	8.8	24.26	5.9
Ganges River**	18,102.14	75.62	Tibet	3101.1*	280.48	9.1	299.53	9.7
Indus River***	1451.26	6.04	Tibet	17.2*	7.70	44.8	6.95	40.4
Total	23,956.62	100.00	—	4122.3	370.51	9.0	360.16	8.7

* 1) From Kang Ersi *et al.*, 2000; 2) From Xie Zichu *et al.*, 2004.

* Planning Office of the Yangtze River Basin, Ministry of Water Conservancy and Power, 1986. Assessment of water resources in the rivers in the southwest China (in Chinese).

** Include the Yarlung Zangbo, the Pumqu River, the Zayü River, the Xibaxa Qu and the Kamen River.

*** Include the Shiquan River and the Xiangquan River.

The proportion of glacier runoff supply to rivers in China differs greatly. The overall trend for the proportion of glacier runoff is increased from the periphery toward the interior of the Qinghai-Tibetan Plateau along with the increasing of the aridity of the climate and the extent of the glaciated area (Figure 7-4). In the interior drainage areas, such as the Hexi corridor and the Junggar Drainage Basin, the proportion of glacial meltwater supply is about 14%, but in the Tarim Drainage Basin located in the far interior, the proportion is 38.5%. As an another example, for the Shiyang River in the eastern section of the Hexi corridor, the proportion is only 4%, 8% for the Heihe River in the middle section, and 32% for the Shule River in the western section (Yang Zhenniang, 1991). In the exterior rivers, the same trend also exists: the proportion of glacier runoff supply grows larger along with the increase in aridity and extent of the glaciated area. For example, the proportion for the Lancang River in southeast Tibet and the upper reaches of the Ganges River is less than 10%, whereas the proportion is nearly 45% for the upper reaches of the Indus River in western Tibet, including the Shiquan River and the Xiangquan River (Figure 7-4).

5. Glacier runoff's regulation of rivers

Glaciers have the ability to regulate river discharge over many years. In humid years with low temperatures, glaciers ablate weak due to insufficient heat energy, and accumulate more ice. In drought years with less precipitation, the warm weather cause glaciers to ablate more, and a larger amount of glacial meltwater is discharged. Therefore, the rivers that receive more glacier runoff in the mountain areas of West China are not short of water in drought years, and in wet years glacial discharge decreases, thus mitigating river runoff fluctuation between wet years and drought years. This effect is evident from changes in the contribution from glacier runoff between 1992~1997, computed from observation data collected at the Yingxiong Station on the Urumqi River (Table 7-5) (Ye Baisheng *et al.*, 1999). The glacier area in the upper reaches of the Urumqi River (above Yingxiong Station) is 37.95 km^2, only 4.1% of the whole drainage area. Based on the results from the observed runoff data from glacier, the average contribution from glacier runoff is 11.3% between 1982 and 1997. However in drought years with high temperatures, such as in 1986, the contribution is 28.7%, while in wet years, such as in 1987, the contribution is only 5.1%. The result indicates that glaciers, as solid reservoirs, have the ability to regulate river discharge.

Based on runoff data in major rivers in West China, the statistical results obtained from

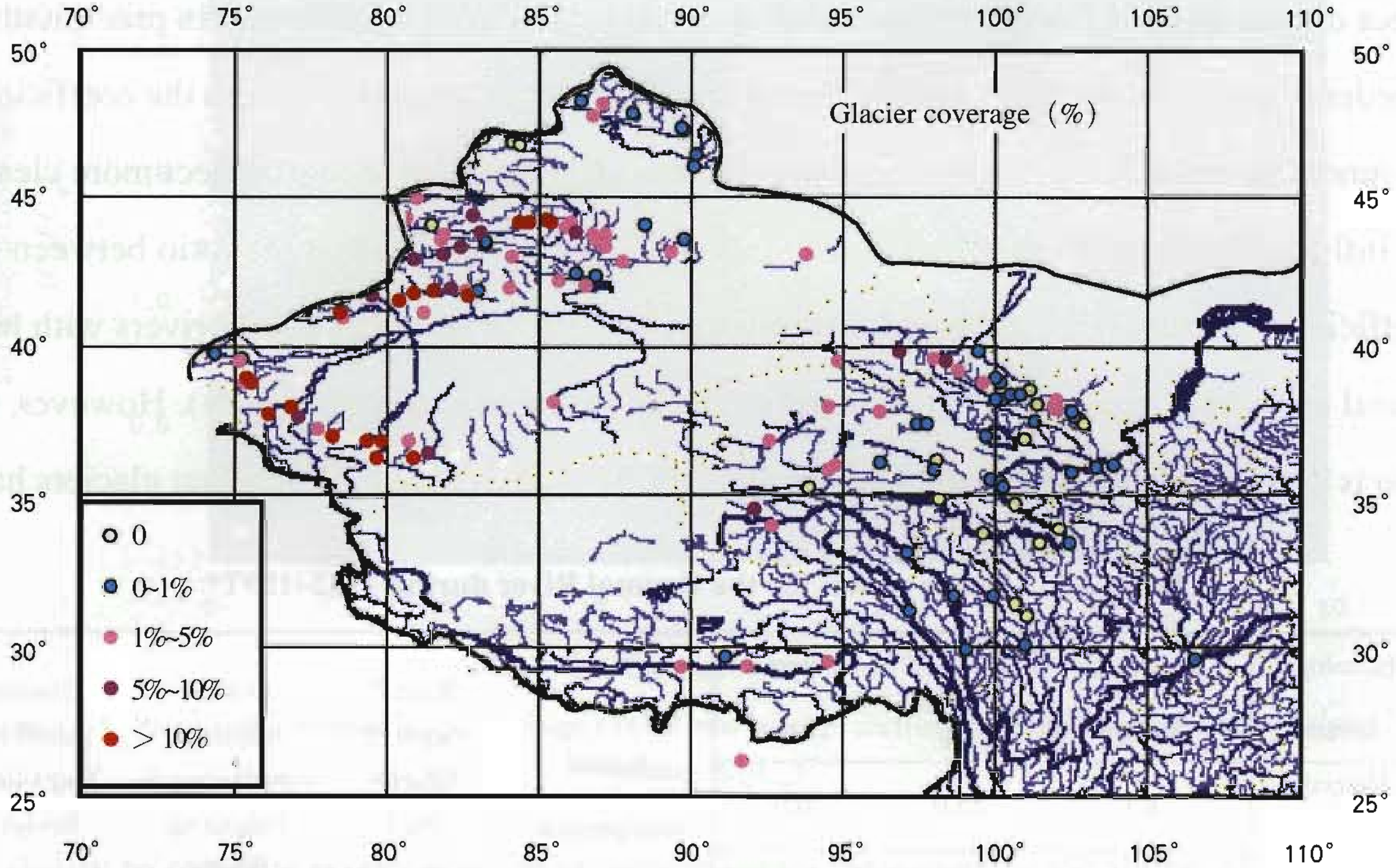


Figure 7-3 Glacier coverage for main hydrological stations at rivers in mountainous areas in West China

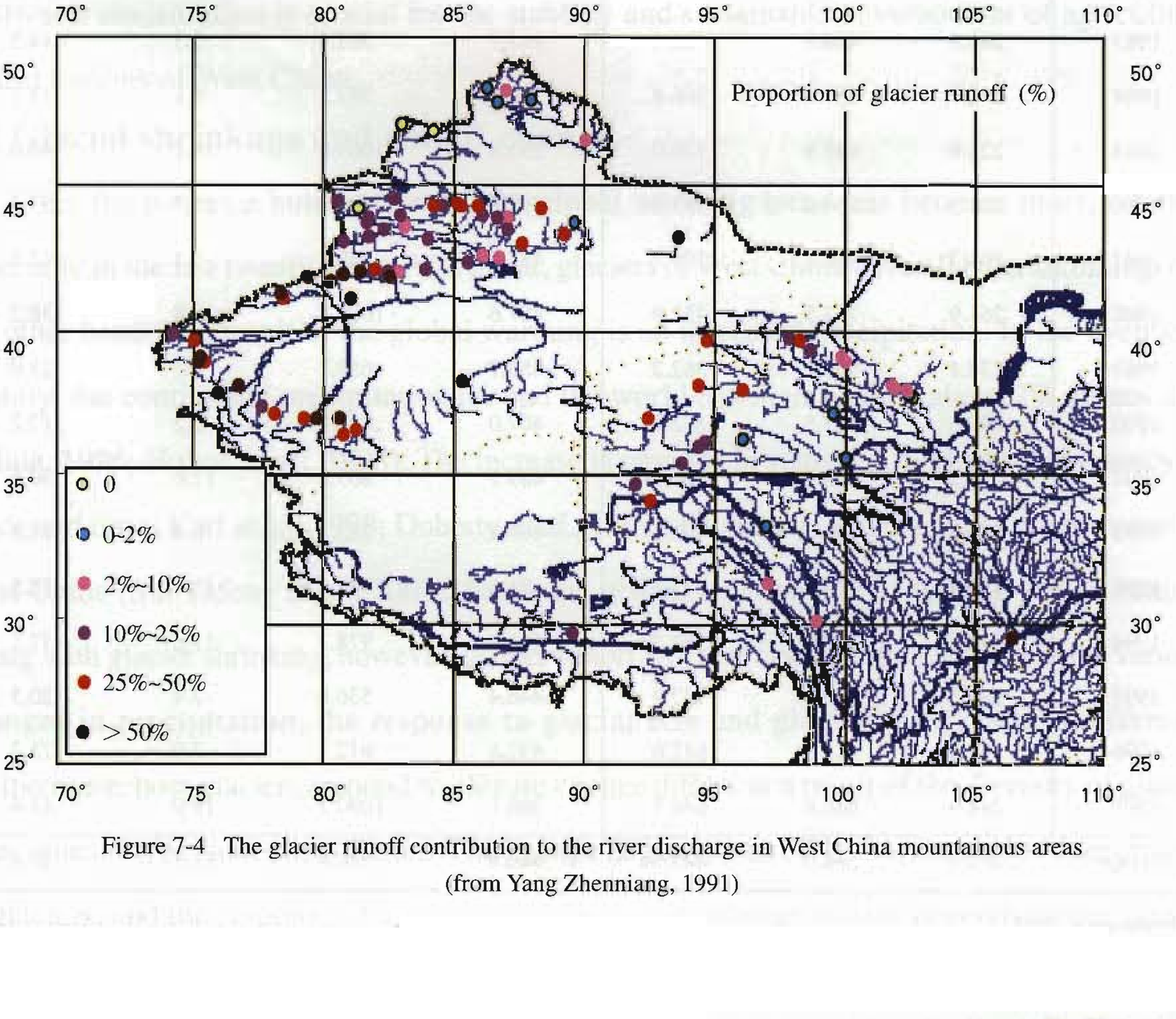


Figure 7-4 The glacier runoff contribution to the river discharge in West China mountainous areas
(from Yang Zhenniang, 1991)

this data and additional data (Ye Baisheng *et al.*, 1999) illustrate more clearly the regulation effect of glacier runoff. Variation in runoff is greatly influenced by variation in precipitation. In order to eliminate the impact of the precipitation on runoff, the ratio between the coefficients for runoff variance (C_{vp}) and precipitation variance (C_{vr}) has been used to reflect more clearly the influence of factors other than precipitation. Figure 7-5 shows that the ratio between the coefficients for runoff variance and precipitation variance is less than 0.5 for rivers with high glacial meltwater supply (contribution from glacial meltwater more than 30%). However, the ratio is greater than 1.0 for rivers without glaciers. This obviously indicates that glaciers have

Table 7-5 Glacier runoff for the Urumqi River during 1982~1997*

Hydrologic station	Yingxiong Bridge	Glacier No.1 hydrologic site	Bare cirque	Annual precipitation	Runoff depth of Glacier No.1	Glacial meltwater contribution at Yingxiong Bridge	Glacier runoff at Yingxiong Bridge
Glacial coverage (%)	4.1	55.0	0.0				
Year	Annual runoff (mm)	Annual runoff (mm)	Annual runoff (mm)	(mm)	(mm)	(%)	($\times 10^6 m^3$)
1982	273.5	430.1	346.1	475.9	498.5	7.5	18.9
1983	248.8	400.9	423.4	414.7	382.5	6.3	14.5
1984	260.8	351.0	306.6	380.1	387.3	6.1	14.7
1985	222.9	645.9	126.0	293.4	1069.8	19.7	40.6
1986	201.3	954.2	397.5	392.8	1408.0	28.7	53.4
1987	266.2	410.8	509.7	433.5	330.1	5.1	12.5
1988	261.9	757.5	452.9	487.6	1005.8	15.8	38.2
1989	278.1	526.1	362.2	458.7	659.7	9.7	25.0
1990	299.6	421.5	382.1	407.0	453.7	6.2	17.2
1991	274.2	623.1	401.9	489.7	803.5	12.0	30.5
1992	245.5	391.7	402.3	409.3	383.1	6.4	14.5
1993	286.7	727.4	473.3	471.6	934.6	13.4	35.5
1994	345.8	802.6	587.3	566.9	978.1	11.6	37.1
1995	295.5	626.3	737.2	446.4	536.0	7.4	20.3
1996	357.1	612.0	612.0	632.4	612.1	7.0	23.2
1997	248.9	886.8	636.7	388.1	1090.7	18.0	41.4
Average	272.9	598.0	447.3	446.8	720.8	11.3	27.4

* Ye Baisheng *et al.*, 1999.

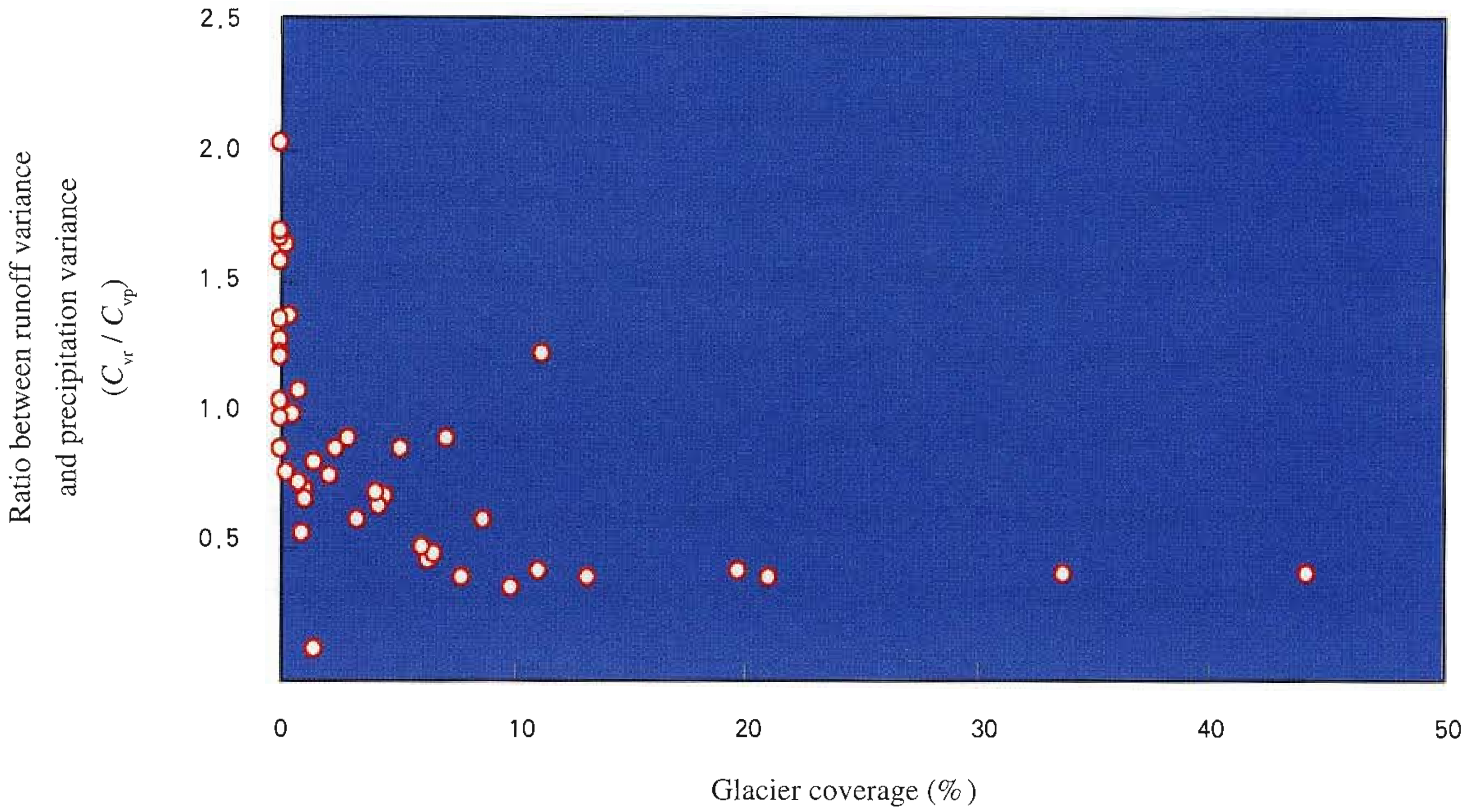


Figure 7-5 Relationship between glacial coverage and the ratio between coefficients of runoff variance and precipitation variance (C_{vr}/C_{vp})

the ability to regulate river runoff over many years. Consequently the threat of drought or flood is relatively small for rivers with a higher contribution from glacial meltwater. Glacial meltwater contribution is crucial for the stability and sustainable development of agriculture in arid regions of West China.

7.2 Glacial shrinkage and runoff change

Over the past one hundred years, the global warming trend has become more notable, especially in the last twenty years. As a result, glaciers in West China have all been shrinking. On the other hand, one result of the global warming is an increased precipitation. In the twentieth century, the continental precipitation around the world has increased by about 2% (Jones and Hulme, 1996; Hulme *et al.*, 1998). The increase is obvious in statistics, but lacks consistency in space and time (Karl *et al.*, 1998; Doherty *et al.*, 1999). Climate warming has clearly occurred in West China (Shi Yafeng *et al.*, 2003), hastening glacial ablation and increasing glacier runoff. Along with glacier shrinking, however, glacier runoff will decrease in future. Owing to the various changes in precipitation, the response to glacial size and glacier runoff is also different. Furthermore, how glaciers respond to climate change differs as a result of the diversity of glacier sizes, glacier types and other factors. The change in glacier runoff is more complex than change in glaciers, and the response of glacier runoff to climate change mainly depends on the size of glaciers, the increasing speed of air temperature and glacial types.

1. Observing results of the increase in glacier runoff

The climate-warming trend in West China has resulted in a notable increase in glacier runoff. Figure 7-6 illustrates the changes in annual runoff and related climate factors at the Glacier No.1 hydrologic station at the source of the Urumqi River in the past 20 years. Glacier runoff obviously increased after 1995, and the variation in runoff is in accord with the variation of summer air temperature, which indicates that the increase in air temperature is the key factor affecting the increase in glacier runoff. Precipitation increased 95.2 mm (20%) and the summer air temperature increased 0.8℃ between periods of 1995~2003 and 1980~1994. The glacial mass balance decreased by 286 mm, and the corresponding increase in runoff was 236.8 mm (35%). 11% of the runoff increase is contributed from the increased precipitation and about 20% from the loss of glacial mass loss.

To quantify the effect of climatic change on the glacier, we examine the relationships among summer temperature, precipitation and glacier mass balance and runoff. Figure 7-7a shows the relation between summer precipitation and mass balance/runoff. Summer precipitation is negatively correlated with mass balance and positively associated with runoff. These relationships, although very weak statistically, are reasonable, as higher precipitation leads to higher runoff and lower glacier ablation. Similarly, summer temperature is negatively correlated with mass balance and positively associated with runoff (Figure 7-7b). These relationships, statistically significant at 99%, are expected for glacier basins, because higher temperature leads to higher

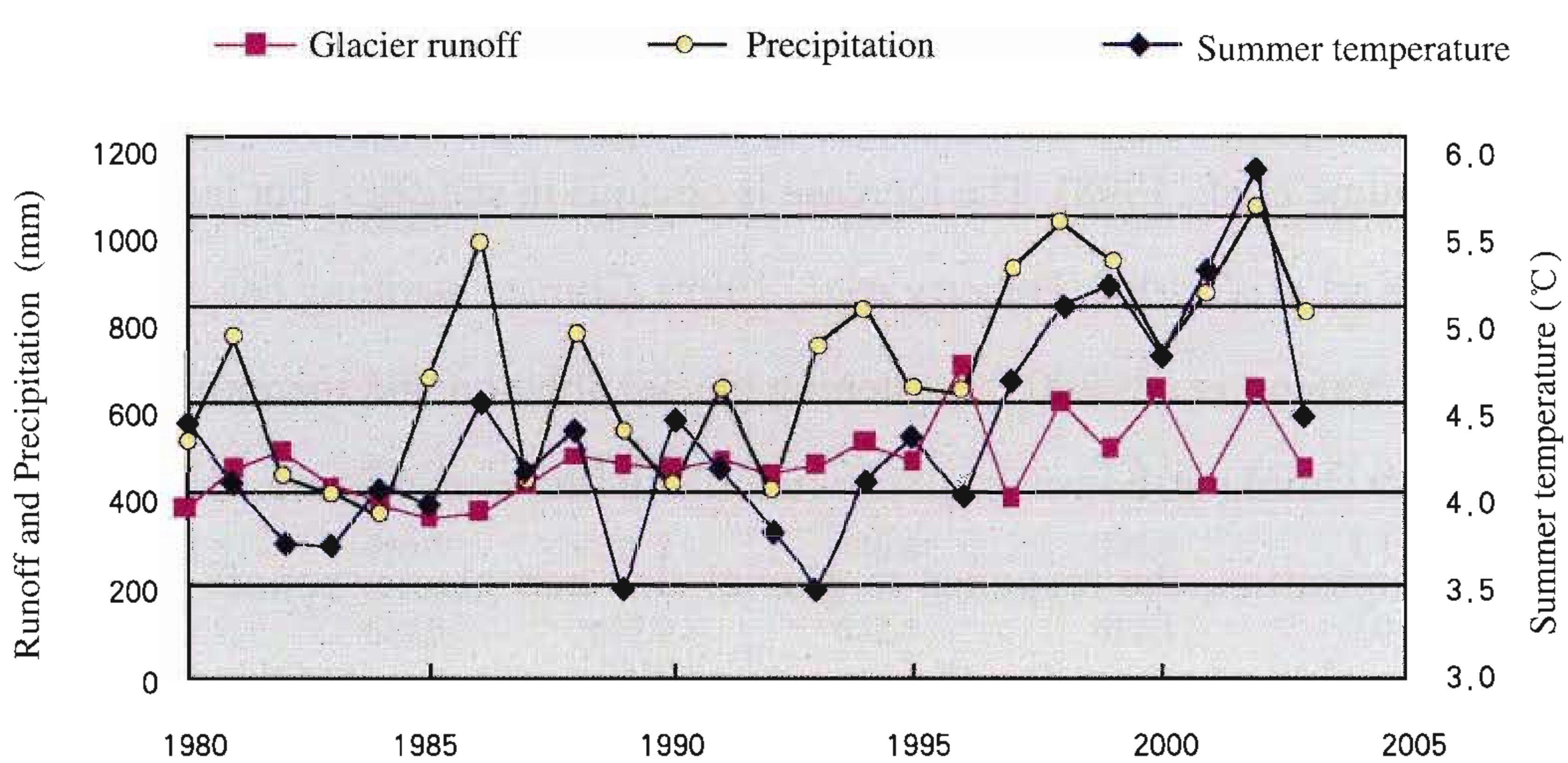


Figure 7-6 Glacier runoff, annual precipitation, and summer air temperature at the Glacier No.1 hydrologic station at the source of the Urumqi River during 1980~2003

glacier ablation (negative mass balance) and thus higher runoff. Regression results in Figure 7-7b suggest that the 1℃ summer temperature change leads to 486 mm glacier mass loss and 250 mm runoff change over the basin. This result shows that the mass balance of this small glacier (53% of the basin) is more sensitive than basin runoff to temperature variation. The runoff positive sensitivity to summer air temperature increase is only from glacier mass loss. Considering the 53% glacier coverage of the basin, 250 mm runoff sensitivity to the 1℃ summer temperature increase is equivalent to 470 mm glacier mass loss. The result completely matches the sensitivity of glacier mass balance to climate warming. Relative to precipitation, summer temperature is a

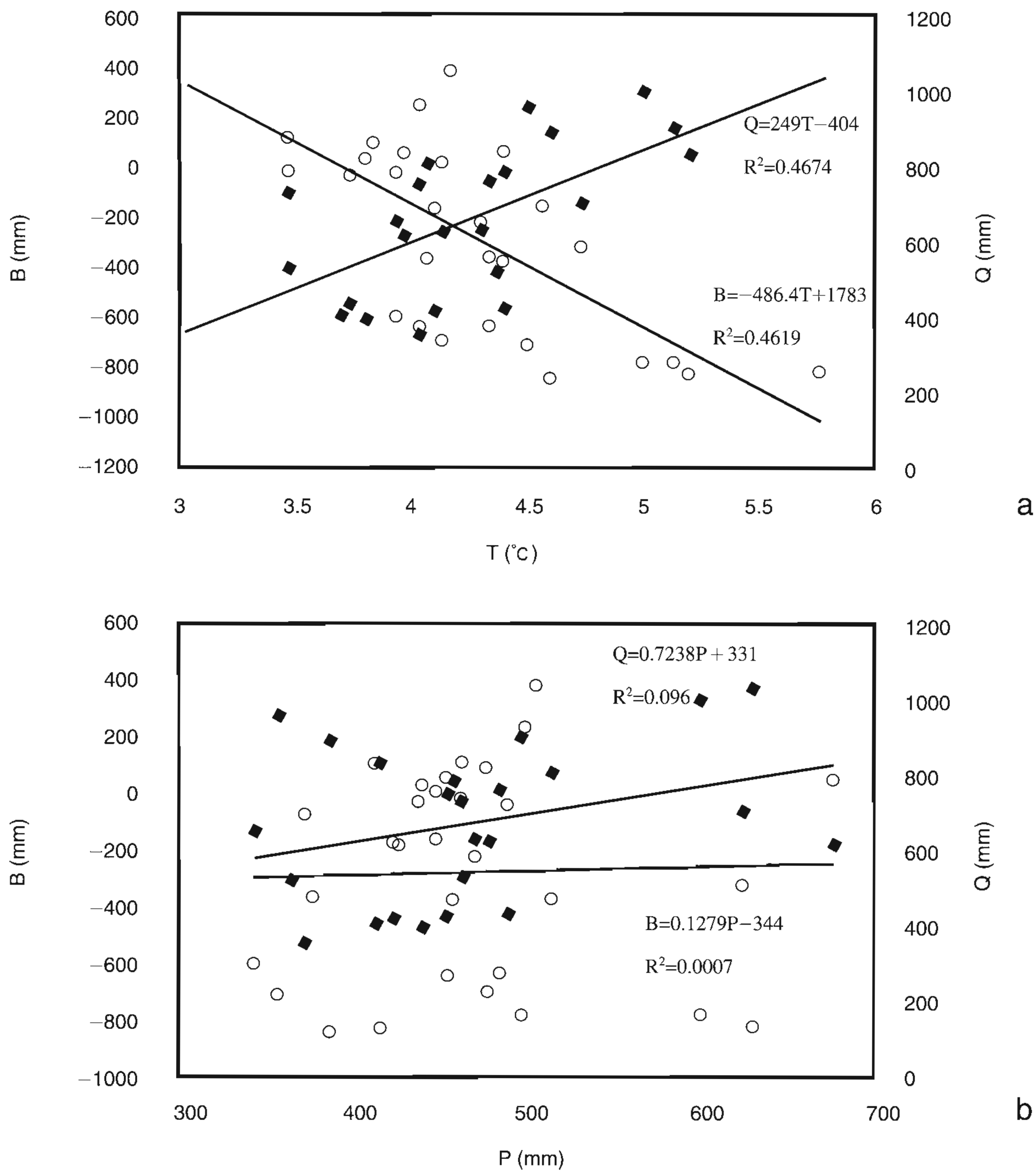


Figure 7-7 Regression relationships of summer temperature (Ts) and precipitation (P) vs. mass balance (B) and runoff (Q) during 1959~1966 and 1980~2003 with observed period

more important factor to affect the glacier mass balance and runoff (Oerlemans and Fortuin, 1992).

2. Responses of various glacier size to climate change

Researchers conducted a simulation of the responses of glaciers runoff for various glacier size to climate warming for the Ili River basin, using a one-dimension glacial flow model based on the glacier No.1 in source region of the Urumgi River (Ye Baisheng *et al.*, 2003) (Figure 7-8). The results indicate that the peak flow of runoff depends on the speed of air temperature increase.

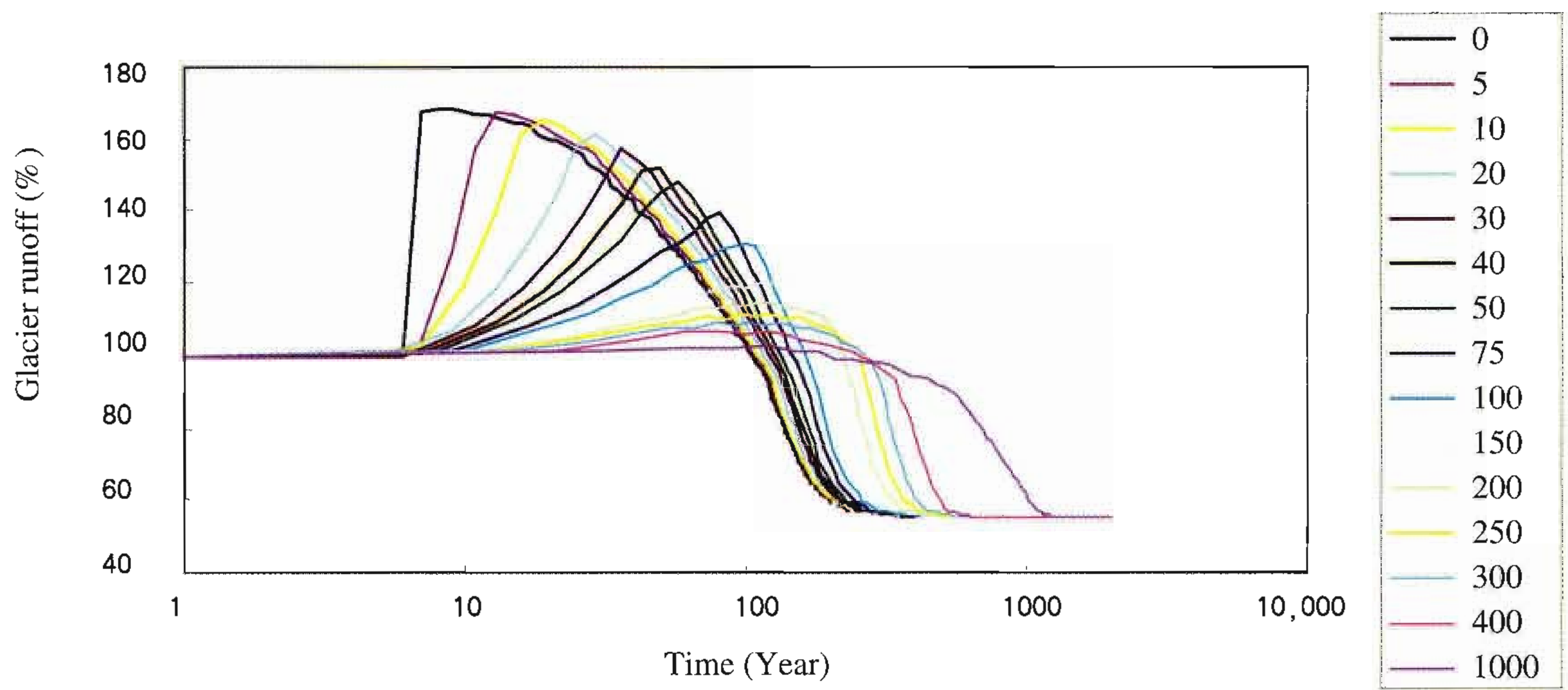


Figure 7-8 Responses of glacier runoff to different speeds of air temperature increase (legend is time needed to raise air temperature 1℃,Year)

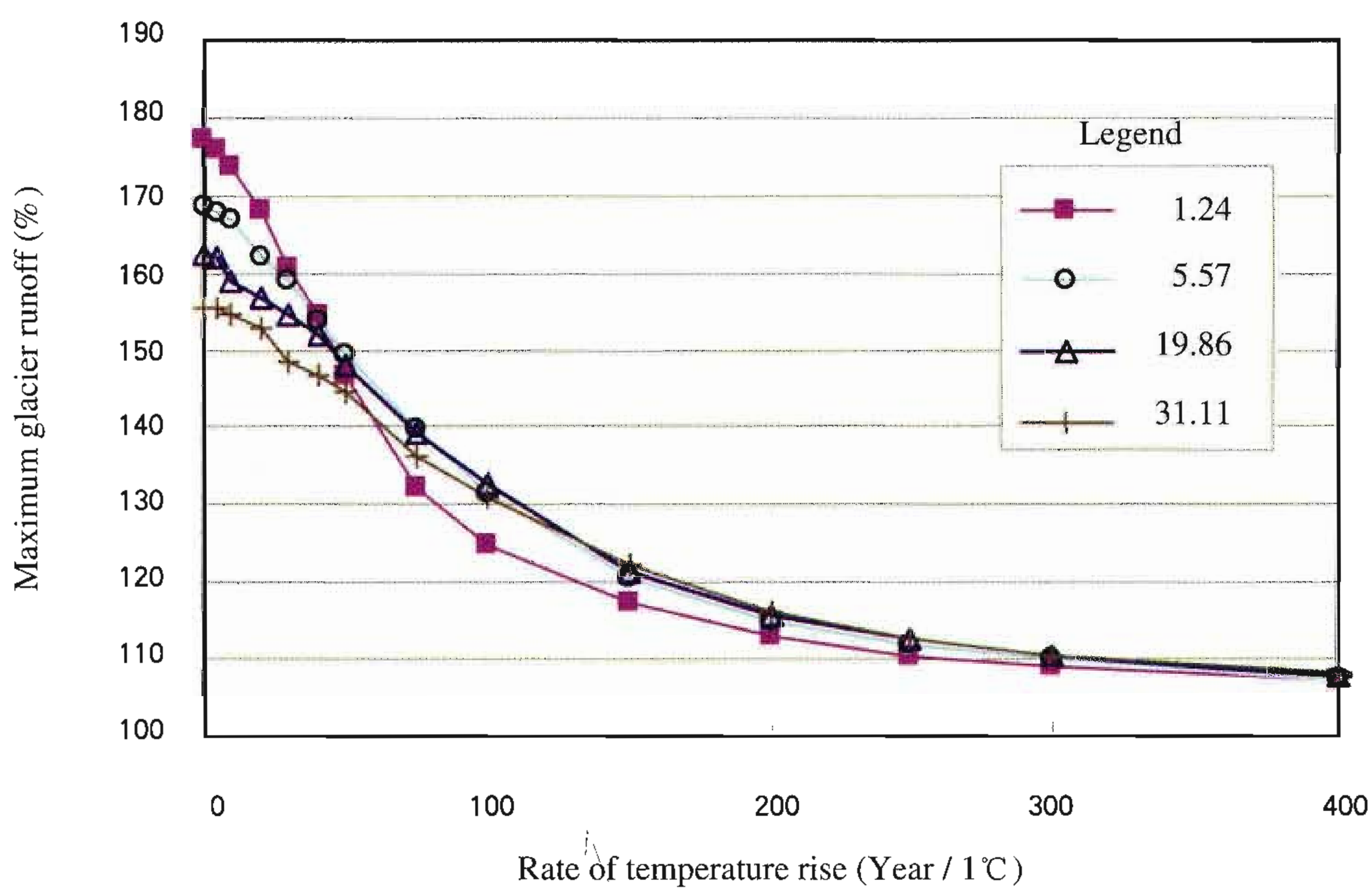


Figure 7-9 Changes in glacier runoff peak according to different speeds of air temperature increase and various glacier sizes (legend is glacier area, km²)

The more quickly the air temperature rises, the earlier the runoff pick occurs and the larger the runoff peak becomes. Smaller glaciers are more sensitive to climate change. Their runoff peak is larger, and their attenuation occurs more quickly. The time that runoff peak occurs is related to the speed of air temperature increase, also indicating that when glaciers are smaller, their runoff is more sensitive to climate change. The discrepancy between runoff amount and air temperature change is in fact an expression of the lag response of glaciers to climate change. According to the observations and statistics, when air temperature increases 1℃, glacier runoff increases by 60% to 80% for the continental glacier region (Figure 7-9).

3. Response of different types of glaciers to climate change

The Chinese glaciers are divided into maritem, sub-continental and extreme-continental glaciers based on a study of the characteristics of the Chinese glaciers (Shi Yafeng and Xie Zichu, 1964; Xie Zichu *et al.*, 1982). The glacial mass balance level (m) for each type of glacier is: $m > 1500$ mm for maritem glaciers; 500 mm $< m <$ 1500 mm for sub-continental glaciers; $m < 500$ mm for extreme-continental glaciers. Glacier runoff in maritem glaciers is more sensitive to the variation in air temperature due to the plentiful precipitation and higher temperature in maritem glacial areas. Continental glaciers, on the other hand, respond relatively slowly to climate change. This is evident either from glacier change since the Little Ice Age, or computed by statistical models (Liu Shiyin *et al.*, 2002a,b; Liu Chaohai *et al.*, 2002b). Xie Zichu *et al.* (personal correspondence) have even discovered the zones (within maritem and continental glacier zones) of glacier and the glacier runoff sensitivity to climate change.

As discussed above, glacier runoff increases in response to climate warming. Nevertheless, how much glacier runoff will increase and the future time when runoff will begin to decrease is difficult to predict and estimate at present due to the uncertainty of climate change and the complexity of variation in glacier runoff. Making these predictions would require more sophisticated and detailed research. We should mention that the amount of decrease in glacier runoff is not equal to that of watershed runoff after glaciers shrunk. Glacier runoff would decrease, while at the mean time non-glacier runoff increasing along with the non-glacier surface area increasing. The variation of watershed runoff would increase, however, as a result of glacier runoff's ability to regulate water resources weakening due to the decrease in total glacier area.

CHAPTER 8 GLACIER CHANGES IN WEST CHINA

Liu Shiyin and Ding Yongjian

8.1 Glacier changes since the Little Ice Age

The "Little Ice Age" (LIA) is a period of three cold phases during the 15th ~19th centuries, when glaciers advanced and formed about three fresh end moraines. The timing of these three cold phases differed greatly in different parts of West China. Chronological data from end moraines, ice cores and tree ring width indicate that glaciers expanded to their largest size during the 17th century, which may be related to the solar radiation Maunder Minimum Event (1645~1715) (Wang Ninglian *et al.*, 2000).

By using aerial photography in combination with 1 : 50,000/1 : 100,000 scale topographical maps, we can determine the extent of the LIA glaciers, including their glacier area, length and terminus altitude. Ice volume during the LIA can be estimated from the statistical relationship between the volume and area of glaciers. Studies of glacier change since the LIA maximum began in the 1980s. Wang Zongtai (1992) has measured the LIA glacier extents of over 800 glaciers in the Qilian Mountains, the Tianshan Mountains, the Altay Mountains, the Kunlun Mountains and the interior region of the Qinghai-Tibetan Plateau. Su Zhen and Shi Yafeng (2002) have surveyed the LIA glacier extents of more than 1000 glaciers in the southeast Tibet. Wang Ninglian and Ding Lianfu (2002), Liu Shiyin *et al.* (2002a, 2003), and Lu Anxin *et al.* (2002) have also measured the LIA glacier extents in the eastern Tanggula Range, the A'nyemaqen Range at the source of the Yellow River, the Qilian Mountains, and the Geladaindong area at the source of the Yangtze River. Glacier changes between the LIA and the 1950s~1980s can be determined by comparing glaciers' sizes, lengths, and terminus altitudes from various dates. With the widely used RS and GIS techniques for glacier mapping, we can compare glacial changes during a certain period using a GIS-based glacier inventory system as shown in Figure 8-1.

By combining the above-mentioned data with that of 844 recently measured glaciers in the middle and western Himalayas and inner Qinghai-Tibetan Plateau, we have determined the LIA

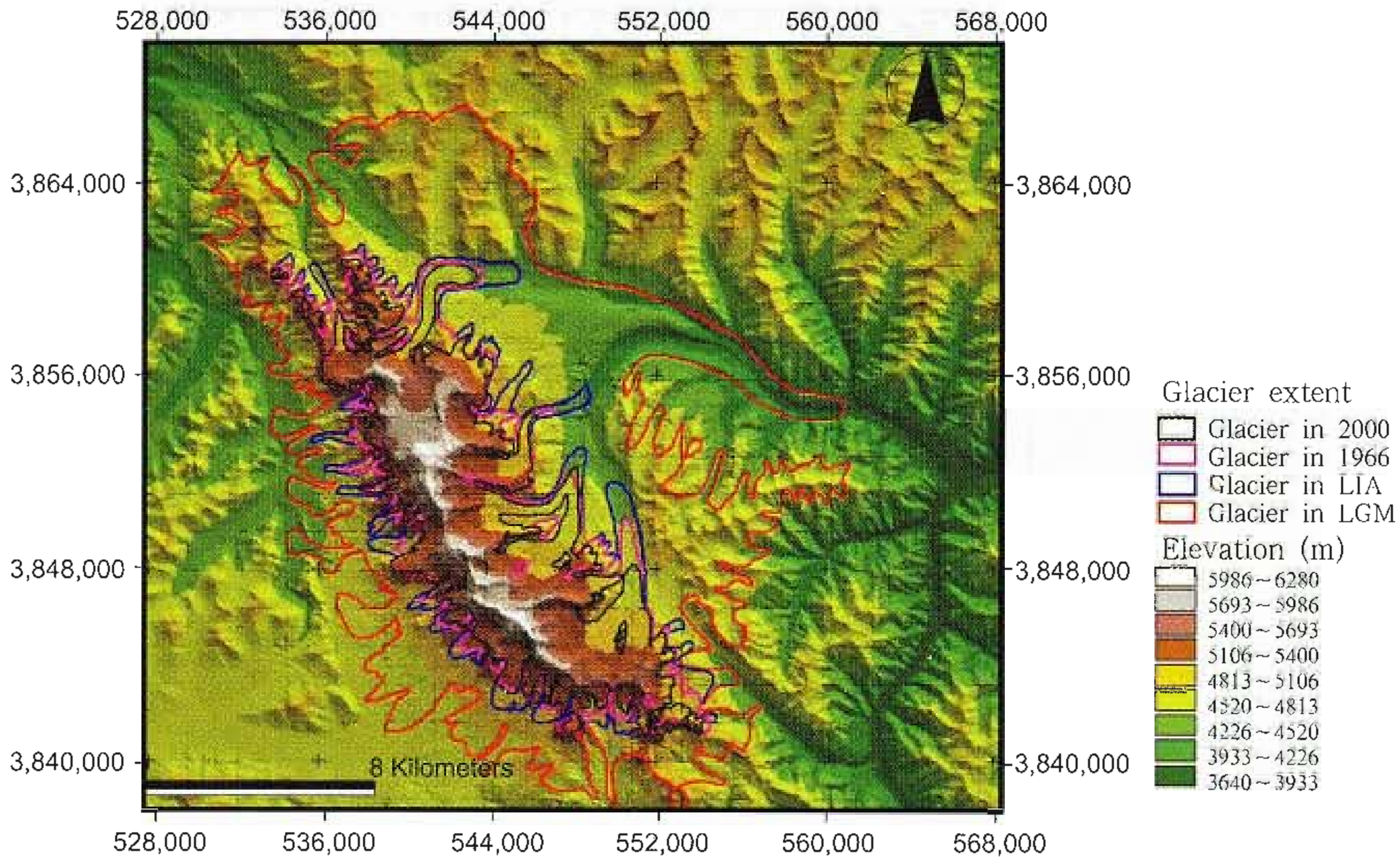


Figure 8-1 Overlay analysis of glaciers in the A'nyemaqen Range at the source of the Yellow River
(LIA maximum: blue; 1966: pink; and 2000: black; the background is a DEM derived from 1:100,000 topographical maps)
(Produced by Liu Shiyin)

glacier extents for over 3100 individual glaciers in West China.

Statistical analyses of the above-mentioned data reveal that a linear relationship exists between the LIA area (S_{lia}) and that of modern glaciers (S_m), the same for LIA ice volume (V_{lia}) and modern ice volume (V_m), and for LIA length (L_{lia}) and modern length (L_m) as follows:

$$S_{lia} = 1.0172 \times S_m + 0.3285 \quad (R^2 = 0.99, n=2409) \tag{8-1}$$

$$V_{lia} = 1.0161 \times V_m + 0.028 \quad (R^2 = 0.99, n=2408) \tag{8-2}$$

$$L_{lia} = 1.0533 \times L_m + 0.3351 \quad (R^2 = 0.98, n=1372) \tag{8-3}$$

Glacial ice volume is calculated by the following equation (Liu Shiyin *et al.*, 2003):

$$V = 0.04S^{1.35} \tag{8-4}$$

(V: glacial ice volume in km^3; S: glacier area in km^2)

By applying these equations, we can calculate geometrical changes in glaciers in West China since the LIA without conducting field measurements (Table 8-1).

Table 8-1 shows that glacier area in West China has decreased by roughly 16,013 km^2, 21.2% of the total glacier area during the LIA maximum. This mass loss corresponds to a total ice volume decrease of 1373 km^3 ($12,358 \times 10^8$ m^3 water equivalent). However, the degree of glacier shrinkage since the LIA shows an obvious regional patterns. Glacial shrinkage demonstrates a radial pattern with the degree of shrinkage increasing gradually from the central Qinghai-Tibetan Plateau toward its surrounding mountains. For example, regions located far from the interior of

Table 8-1 Glacier area changes since the Little Ice Age in West China

Water system	Glacier number	Area of modern glaciers (km^2)	Area decrease since the LIA (km^2)	Percentage of glacier area decrease (%)	Ice volume of modern glaciers (km^3)	Ice volume decrease since the LIA (km^3)	Percentage of ice volume decrease (%)
Ob River	403	289.3	−137.4	−32.2	16.4	−11.6	−41.4
Yellow River	176	172.4	−60.8	−26.1	12.3	−5.1	−29.3
Yangtze River	1332	1895.0	−470.2	−19.9	147.3	−39.6	−21.2
Mekong R.	380	316.3	−130.3	−29.2	17.9	−10.9	−37.8
Salween River	2021	1730.2	−693.7	−28.6	115.0	−58.4	−33.7
Ganges R.	13,008	18,102.1	−4584.5	−20.2	1622.8	−389.6	−19.4
Indus River	2033	1451.3	−692.8	−32.3	93.9	−58.4	−38.3
Central Asian Region	2385	2048.2	−818.7	−28.6	143.7	−69.0	−32.4
East Asian Region	19,298	25,584.3	−6779.4	−20.9	2653.5	−582.4	−18.0
Qinghai-Tibetan Plateau Region	5341	7836.1	−1645.4	−17.4	777.5	−148.1	−16.0
Total	46,377	59,425.2	−16,013.2	−21.2	5600.3	−1373.1	−19.7

the Qinghai-Tibetan Plateau, like the southern slopes of the Altay Mountains, the Ili River basin, the northwestern Tianshan Mountains, source regions of the Mekong River, the Nujiang and Yangtze Rivers in the Hengduan Mountains, and lower reaches of the Yarlung Zangbo (Figure 8-2), have lost much more glacier area and ice volume than the central part of the Plateau. Such a regional pattern of glacial shrinkage is closely related to the location of different glacier types and their response sensitivities to climate change.

The above estimation of glacial shrinkage did not include the ice loss resulting from the total disappearance of small glaciers since the LIA maximum. A study by Wang Ninglian and Ding Lianfu (2002) indicated that about 184 glaciers less than 0.6 km in length might have completely disappeared in the Bujiagangri region of the eastern Tanggula Range since the LIA, accounting for a total glacier area of 24 km^2, roughly half of the glacier area decrease. Approximately 82.8% of modern Chinese glaciers are smaller than or equal to 1 km^2, suggesting that many glaciers smaller than 1 km^2 existed at the time of the LIA maximum and disappeared during the later warm period. As a result, the above estimation of glacial shrinkage could be considerably lower than the actual change of area and volume of glaciers since the LIA maximum.

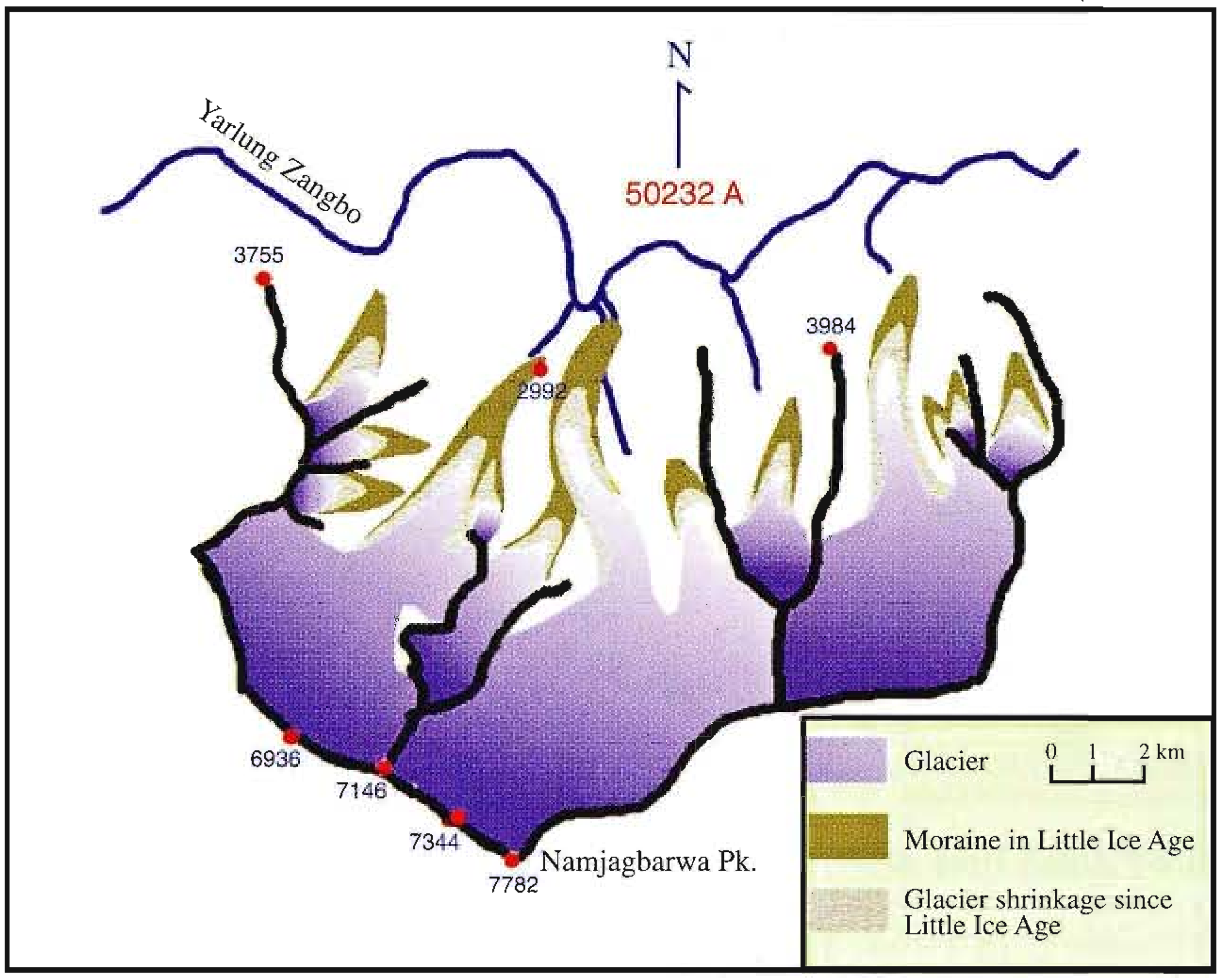


Figure 8-2 Glacier distribution and changes since the Little Ice Age at the Namjagbarwa Peak

8.2 Glacier changes during recent decades

Widespread glacial changes in West China during recent decades are evident in the monitored results of a representative glacier region obtained from satellite images. Glacier No.1 at the source of the Urumqi River in the Tianshan Mountains is the glacier with the longest and most continuous measurements in China. In addition, some other glaciers, like the Qiyi Glacier in the middle part of the Qilian Mountains and the Hailuogou Glacier on the southern slope of the Mount Gongga, were measured discontinuously during the 1970s and 1990s. Others, like the Xiao Dongkemadi Glacier in the Tanggula Range and the Meikuang Glacier in the eastern Kunlun Mountains, have a shorter record of observation since the end of the 1980s. However, the mass balance history of the Qiyi and Hailuogou Glaciers was reconstructed from the meteorological and hydrological observations near these two glaciers.

Observations of the mass balance and terminal position of Glacier No.1 show that this glacier has been retreating since the 1960s. In 1993, the originally connected eastern and western branches of Glacier No.1 separated completely from each other, resulting in a retreat of 139.7 m during 1962~2001. Since then, the eastern and western branches have been retreating at an average annual speed of 4.5 m. Repeated mapping of Glacier No. 1 shows that the glacier area has shrunk from 1.95 km^2 in 1962 to 1.73 km^2 in 2001 (Li Zhongqi *et al.*, 2003). The glacier's retreat results from a total mass loss of 10,597 mm during 1959~2002, equal to a reduction in the glacier's thickness of 10.6 m. Since 1995~1996 the glacier mass loss has been accelerating. The Qiyi Glacier had a positive mass balance during 1956~1988 with an accumulated mass balance of 1637 mm (Liu Chaohai *et al.*, 1992), and, in general, the glacier had a low mass balance level. In the year 1976 a transition occurred, however. The glacier achieved a balance state in that year, but afterwards the glacier's mass balance switched from a positive trend to a negative trend. Recent observations indicate that the glacier's retreat did accelerate under the influence of regional climate warming (Liu Shiyin *et al.*, 1998). Observations of the Xiao Dongkemadi Glacier and the Meikuang Glacier also show a reversal to negative mass balance, with an accelerated mass loss after 1993. As a response to their negative mass balance, both glaciers started to retreat in 1994. The Xiao Dongkemadi Glacier, for example, has retreated by 13 m since 1994.

We have collected information about glacier changes on a regional scale from repeated aerial photographs, remote sensing and extensive field investigations of some representative glaciers. Repeated aerial photographs were taken of glaciers in the Urumqi River (1964~1992), the Sikeshu River (1962~1989), and the Kax River (1962~1989) in the Tianshan Mountains (Liu Chaohai *et al.*, 2002b). A total of 155 glaciers in the Urumqi River, 30 glaciers in the Sikeshu River, and 66 glaciers in the Kax River showed predominant shrinkage during the study periods; only one glacier in the Sikeshu River was in a state of advance, and three glaciers were in a stable state. Altogether, the glacier area in the arid region of the northwest China decreased by 4.9%, and their terminus retreated at annual speeds between 3.5m and 6.2m. Comparisons of topographical maps and Landsat images revealed that glaciers have generally been retreating in the western Qilian Mountains (1956~1990) (Liu Shiyin *et al.*, 2003), at the source of the Yangtze River (1969~2000) (Lu Anxin *et al.*, 2002), at the source of the Yellow River (1967~2000) (Liu Shiyin *et al.*, 2002c), in the Gangrigabu Mountains (Figure 8-3), in the eastern Pamirs (Figure 8-4), as well as at the Purog Kangri Ice Field (1974~2000) (Pu Jianchen *et al.*, 2002). Of all these regions, glaciers in the A'nyemaqen Range at the source area of the Yellow River have experienced the largest retreat or 17% of the glacier area during 1967~2000. The region with the second largest glacial retreat was the

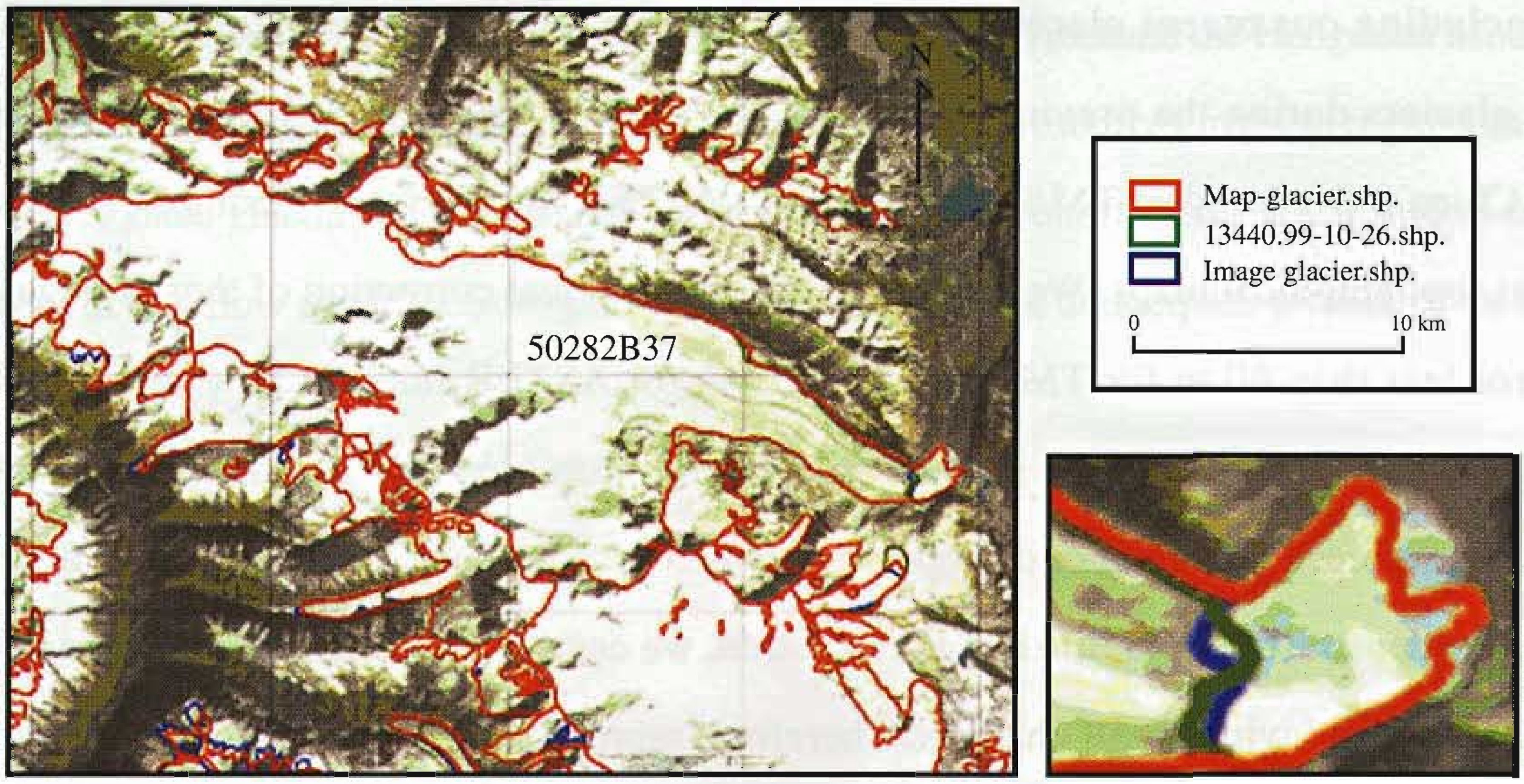


Figure 8-3 Terminus variations of the Yalong Glacier from 1980 to 2001 (Red: 1980; Green: 1999 and Blue: 2001)

western Qilian Mountain (12%), and the least was the source of the Yangtze River (1.7%) and the Purog Kangri Ice Field. On the other hand, some glaciers were in a stable state in the A'nyemaqen Range and in the Geladaingdong area, and some glaciers were even in a state of advance.

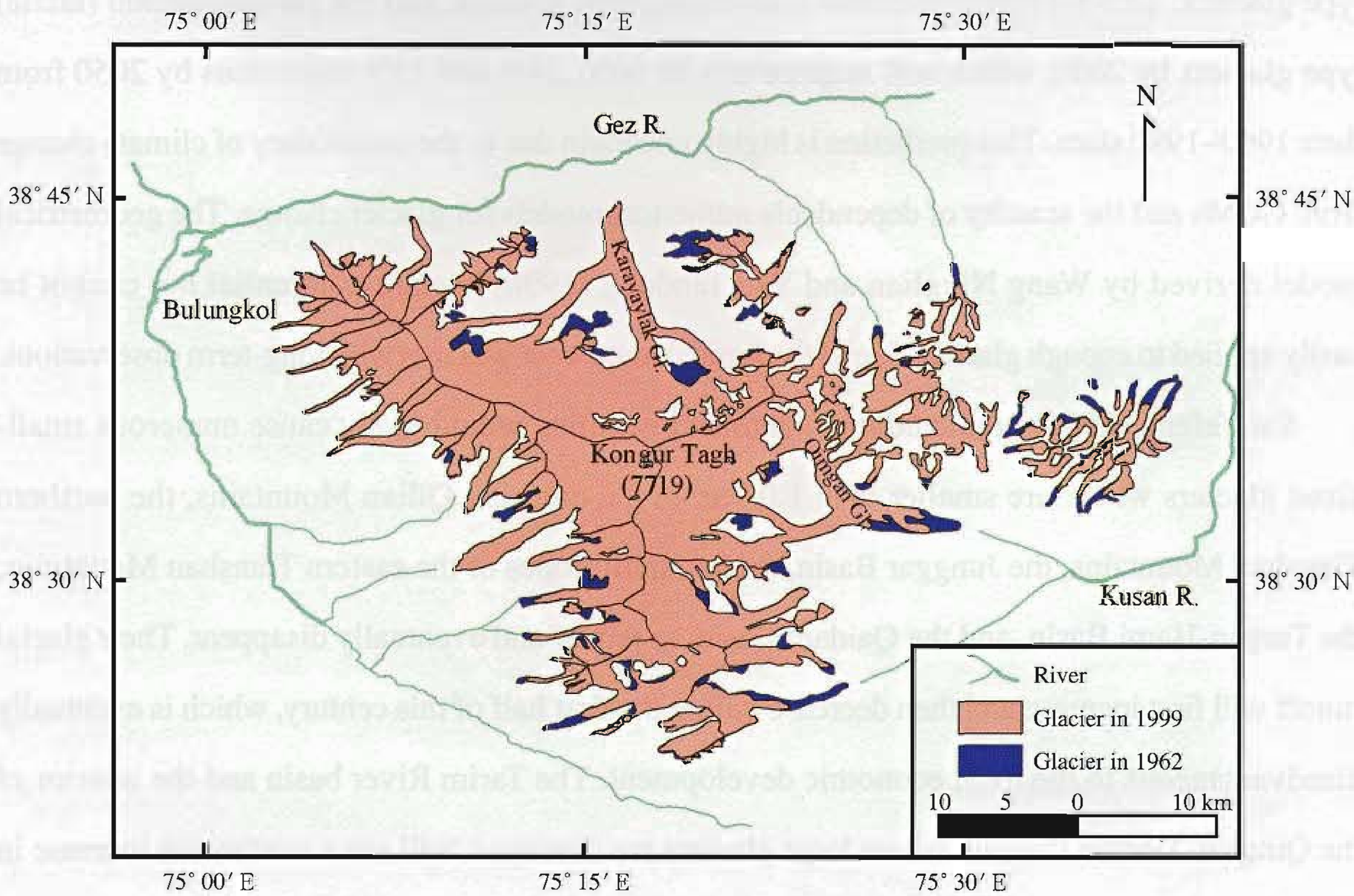


Figure 8-4 Glacier change of Kongur Tagh in the Pamirs since 1962

Including our recent glacier data collection, we have observed the changes of over 1700 glaciers during the previous decades in selected representative mountain regions in West China using Landsat TM/ETM$^+$ and Terra ASTER images taken during 2000~2002 as well as topographical maps. We made a careful geometrical correction of these images with an error less than 60 m for TM/ETM$^+$ and 30 m for ASTER images. If we exclude those glaciers whose length change is less than the correction error, we find that over 80.8% of glaciers have been retreating or disappearing. However, 19.2 % glaciers have been advancing. Given the constraint of satellite image resolution, we cannot provide a rational interpretation for glaciers displaying small changes. Therefore, mindful of these considerations, we offer general conclusions about recent glacier changes in West China.

8.3 Glacier changes in the future and its impact on water resources in West China

Shi Yafeng and Liu Shiyin (2000) have predicted glacier changes that will occur due to global warming in this century. They predict that three types of glaciers in West China will experience different degrees of intensive shrinkage: a glacier area decrease of 30% for maritime type glaciers, 12% for sub-continental (sub-arctic) type glaciers, and 5% for continental (arctic) type glaciers by 2030, which will respectively be 50%, 24% and 15% reductions by 2050 from their 1960~1980 sizes. This prediction is highly uncertain due to the uncertainty of climate change from GCMs and the scarcity of dependable numerical models for glacier change. The geometrical model derived by Wang Ninglian and Yao Tandong (1996) has great potential but cannot be easily applied to enough glaciers due to the limited number of glaciers with long-term observations.

Shi Yafeng (2001) predicted that continued warming would likely cause numerous small-sized glaciers which are smaller than 1.0 km^2 in the northern Qilian Mountains, the northern Tianshan Mountains, the Junggar Basin, the southern slopes of the eastern Tianshan Mountains, the Turpan-Hami Basin, and the Qaidam Basin, to retreat and eventually disappear. Their glacial runoff will first increase and then decrease during the first half of this century, which is eventually disadvantageous to the local economic development. The Tarim River basin and the interior of the Qinghai-Tibetan Plateau, where large glaciers are dominant, will see a continuous increase in glacial runoff until 2050, which is advantageous to economic development in those regions.

Meanwhile, maritime type (temperate) glaciers in the southeast Tibet and the Hengduan Mountains will experience an accelerated ablation. Changes to the water resources in these regions may not be obvious since glacial runoff is a small percentage of river runoff there. Yet, disasters such as floods or debris-flow resulting from glacier change will increase and require protective measures.

CHAPTER 9 APPLICATIONS OF *GLACIER INVENTORY OF CHINA*

Wang Zongtai

Glacier Inventory of China contains more than 1,760,000 pieces of information, laid out in systematic and unified arrangements, enabling to a wide range of applications and providing basic information for scientific research on glaciology and economic development.

9.1 Glacier Inventory and glaciological researches

A glacier inventory provides the most basic information for research on glaciology. The successful completion of *Glacier Inventory of China* is a milestone in the progress of Chinese glaciological research.

Glaciology research in China began with a preliminary investigation of modern glaciers in the Qilian Mountains in 1958 and the subsequent publication of the first monograph on glaciology in 1959, *i.e. Report on Investigation of Glaciers in the Qilian Mountains*. Although large-scale investigation of glaciers in the Tianshan Mountains, at the Mount Qomolangma and other regions in the Qinghai-Xizang (Tibet) Plateau soon followed, little was known about the quantity, distribution and features of glaciers in China. The Lanzhou Institute of Glaciology and Geocryology, CAS, started to compile a comprehensive Chinese glacier inventory in 1978 in response to the summons of Temporal Technical Secretariat (TTS) of *World Glacier Inventory*. Three years later in 1981, a volume of glacier inventory in the Qilian Mountains volume was published, marking the beginning of systematic compilation of *Glacier Inventory of China*. After more than 20 years of hard work, a total of 12 volumes and 22 issues of *Glacier Inventory of China* was published in 2002. Additional articles and monographs on the quantity, distribution and characteristics of Chinese glaciers on a regional and national scale have been published along with this inventory. All of these scientific efforts laid a solid foundation for quantitative analyses of regional characteristics of glaciers in China and provided background information for research on recent glacier changes in response to global warming. The Dund Flat-topped

Glacier in the Qilian Mountains, the Purog Kangri Ice Field on the Qinghai- Xizang Plateau and the Guriya Ice-Cap in the western Kunlun Mountains, all were primarily surveyed in *Glacier Inventory of China*. They are determined as ideal places for ice-core drilling and paleo-environmental reconstruction. The investigation on glaciers in the Altay Mountains coupled with compilation of the glacier inventory and development of an ice thickness sounding radar, which has been used on dozens of glaciers, made it possible to accurately estimate the ice volume of glaciers and a significant step forward for research on glaciers at regional and national scales in China.

9.2 Glacier Inventory and glacier water resources

Total global water resources are approximately 13.86×10^8 km^3, of which all sources of freshwater account for only 2.5%. Snow and glaciers store an estimated sum of 68.7% of this freshwater. Apart from the Arctic and Antarctic areas, 66% of ice and snow resources lie in Asia, 30% of which is in China (Wang Zongtai and Su Hongchao, 2003). Glaciers are valuable and high-quality sources of freshwater in Chinese western arid regions. Total glacier volume in West China, equivalent to $50{,}400 \times 10^8$ m^3 of freshwater, is 9.7 times as the annual total river runoff (5176×10^8 m^3) in that region. These glacier water reserves recharge rivers that originate from glaciers at an annual rate of 616×10^8 m^3, accounting for 12% of the average annual runoff in West China. Since large parts of glaciers in China are located in the northwest arid regions, the percentage of glacier meltwater recharging that region's rivers is higher than the national average. For example, rivers like the Yarkant, the Yurungkax, the Gez, the Muzart and the Ogan in Xinjiang have a glacier meltwater contribution as high as 53.0%, 59.3%, 77.8%, 81.1% and 85.6%, respectively, of the total surface runoff.

Glacier Inventory of China provides a scientific basis for estimating and projecting glacier water resources, crucial to many aspects of research and water resource planning. These studies and plans include: the State Key Project for *Water Resource Assessment* in 1985; the project of the Water Conservancy and Hydropower Planning Institute for *National Water Resources Planning Services* in 2003; and various projects in the western provinces: including *Gansu Province Inland River Water Resources Assessment; Plan for the Reasonable Development and Utilization of Water Resources in Gansu Province; Xinjiang Water Resources Planning and Assessment, and*

Ice-Snow River Runoff Estimation; Study on Water Balance in Xinjiang; Xinjiang Water Resources Survey; Planning and Development of Water Resources in Qinghai Province and the Tibet Autonomous Region.

The information contained in *Glacier Inventory of China* is crucial for water conservancy and hydropower generation. For example, mountain reservoirs on the Yurungkax River in Xinjiang, water conservancy engineering along the Yarkant River in Xinjiang, irrigation engineering on the Shule River in Gansu Province, and the construction of the Heihe River Reservoir required the accurate estimation of glacier runoff and its changes. The implementation of the Western Region Development Strategy and China's advancement to a prosperous and ecologically sustainable society, with its accompanying urbanization, industrialization, agricultural development, afforestation and grassland restoration, will certainly create a notable increase in water consumption. China is facing a severe conflict between water demand and supply, requiring a careful water resources planning, development and utilization at the watershed level, as well as construction of more regulatory reservoirs in mountainous regions. The prospects for application of *Glacier Inventory of China* are therefore extensive.

9.3 Glacier Inventory and glacier disaster prevention

China is subject to a variety of ice and snow disasters, of which glacier meltwater floods, glacial lake outburst floods, and glacial debris-flow are the three most destructive calamities (Figure 9-1).

Glacial floods fall into two categories: glacier meltwater floods and glacial lake outburst floods. A mega-flood in the summer of 1972 devastated bridges and roadbeds of the China-Pakistan highway near the Batura Glacier (glacier area of 285 km^2 and length of 59 km) in the Pakistan side of the Karakorum Mountains. In order to forecast this type of flood on the basis of the size of glaciers, their advancement or retreat, and parameterized temperature fluctuations, scientists from the Lanzhou Institute of Glaciology and Geocryology, CAS, took two years field work during 1974~1975, then suggested a reasonable and economic project to reconstruct this section of the highway that has been running successfully since then. The Yarkant River in Xinjiang has seen 15 floods since 1953. During one of these devastating floods on September 4, 1961, river discharge surged from 80.6 m$^3 \cdot s^{-1}$ to 6270 m$^3 \cdot s^{-1}$ within 20 minutes (Zhang Xiangsong and

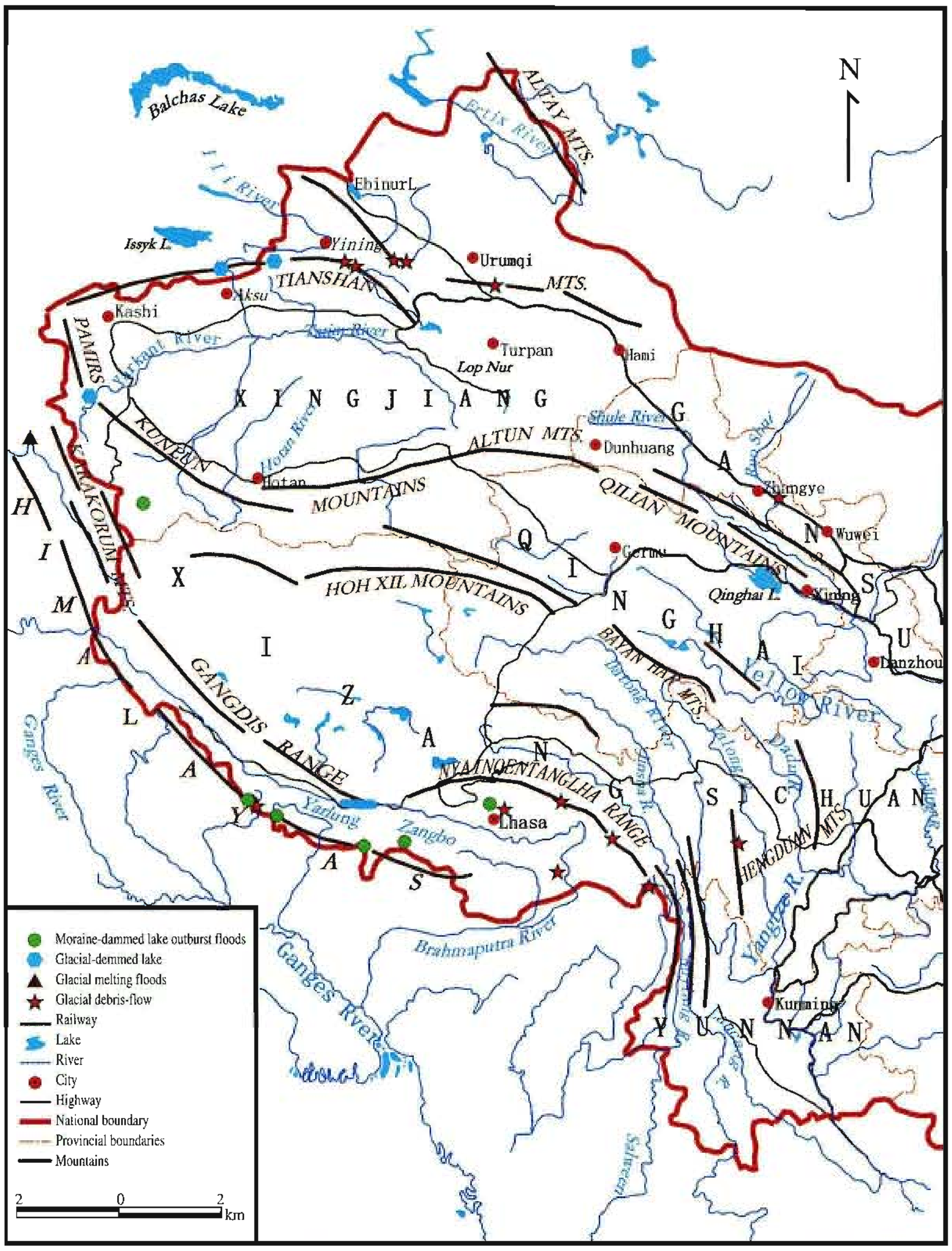


Figure 9-1 The distribution of glacial flash floods and glacial debris-flow

Zhou Yuchao, 1990). An ice-dam glacial lake in a narrow valley blocked by glacier advancement (Kyagar Glacier and Teram Kangri Glacier) during the 1960s and 1980s at the Kulqin riverhead caused this flood when the rising lake level raised hydraulic pressure and subsequently the ice dam collapsed. The South Inylchek Glacier (63.5 km in length and 567.2 km^2 in area) at the border between China and Kyrgyzstan channels its meltwater into the Kumalike River in Xinjiang. The terminus of this glacier blocks a branch valley where the North Inylchek Glacier is located and forms the Merzbacher Lake, which is 4.5 km long and 1.5 km wide at its high water level. Outburst floods have happened there 34 times since 1956 due to ice-dam periodical failure. In the Himalayas, numerous moraine-dammed lakes came into being after the Little Ice Age. The Pumqu and Boiqu River basins in Tibet alone have 274 such lakes. Some of these lakes have large water storage capacity, up to 0.2×10^8 m^3, and their outbursts have and will result in

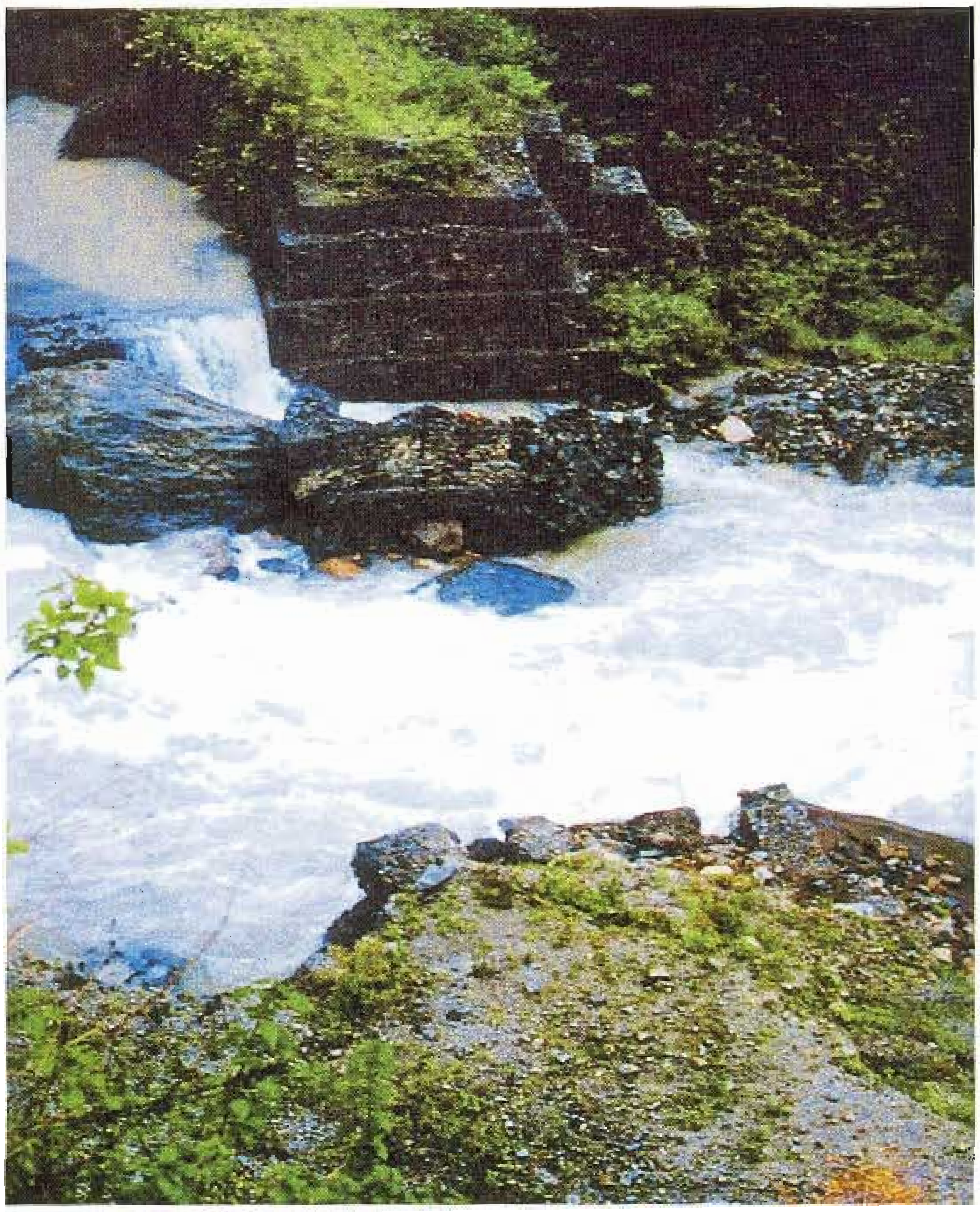


Photo 9-1 The outburst floods of the Cirenma Co end moraine-dammed lake at the Boiqu River in July 1982 devastated the Friendship Bridge on the China-Nepal Highway(Liu Chaohai)

glacial lake outburst floods or glacial debris-flow (Liu Chaohai and Sammal C.K, 1988). For example, in July 1982 the outburst flood of the Cirenma Co, an end moraine-dammed lake at the Boiqu River, devastated not only the China-Nepal highway and the Friendship Bridge lying 50 km away (Photo 9-1), but also the Sun Kosi hydropower station in Nepal. In the same year the outburst of the Jinco Lake, a moraine-dammed lake in Dinggye County inundated eight villages and a vast amount of farmland, killing more than 1600 livestock. The head of the Nyang Qu has 49 moraine-dammed lakes, the largest of which, the Sangwang Lake, has an area of 5.4 km^2. The outburst of this lake in July 1954 released 2.8×10^8 m^3 of lake water and formed a rare glacial flash floods (Chen Chujun *et al.*, 1996). The outburst of the Digetesuo moraine-dammed lake in the upper Lanmoqie Valley in the eastern Nepal released tens of millions cubic meters of lake water in four hours, destroying 14 bridges in Lanmoqie Valley and nearly a whole hydropower station.

Glacial debris-flow is a special type of flood of loosely packed materials such as soil, sand

and stones occurring in areas where modern glaciers develop and snow accumulates. Abundant ice and snow meltwater, large amounts of loose moraine materials, and steep valleys are the three key factors causing glacial debris-flow. The Lanzhou Institute of Glaciology and Geocryology, CAS, has carried out researches on glacial debris-flow since the 1960s after some severe debris-flows occurred in the Guxiang Gully, Bomi County and other sites along the Sichuan-Xizang (Tibet) Highway.

The areas susceptible to glacial debris-flow are also found in the Pamirs, the Karakorum Mountains and the Tianshan Mountains. The heads of the Kuytun River and the Kuqa River include more than 20 valleys that are vulnerable to glacial debris-flow that often blocks traffic (Photo 9-2). The glacial debris-flow at the head of the Sigong River on the northern slope of the Bogda Range devastated a large area of woodland. The Gez-Bulunkoul section along the China-Pakistan Highway in the Pamirs experienced many glacial debris-flow disasters, and the highest frequency of glacial debris-flow occurs in the Airkuran Valley (1~3 times per year). A glacial debris-flow in September 1964 in the Laipu Valley, Dinggye County, in the central Himalayas, spread a vast fan of debris at the valley's mouth (Photo 9-3).

Photo 9-2 Glacial debris-flow and devastated bridges and houses (Deng Xiaofeng)

Photo 9-3 The vast debris fan formed by a glacial debris-flow burying the highway (Deng Xiaofeng)

Photo 9-4 The glacial debris-flow fan at the mouth of the Guxiang Valley (Deng Yangxin)

Glacial debris-flow in maritime type glacier areas mainly occurs in the southeast Tibet and the Hengduan Mountains that border Tibet, Yunnan and Sichuan Provinces. Of these places, the Yiong Zangbo, the Parlung Zangbo, the Dongjiu River, the Nyang Qu, the Jinzhu Qu, the Zayu Qu in the lower reaches of the Yarlung Zangbo experience the highest frequency of glacial debris-flows where there are hundreds of glacial debris-flow gullies (Photo 9-4). The Guxiang, the Peilong and the Dongrunongba are three of these valleys that have become famous for their large, frequent and extremely devastating glacial debris-flows. The huge Guxiang glacial debris-flow in 1953, for example, released a mass of o.1 × 10^8 m^3 of mud and sand and spread a debris fan in an area of 3 km^2, blocking the Parlung Zangbo and forming a lake 5 km long and 1 km wide. The outburst of this new lake inundated a wide area of farmland and blocked the local traffic.

With continuing economic development in mountainous regions, glacial debris-flow disasters will become more and more serious. Under the influence of global warming, accelerated glacier shrinkage will increase glacial meltwater discharge, causing a higher occurrence of glacial debris-flow and forming new regions prone to these disasters.

Disasters such as glacial floods, glacial debris-flows and glacier lake outburst floods result from glacial activity and vary in their intensity according to differences in the location and physical characteristics of glaciers. The location, size and characteristics of glaciers documented in *Glacier Inventory of China* provide a scientific basis for prediction, forecasting and prevention of these disasters. Using information in *Glacier Inventory of China*, the Xinjiang Water Conservancy and Hydropower Planning Institute improved the precision of its forecasting during the Yarkant River flood event in August 1999, coordinating various flood-control departments to take prompt and effective measures to gain time for flood protection, minimize losses, and maximize hazard-prevention and social benefits. This is an exemplary success in using *Glacier Inventory of China* for disaster prevention and reduction.

9.4 Glacier Inventory and environmental monitoring

1.Glaciers being an indicator of climate change

Any changes in temperature and precipitation will produce corresponding fluctuations in glaciers. Different scales of glacial and interglacial ages in the earth's recent history are the result of glacial fluctuations in response to climate alterations. We can date the organic matter and radioactive isotopes contained in glacier and moraine formed during glacial periods using various methods, such as ice core, radiocarbon dating, paleomagnetism and lichenometry etc, from which paleoclimate and paleoenvironmental conditions can be reconstructed. For example, the lichenometry of the end moraines below No.1 Glacier at the Urumqi riverhead formed during the Little Ice Age shows that three glacier advances occurred at 1538 ± 20 A.D., 1777 ± 20 A.D., and 1871 ± 20 A.D., respectively, with average annual temperature and summer temperatures lower by 1.3℃ and 0.65℃, respectively, and annual precipitation higher by 50~65 mm than present (Wang Zongtai, 1991). Oxygen isotopic evidence from the Dund and Guriya Glacier ice cores verified the occurrence of three cold phases, corresponding to three periods of glacier expansion.

The overall trend of the earth's climate since the Little Ice Age has been warming with variability, resulting in obvious glacier shrinkage. The changes in glaciers lag behind that in climate, and the duration of the lag time depends on the size of glaciers. Glaciers longer than 10 km have several decades lag time; whereas smaller glaciers shorter than 1 km have a lag time less than 10 years. Small glaciers are more sensitive to climatic change. Statistical analyses of the expansion and shrinkage of 178 glaciers indicate that most glaciers in China were retreating between the 1950s and 1970s in response to the increased temperature during the 1940s. These analyses also demonstrate that the number of retreating glaciers was decreasing as glaciers were expanding, reflecting temperature decreases between the 1960s and 1970s. Since the 1980s more glaciers have shrunk in response to the rapid increase in temperature.

2. Glaciers being a natural rain gauge

Snow precipitated onto glaciers' middle and upper sections is preserved that forms the annual layers, called the net accumulation of glaciers. The amount of the net accumulation measured at these altitudes is an approximation for annual precipitation in alpine areas.

Ablation equals to accumulation at the equilibrium line altitude. Since glacial ablation is closely linked to summer temperature, we can induce the mean summer temperature at this height to estimate glacial ablation, in other words, to estimate annual precipitation in alpine areas. Liu Chaohai *et al.* (1988) estimated the temperature and precipitation in glacial areas from summer mean temperature at nearby ELAs, which were included in the volume of *Glacier Inventory of China* concerning the Tianshan Mountains. It was found that the maximum annual precipitation of 1200 mm happened on the southern slope of the Awulale Range and the northwestern slope of the Nalati Range in the Tianshan Mountains. The minimum annual precipitation of 400 mm occurred in the southern range of the Tianshan Mountains.

3. Glaciers being a storage of environmental information

Natural and human indication substances of environmental significance fall together with snow onto glaciers and are preserved in the snow and ice layers (Photo 9-5). The oxygen isotope in glacier ice is temperature dependent and decreases/increases by 1.0‰ with an increase/decrease in temperature of 1.6℃ on the northern part of the Qinghai-Xizang Plateau (Yao Tandong *et al.*, 1995). Based on this relationship, the 1.5‰ increase in $\delta^{18}O$ during 1975~1990 equals to a temperature increase of 2.4℃. Information gathered at the Tianshan Glaciological Station at the Urumqi riverhead indicates that the relationship between the monthly mean oxygen isotopic

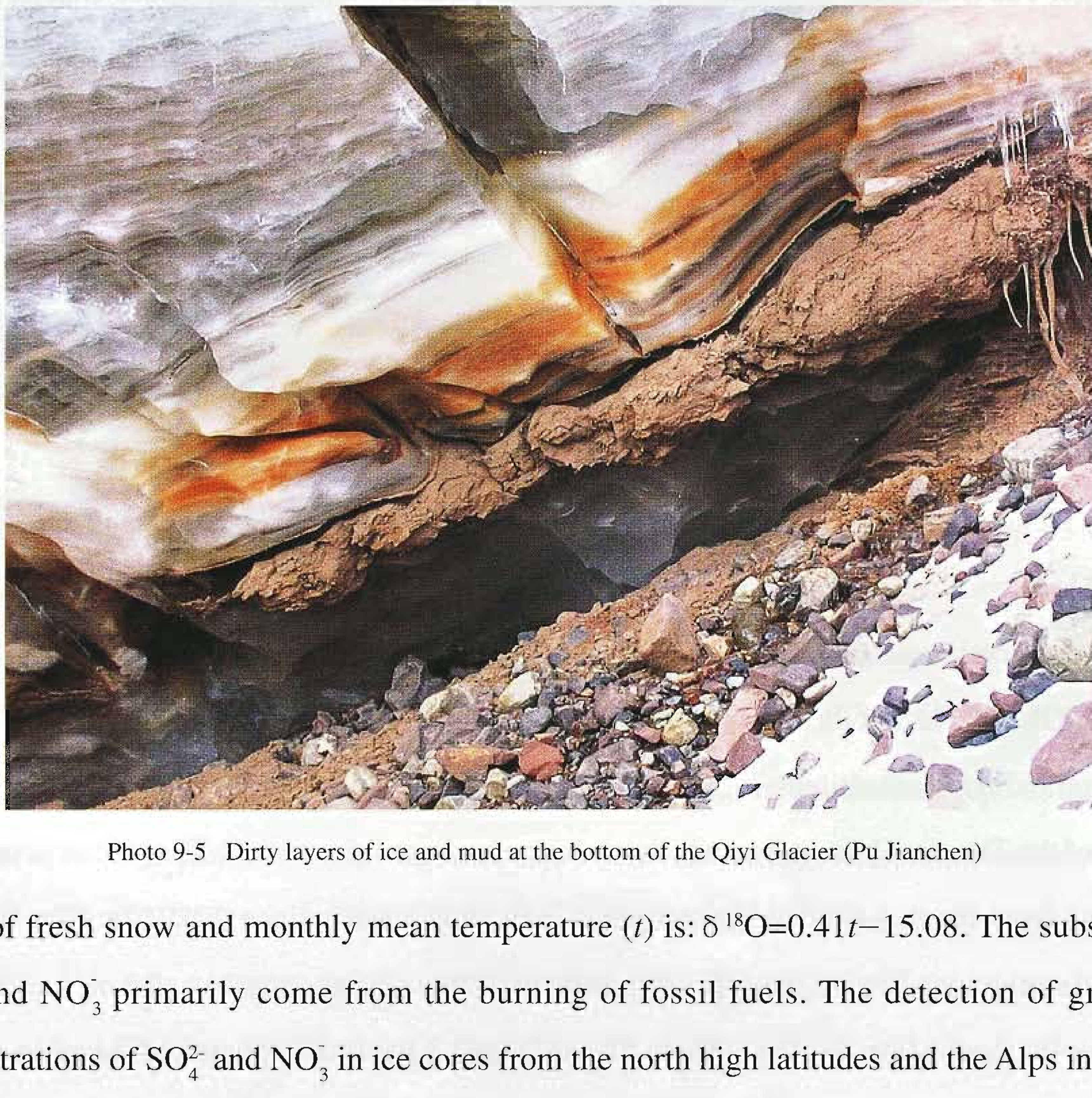


Photo 9-5 Dirty layers of ice and mud at the bottom of the Qiyi Glacier (Pu Jianchen)

value of fresh snow and monthly mean temperature (t) is: $\delta^{18}O=0.41t-15.08$. The substances SO_4^{2-} and NO_3^- primarily come from the burning of fossil fuels. The detection of growing concentrations of SO_4^{2-} and NO_3^- in ice cores from the north high latitudes and the Alps indicates they are from industrial pollution. In contrast, the Guriya ice core shows no growing concentrations of SO_4^{2-} and NO_3^- for the past 100 years, indicating that this region has not been polluted. Concentrations of Ca^{2+}, Na^+, Ma^{2+} and K^+ are lower in warm periods and higher in cold periods. Their peaks of concentration occur during the transitions between warm and cold phases, from which we can infer the climatic instability on the Qinghai-Tibetan Plateau. Particulates such as volcanic ash, cosmic dust and black carbon preserved in ice and snow layers indicate the occurrence of volcanic activity, dust storms and natural fires during the past time. In addition, glacier ice and snow layers can also preserve D, CO_2, CH_4, ^{14}C, ^{10}B, ^{36}Cl, P_6, and microbes and their DNA, revealing the related environmental events.

9.5 Glacier Inventory and tourism development

The exquisite scenery of glaciers (Photo 9-6, Photo 9-7) is a unique tourism resources found far from human domains. Switzerland began development of glacier tourism over a hundred years ago. The United States of America founded the Walton International Peace Glacier Park in the Rocky Mountains. Argentina also established a glacier park on the Patagonia Plateau. China has developed several glacier tourism sites that have already become popular scenic spots.

The Qiyi Glacier (Code 5Y437C18) (glacier area of 2.78 km^2 and terminal altitude at 4310 m a.s.l.) is located at the head of the Liugouquan Valley, along the Beida River tributary, in the northern slope of the Qilian Mountains. The Investigation Team on Utilization of Snow and Ice Resources in the Qilian Mountains, the Chinese Academy of Sciences, made the first survey of this glacier in 1958 and named it as “Qiyi” (“July 1”). It became a tourist site in 1985. At present this site includes accommodations and infrastructure for visitors and management, and a road to about 2 km downstream of the glacier terminus. Every summer many tourists visit this glacier to enjoy the marvelous scenery.

The Glacier No.1 at the headwaters of the Urumqi River (Code 5Y730C29) (glacier area of 1.94 km^2 and terminal altitude at 3730 m a.s.l.) is located in the northern slope of the Tengger Range of the Tianshan Mountains, which has been monitored since 1959. The glacier is only 120 km away from Urumqi City and has attracted individual tourists since the 1980s. The Xinjiang Uygur Autonomous Region has officially designated this glacier a tourism site.

The Baishuihe Glacier No.1 (Code 5K413D1) (2.7 km in length and 1.52 km^2 in area) is located in the eastern slope of the Yulong Xueshan, about 100 km away from Lijiang City in Yunnan Province. The glacier's surroundings include magnificent woodlands and meadows elevated above a subtropical setting. The snow-covered mountains, forests and gorges form a diversified landscape. Since its development in the 1990s, a ropeway has been built along the glacier's tongue, attracting numerous domestic and overseas tourists, and making it one of the most popular scenic spots in Yunnan Province.

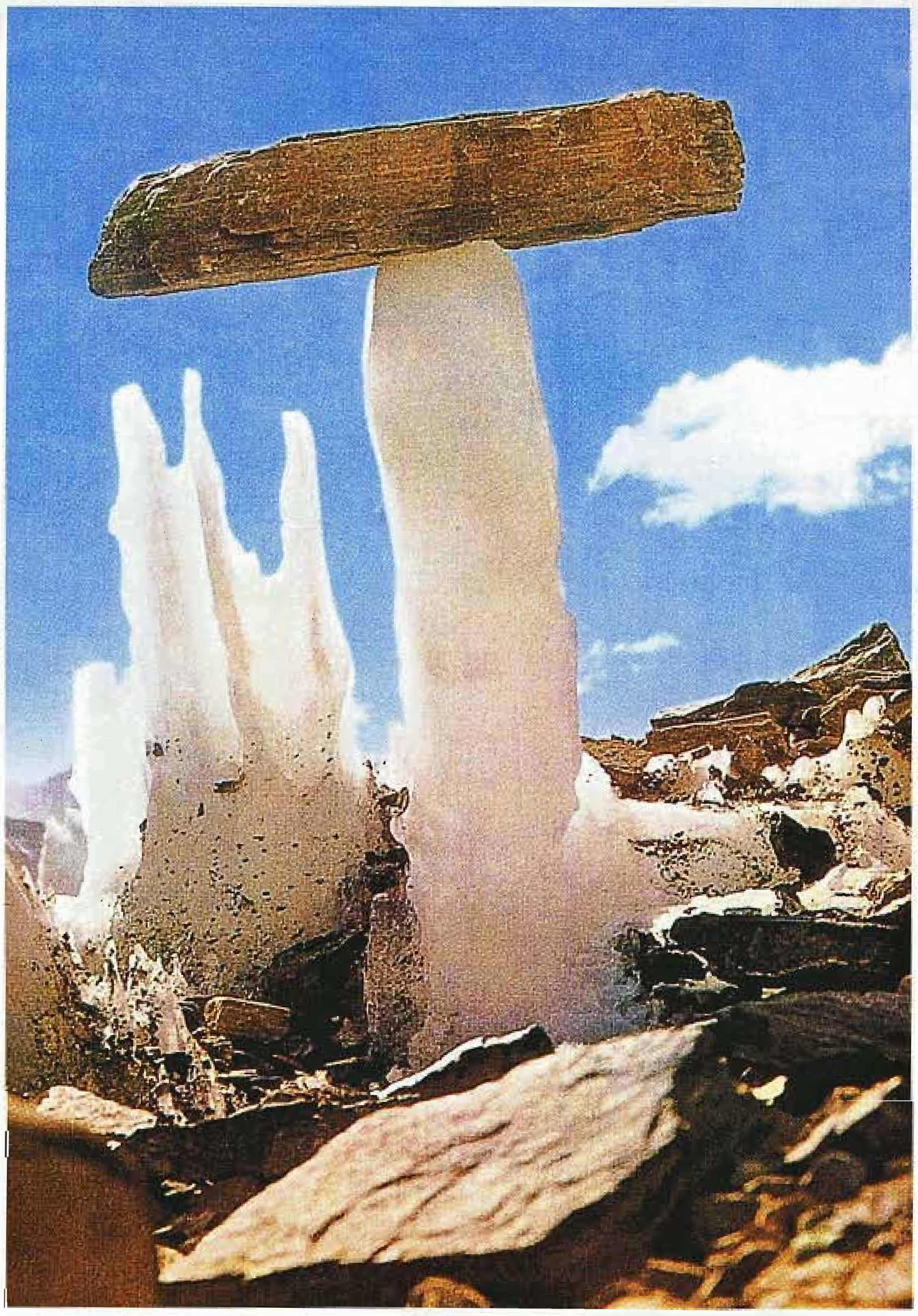


Photo 9-6 An ice mushroom with a flat cap and long neck (Cited from *Chinese Glaciers*, 1980)

The Hailuogou Glacier (Code 5K612F8), a valley glacier on the eastern slope of the Mount Gongga in Sichuan Province, covers a glacier area of 25.7 km^2 and the terminal extends downward to an altitude of 2980 m a.s.l. The peak of this glacier's backwall stands 7556 m a.s.l., and its magnificent ice falls with altitude span of 1050 m. Along the valley occur hot springs, dense forests, and a variety of blossoming flowers. An unprecedented number of tourists have come by road and ropeway to the glacier's midsection since. Tourism development began here in the 1990s.

These glacier parks presently operated are just the prologue in the glacier tourism development in China. There are abundant glacier tourism resources in West China. By combining glacier tourism, mountaineering and exploration, tourists can experience firsthandly a marvelous expanse of ice field, free their spirits, strengthen their strength and willpower, and enjoy unbelievably beautiful scenery. Yet this type of tourism requires a further development of glacier resources.

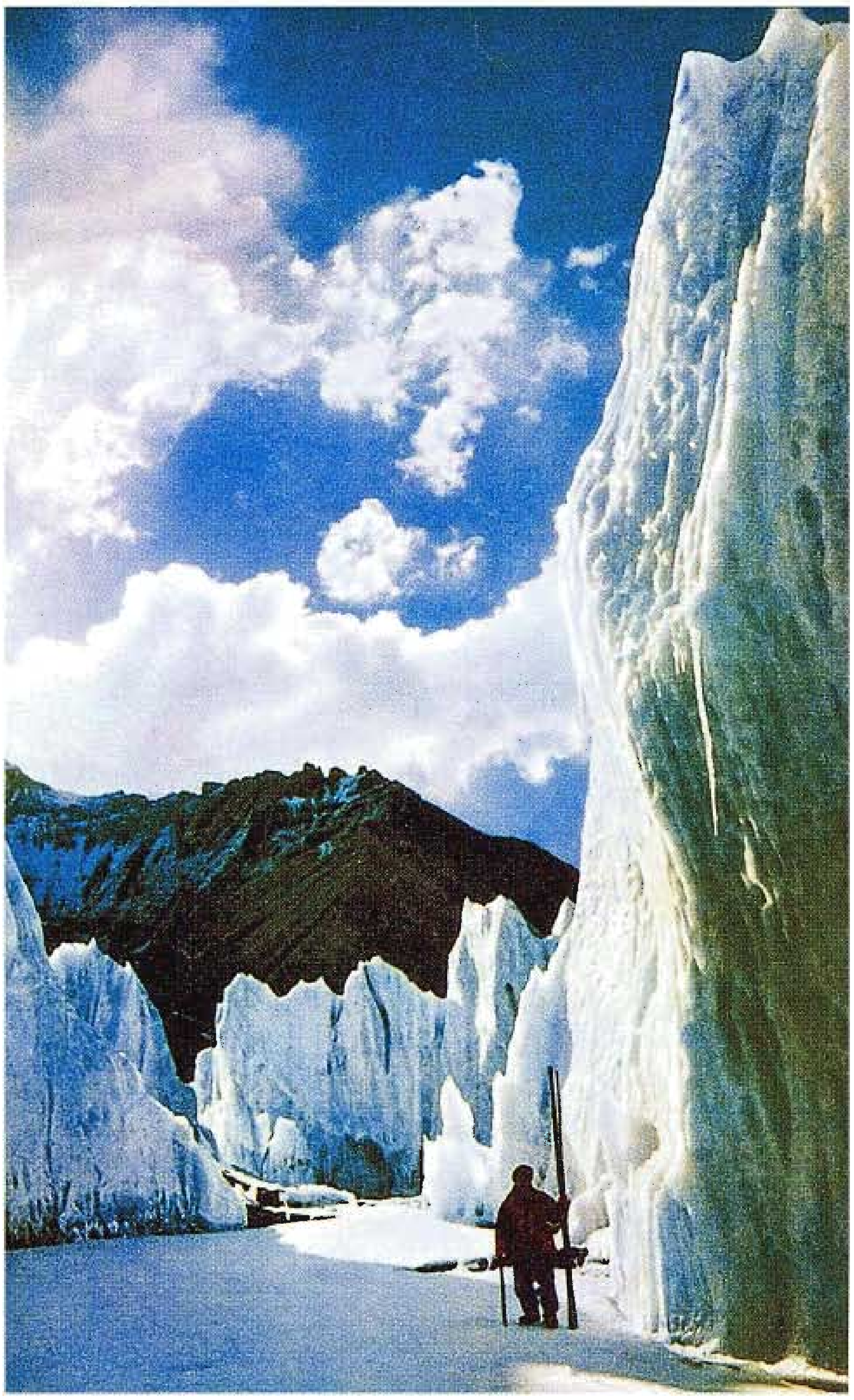


Photo 9-7 An ice-tower on the Rongbuk Glacier on the northern slope of the Mount Qomolangma (Wang Zongtai)

From information about the location, shape, characteristics, and comprehensive assessments of glaciers provided in *Glacier Inventory of China*, we list the following glaciers that may be potential for development as glacier parks.

The Kanas Glacier in the Altay Mountains (Code 5A255E21) is located at the head of the Burqin River. It is 10.8 km in length, 30.13 km^2 in area, and its terminal altitude stretches as low as 2416 m a.s.l. This large glacier features a gorgeous scenery, and the Kanas Lake scenic spot is only 60 km away from the glacier. Together these two sites can form a first-class tourist attraction.

There are 469 glaciers around the Mount Bogda with a total area of 213.85 km^2 and terminus ranging in altitude from 3100m a.s.l. to 3300 m a.s.l. This region features a great many diverse landscapes and high, ice-capped mountains. Tourists can see forests, meadows and unique panoramas in the valleys. The Tianchi Lake, a famous scenic spot, sits nestled in the arms of the mountains. The Lanzhou-Xinjiang Railway passes through the southern part of this region. Cities like Urumqi, Fukang and Jimusar are all located within a radius of 50 km, making it an ideal place for development of an alpine glacier park.

The Muzart Glacier in the Tianshan Mountains (Code 5Y681D24) is located at the head of the Muzart River on the eastern slope of Hantengri-Tomur Knot. One of 33 glaciers larger than 100 km^2 in China, which is 33 km long, 137.7 km^2 in area with its terminal extending down to 2950 m a.s.l. Breathtaking ice scenery on the surface of the Muzart Glacier includes crossing ice cliffs and ice channels that look like a maze. Since the Muzart Valley has a broad and even bottom and a 3600m a.s.l. high mountain pass, it is the favored shortcut connecting the Ili region with the southern Xinjiang (120 km) and has long been a strategic gateway linking north-south traffic in the western Xinjiang. During the Tang Dynasty, the famous monk Xuanzang crossed the Muzart Glacier by way of the Issyk Lake on his journey to India to fetch Buddhism scriptures. The Qing Dynasty government established seven military posts in this valley to protect military traffic and trade (Shi Yafeng and Wang Zongtai, 1979). The Three Region Revolutionaries in the northern Xinjiang marched through this gateway into the southern Xinjiang in the 1940s. The part of the north Muzart Valley is densely vegetated with forests and meadows. The valley scenery and hot spring baths appeal to tourists. The Muzart Glacier has quite a few scenic spots with cultural significance. As one of China's glaciers larger than 100 km^2, the Muzart Glacier combines high tourism value with essential conditions for development, potentially making it a first-class tourist site featuring glacier exploration.

The eastern slope of the Mainri Xueshan has fourteen glaciers. Among them three glaciers are larger than 10 km^2, and the largest one is 15.98 km^2 in area. The Mingyong Glacier (so-called the Nainuogeru Glacier, Code 5L222B9) is 12.55 km^2 in area and 11.5 km in length, and its terminal extends to 2700 m a.s.l. It is easy to climb because it is the lowest glacier in the Hengduan Mountains. These glaciers are only 15 km away from Deqin County and the Lancang River and 6 km away from the Yunnan-Tibet highway. The highest peak, Mainri Jokul, stands at 6740 m a.s.l., right in the pathway of monsoonal currents from the Indian Ocean. The annual precipitation near the snowline altitude (4800~5200 m a.s.l.) is over 1500 mm and the annual temperature at the glacier terminus (2700 m a.s.l.) is 9.8℃. The climate there is comfortable, and the colorful landscapes of evergreen forests and blue rivers below and glacier-encircled white mountains above make the legendary "Shangrila" all the more attractive.

Finally, the Laohugou No.12 Glacier in the Qilian Mountains (Code 5Y448D12) together with the Rongbuk Glaciers (Code 5O193B142) at the Mount Qomolangma are ideal for tourism, mountaineering and exploration and good prospects for tourism development.

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