第5卷 第3期 冰 川 冻 土 Vol. 5 No. 3
1983年 9 月 JOURNAL OF GLACIOLOGY AND CRYOPEDOLOGY Sept. , 1983

Characteristics of Firn Stratigraphy in a Glacier of Sigong River Headwaters, Mt. Bogda Region, Eastern Tian Shan

Okitsugu Watanabe*, Yutaka Ageta** and Ren Jiawen***

(*Water Research Institute, Nagoya University, Nagoya, 464 Japan; **Faculty of Education, Yamaguchi University, Yamaguchi, 753 Japan; ***Lanzhou Institute of Glaciology and Cryopedology, Lanzhou, China)

Abstract

Firn stratigraphic studies of glaciers in the eastern Tian Shan were carried out during the summer of 1981.

This is a preliminary study for the clarification of long term climatic change by means of analyses of snow-ice cores obtained from the glaciers. Firn cores to the depth of 2-6 meters from the surface were obtained by means of a hand auger on Glacier D-4 on the north slope of Mt. Bogda and the west part of Glacier No. 1 in the area of Urumqi river head waters.

Stratigraphic descriptions, measurements of physical properties and analysis of oxygen isotopic contents were made. Using those data, stratigraphic interpretation of an assessment of annual layers and the process of superimposed ice formation are attempted. As annual net balances at the several sites of Glacier D-4, various amounts of around 1,000mm are found. This is an unexpected value in comparison with the value of precipitation obtained previously in the vicinity of the glacier.

Mass balance measurements by the stake method were made on Glacier D-4. A linear relation between mass balance and altitude on the glacier in the warmest season is found.

I. Introduction

The eastern part of the Tian Shan is one of the most arid and far inland glacierized regions in the world (Fig. 1). The Mt. Bogda region, in particular, is just like an island surrounded by a sea of desert. It is glaciologically interesting to reveal characteristics of the precipitation and the firnification processes under such geographic and climatic conditions.

In the other hand, glaciers distributed in the area surrounding Mt. Bogda (5,445m a.s.l.) are the main water reservoir and source of rivers to oases south and north of the Mt. Bogda range. Changes in the glacial conditions are closely related to human life and history in these regions.

From the firn stratigraphic view point, firn and ice layers of glaciers are a reservoir of climatic records such as variation of temperature and precipitation. For the purpose of clarification of long-term climatic change, stratigraphic analysis of snow-ice cores obtained by glacier boring is the most effective means as obvious from the work performed in Antarctica and Greenland.

This is a preliminary study for such an attempt on the glaciers in the inland mountains of the continent in the future. This field work was done during the period from the end of July to the middle of August, 1981 as a part of the China-Japan Cooperative Glaciological Expedition.

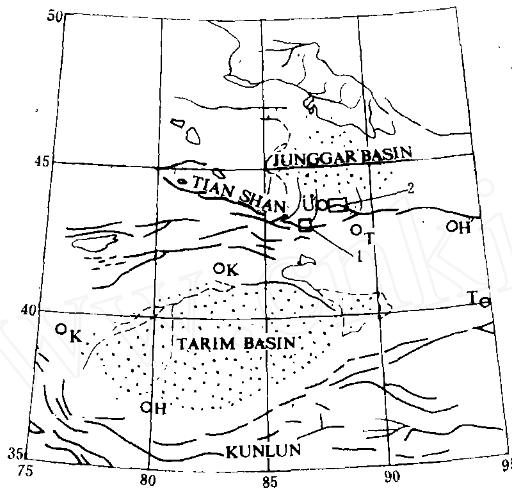

Fig. 1. Research areas in the Tian Shan
1. The area of Urumqi river headwaters
2. The area of Mt. Bogda

Ⅱ. Glaciological setting of the glaciers located in the headwater of the Sigong river

Mt. Bogda is located about 2,400km from the nearest ocean. Therefore, glaciers in this area belong to the continental type (Shi and Li, 1981).

An unnamed glacier, where these observations were made, is located in the head of the Sigong river as shown in Fig. 2 (1). According to the glacier inventory, this glacier is catalogued as number 5Y725 (indicating the drainage area) D-4 (indicating the individual glacier).

In this paper, this glacier is tentatively named Glacier D-4. Glacier D-4 starts from a snow peak at an altitude of 4,348m, which is located at 3km north from the highest peak of Mt. Bogda (5,445m), and tongue of which goes down to 3,600m a.s.l. As shown in Fig. 3 this glacier is a cirque-valley glacier with an area of 2.96km^2 and flows toward the north in the accumulation area turning to the west in the ablation area.

A brief summary of climatic data (prepared by the Lanzhou Inst. of Glaciology and Cryopedology) on the northern slope of Mt. Bogda are as follows:

At the firn line (about 3,800—3,900m a.s.l.)
annual mean air temperature: -9℃
annual precipitation : 670mm

At 3,600m a.s.l.
annual mean air temperature: -6℃
annual precipitation : 645mm

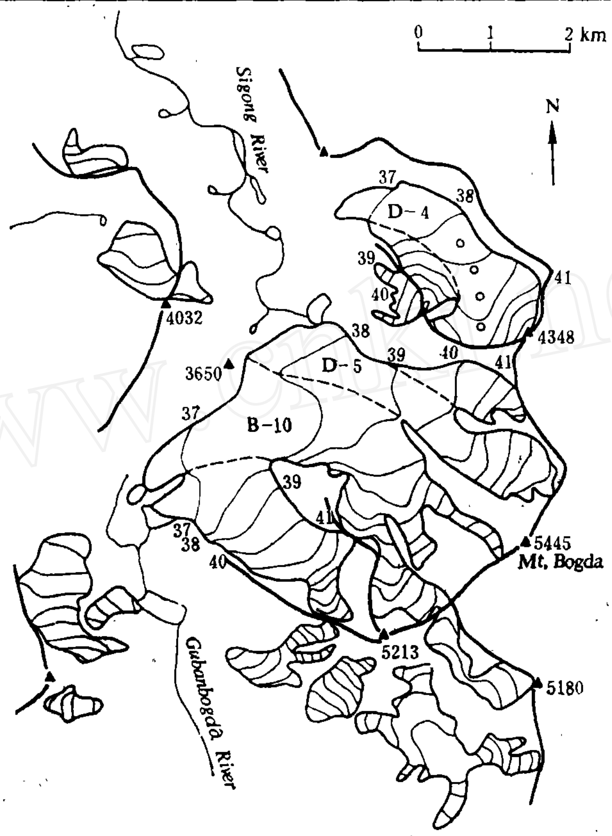

Fig. 2-(1). Distribution of glacier on the north slope of Mt. Bogda. Notes: D—4 D—5 B—10: the cataloged number of the glacier; open circle: site for stratigraphic observation on the glaciers; contour interval: 100m

Ⅲ. Mass balance and firn stratigraphic studies on Glacier D-4 and the vicinity

Ⅲ-1 Mass balance measurements

General climatic conditions in the Mt. Bogda region have been reported by Wu et al (1983). Results of local climate observations in the summer of 1981 at the base camp (3,640m a.s.l.), near the Bogda fan-shaped diffluence glacier, have been reported by Ageta et al. (1983). The mean air temperature during the period from 25 July to 14 August (21 days), which is the warmest season in the year, was 3.1℃ with a mean daily maximum of 5.7℃ and a mean daily minimum of 0.4℃. The mean lapse rate of air temperature from the end of July to the beginning of August on north slope of the Bogda Mountains was 0.72℃/100m between Fukang (548m a.s.l.) and Tianchi (1,943m, a.s.l.), and 0.68℃/100m between Tianchi and the base camp. Precipitation during the period from 24 July to 14 August (22 days) was 89mm at the base camp and the amounts on glaciers were about 80% of precipitation at the base camp.

Mass balance measurements by the stake method were made on Glacier D-4 during

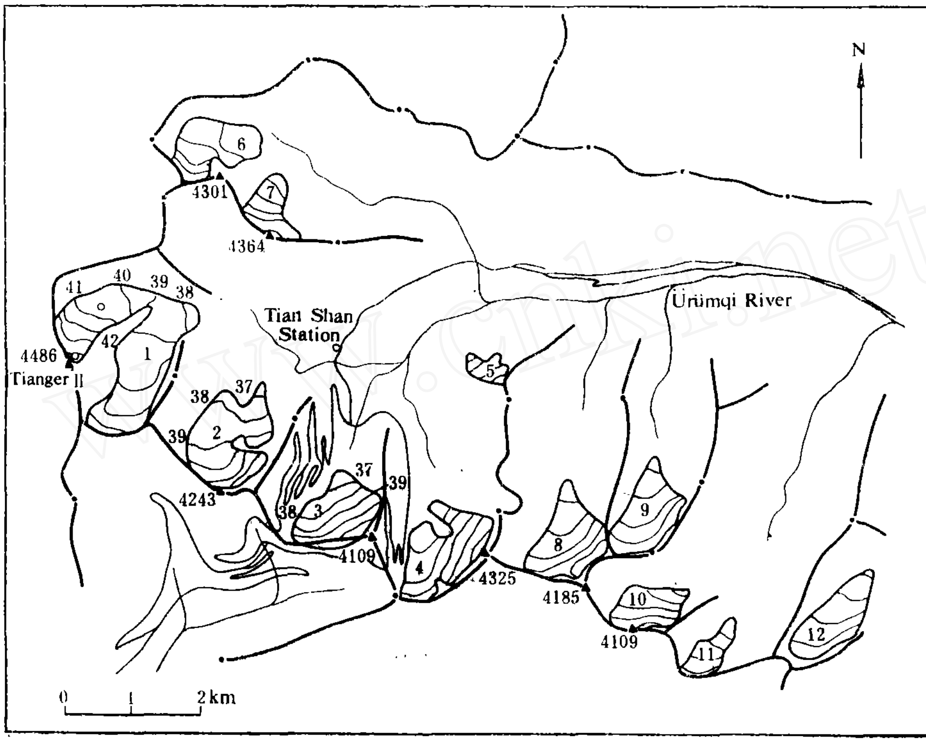

Fig. 2-(2). Distribution of glacier in the area of Urumqi river headwaters. Notes: 1,2,…12: the cataloged number of the glaciers; open circle: site for stratigraphic observation on the glaciers: contour interval: 100m.

our stay in the Mt. Bogda region. The relation between ablation (A: cm water) and the degree day index (ΣT: ℃·day-sum of daily mean air temperature) was obtained as

$$A = 1.5\Sigma T \qquad \text{(Ageta et al, 1983)}.$$

The linear relation between mass balance and altitude on Glacier D-4 in the warmest season was found and shown in Fig. 4

III-2 Firn stratigraphic observations

The purpose of these observations are to interpret the glacio-climatic environment and to assess the annual accumulation of this glacier. Therefore the sites of observations were decided on the basis of glacier zoning, a well-known concept developed by workers such as Müller (1962), into consideration.

The firn line of Glacier D-4 was known to lie at around 4,000m in elevation. Four sites for stratigraphic observation were selected to compare the glacier zoning under various conditions over the glacier, one above the line, the other three (Stations Nos. 6, 7 and 8) below the line including the bare ice area as shown in Fig. 3 .

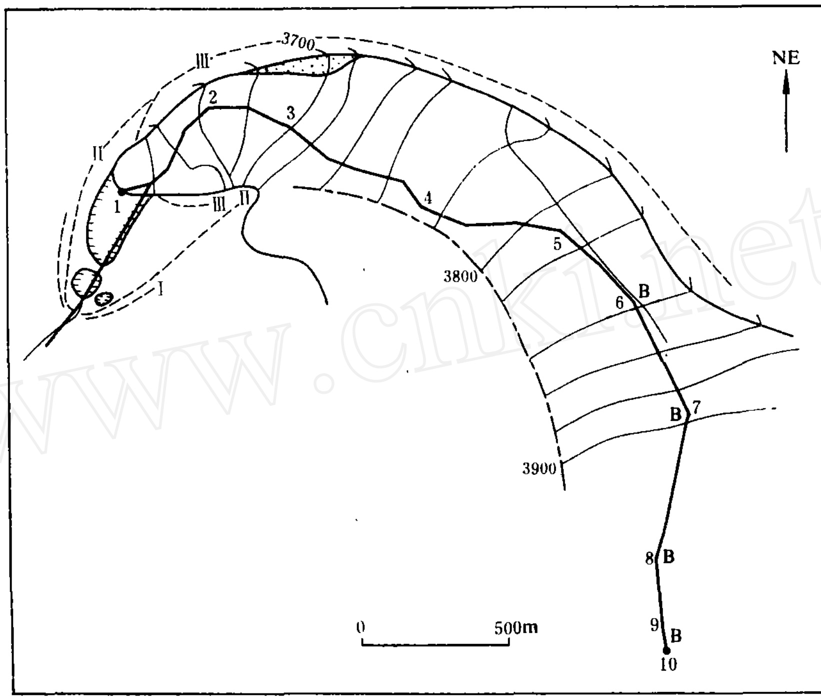

Fig. 3. Sites of stratigraphic observation on Glacier D 4
B: sites of glacier boring for stratigraphic observation; numbers on the glacier: names of stations for observations contour interval: 20

At each site, 2-4m deep coring was performed with a SIPRE type hand auger. The core was studied at the boring site with respect to

1) visible stratigraphy, especially on the occurrence of stratification and superimposed ice;
2) sampling for the measurement of the oxygen isotopic ratio ($^{18}O/^{16}O$) and chemical composition;
3) measurements of physical properties (density, grain size and bubble texture).

The stratigraphic diagrams obtained on Glacier D 4 are shown in Fig. 5 (1) together with the results on Glacier No. 1 in the Urumqi river headwaters (Fig. 5 (2)). The firn stratigraphic observations at Station H3 (4,075m a.s.l.) on Glacier No. 1 and at the summit of Tianger II (4,484m a.s.l.), which is the highest point of Glacier No. 1, were made in the same summer of 1981 by this expedition.

According to studies on the firnification in Urumqi river head waters by Xie et al (1965), occurrence of ice seen in the upper layer of the accumulation area was classified into following categories: ice increment or ice lens (冰片及冰透镜体), superimposed ice (附加冰) and percolation ice (渗浸冰). This basic idea for description of ice occurrence in the firn layer is reasonable and acceptable for our studies. The method of stratigraphic description presented here is based on the idea mentioned above.

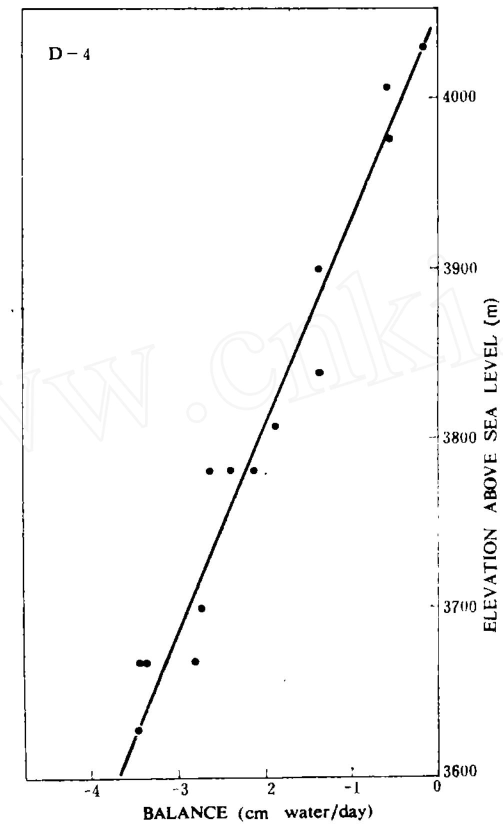

Fig. 4. Relation between mass balance and altitude on Glacier D-4 Results at altitudes lower than 3,800m are averages during the period from July 26 to August 6 (11 days) and those higher than 3,800m are averages during the period from July 27 to August 5 (9 days)

Judging from these stratigraphic diagrams shown in Fig. 5-(1), the equilibrium line and the firn line appear to lie between No. 6 and No. 7, and No. 8 and No, 9-10, respectively.

Two types of ice texture were found: one is bubble-free ice and another is bubbly ice. This difference in presence or absence of bubbles is presumed to reflect a formation process; it depends on the season of the ice formation and refreezing, and on the quantitative characteristics of the melt water infiltration. For the interpretation of the annual layer boundary, sequences of these ice textures in layering are the most effective indicators together with presence of the dust layer.

Well-developed dust layer, not only single-layering, is one of the remarkable stratigraphic features in this region. And deposition of dust beneath the surface granular snow (wet metamorphic snow) was observed in the midsummer of 1981.

The vertical profile of oxygen isotopic content, attached to the right side of each diagram of Fig. 5-(1), show a periodic pattern in the upper-most layer. It cannot be concluded exactly that the similarities of these profiles in Fig. 5-(1) can be attributed to seasonal variation of $\delta^{18}O$ in precipitation, because the homogeniza-

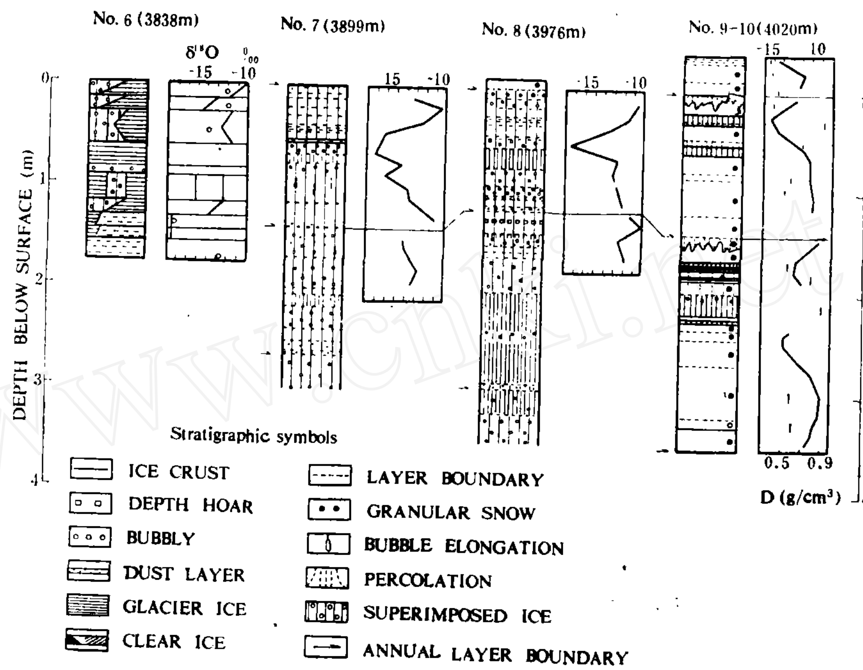

Fig. 5-(1): Stratigraphic diagrams of Glacier D-4
Note: 0 cm level on the depth approximately indicates the end of the previous balance year and some accumulation above that level may not be stable

tion of $\delta^{18}O$ by percolating meltwater usually takes place in the wet snow zone.

In Fig. 5-(1), the occurrence of large amounts of superimposed ice at No. 6 in the ablation zone, is seen. Therfore, it is supposed that a considerable amount of meltwater flowing down on the surface of the ablation zone may be returned to the glacier as nourishment due to crack filling and refreezing. This may be a considerable amount of the nourishment of this glacier.

From the stratigraphic interpretation, the net balance of each balance year from the end of the summer in 1979 and 1980 at each site was assessed and tabulated in Table 1.

Table 1. Net balance at each site of stratigraphic observation (mm water)

Duration	No.7	No.8	No.9-10	H-3	Tianger II
1980.Sum.—1981.Sum.	1110	990	840	175	820
1979.Sum.—1980.Sum.	1000	1400	1500	126	—

Ⅳ. Stratigraphic characteristics of the firn on the north slope of Mt. Bogda

Stratigraphic characteristics of the firn layer, in general, reflect the process of snow accumulation and snow metamorphism in a given place. On the other hand, both of these processes interfere each other and disturb to form the stratigraphic

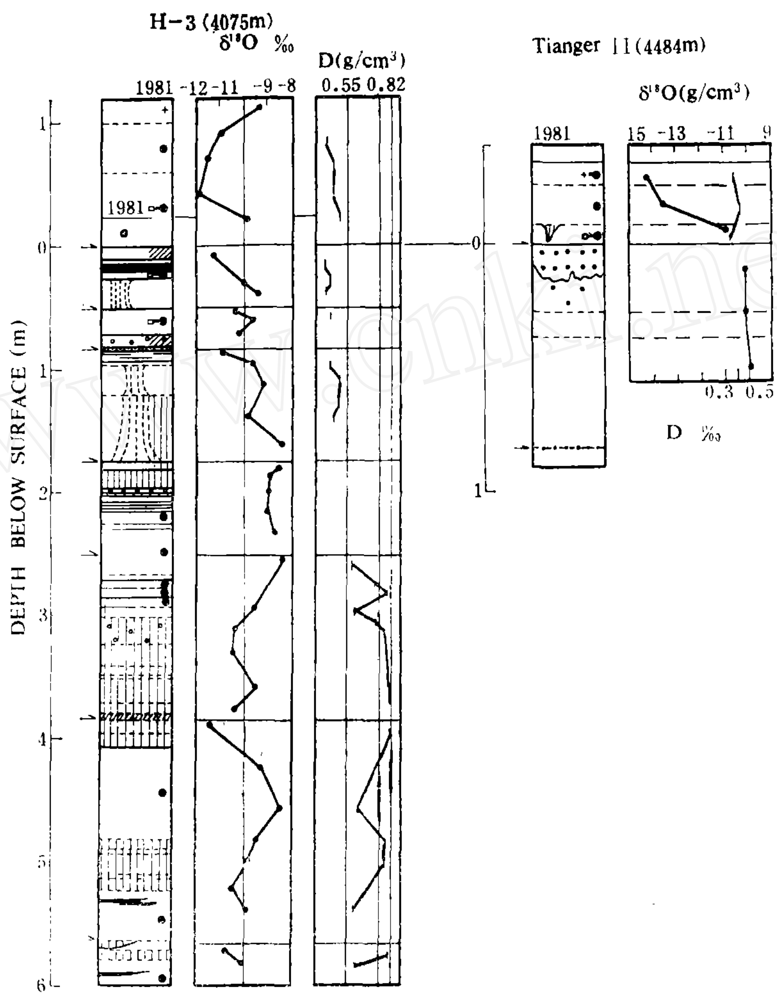

Fig. 5 (2). Stratigraphic diagrams of Glacier No.1 Note: same as Fig. 5 --(1)

record of firnitication. Thus, detailed knowledge of the solid and liquid precipitation and the snow melt is required to interpret fully the firn stratigraphic data.

Although very limited climatic records are available in the Mt. Bogda region, a great deal of glaciological and glacio-climatological informations about the region of the Urumuqi river headwaters has been reported by Chinese glaciologists including Xie et al (1965) and others. For the understanding of stratigraphic characteristics in Mt. Bogda region, this informations in the region of Urumqi river headwaters should be significant because a distance between these region is not so long.

Simplified stratigraphic process in an annual layer are schematically illustrated in Fig. 6. This figure is based on the idea presented by Xie et al (1965), and some additions and adaptations are made, considering the following situation which have been described in their work. At Tian Shan Station (3,589m a.s.l.), 63-68% of the annual preciptation is concentrated in the summer (June-Aug.), while 13% and 16% occur in

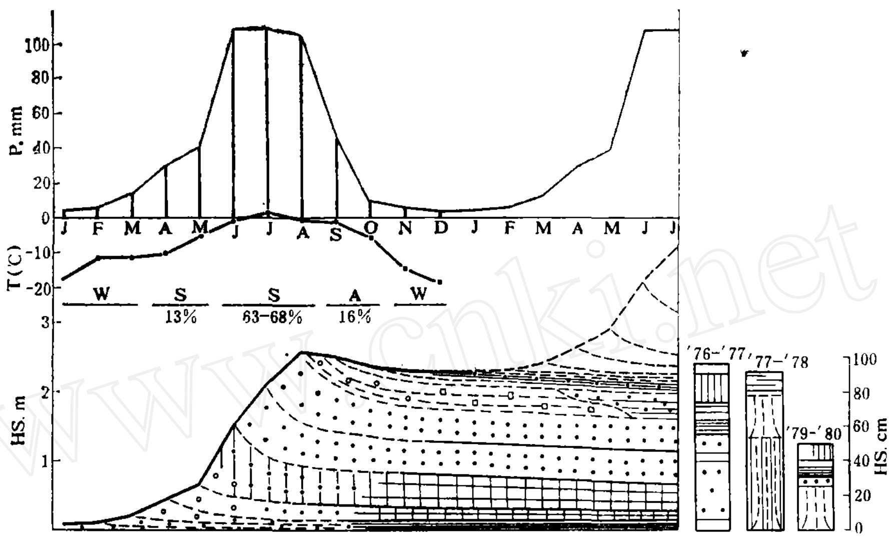

Fig. 6. Schematic diagram of idealized process on accumulation and firnification in the area of the Urumqi river headwaters.
Data of P (precipitation) and T (monthly mean air temperature) are from Xu Shiyuan (1963); stratigraphic symbols used in this figure are the same as in Fig. 5 except for open circles . This symbol used here indicates settled snow. The stratigraphic diagrams, shown in the right side, are H—3 profice in Fig.5—(2). W(winter), S(spring), S(summer) and A(autumn) indicate the durations of the seasons and the percentages attached are seasonal portions to annual precipitation (after Xie et al, 1965)

spring (Apr.-May) and autumn (Sep.-Oct.), respectively as shown in the upper part of Fig. 6. In the accumulation area on Glacier No. 1, since precipitation in winter is small, snow is deposited mainly in autumn and spring, but spring snow is melted away in summer.

Fig. 6 shows an idealized process of accumulation with no melting in summer, and firnification. The idealized process can be compared with the actual stratification at H-3 on Glacier No. 1 (Fig. 5-(2)) in the right side of Fig. 6.

On the mode of superimposed ice formation in an annual layer, there may be two patterns: ice formed by refreezing of percolating water fully penetrating through the layer (ex. '77-'78 layer) and refreezing of water standing on the upper impermeable layer (ex. '76-'77 layer). These two patterns should be correlated to the two types of ice texture in Fig. 5-(1) as described in the previous section. In comparison with complicated structure and ice occurrence at H-3 on Glacier No. 1, simplified structures are found in the stratigraphic diagrams of Glacier D-1 while there are no more than two years of layering.

On the other hand, from the appearance of the stratigraphic sequence for 6 or 7 years at H-3, it also can be said that annual tendency of firnification varies year by year remarkably.

At present, it cannot be clearly concluded that differences appearing between these tendencies in the two regions may reflect a difference of climatic characteristics in these regions since small differences of altitudes cause large differences of stratigraphy as seen in Fig. 5-(1). According to the stratigraphic observations, the ablation zone, superimposed ice zone and wet snow zone can be seen in Glacier D-4. The existence of a percolation zone was not confirmed but should be higher than the observed area. Glacier D-4, which face north, lies from 3,600m a.s.l. at the snout to 4,350m a.s.l. at the highest peak. This feature in the spatial distribution with altitude is different from other glaciers on the north slope of Mt. Bogda, as seen in Fig. 2, while the area of the glacier is comparable to that of others. It may mean that the altitude range around 3,800-4,300m, corresponding to the upper part of the ablation zone, superimposed ice zone and wet snow zone, is the most effective altitude for glacier nourishment in this region in relation to the characteristics of summer precipitation and superimposed ice process.

Vertical distribution of the stratigraphic characteristics and various aspects in the glacier zoning in both regions of Mt. Bogda and Urumqi river headwaters are summarized in Fig. 7 including Ramm hardness profiles attempted on Glacier No. 1.

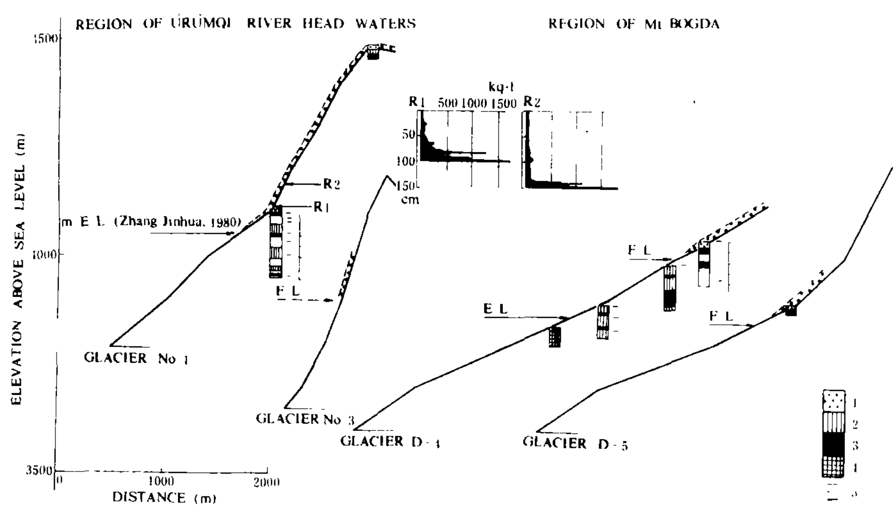

Fig. 7. Vertical distribution of the stratigraphic characteristics and various aspects of glacier zoning in the regions of Mt. Bogda and the Urumqi river headwaters. 1. snow cover; 2. percolated ice; 3. clear ice; 4. deformed glacier ice; 5. annual layer boundary. F.L.: firn line; E.L.: equilibrium line; R1 and R2: Ramm hardness profile on Glacier No. 1

Acknowledgements

The authors are grateful to Prof. Xie Zichu and Prof. Zheng Benxing and their colleagues at the Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, for their encouragement and sincere support in this field investigation.

References

[1] Ageta, Y., Qiu Jiaqi and Yasunar, T. (1983), Relations between Meteorological Conditions and mass balance of a Glacier on the North Slope of Mt. Bogda, in this issue.

[2] Muller, F (1962), Zonation in the accumulation area of the glacier of Axel Heiberg Island, N.W.T. Canada. *J. of Glaciol.* 4, p. 302—318.

[3] 许世远(1963), 中国天山现代冰川作用研究, *Acta Geographica Sinica*, Vol. 29, No. 1, p. 310—329.

[4] Shi Yafeng and Li Jijun (1980), Glaciological research of the Qinghai·Xizang Plateau in China. Proceedings of Symposium on Qinghai Xizang (Tibet) Plateau, Vol. II science press, Beijing, P.1589—1597.

[5] 伍光和、Ageta.y和仇家琪, 1983, 天山博格达山脉的自然地理特征及冰川发育的气候条件，见本刊。

[6] 谢自楚、黄茂桓、米·艾里(1965), 天山乌鲁木齐河源1号冰川雪·粒雪层的演变及成冰作用，天山乌鲁木齐河冰川与水文研究，1—13，科学出版社。

[7] Zhang Jinhua (1981), Mass balance studies on the No.1 Glacier of Urumqi River in Tian Shan, *J. of Glaciology and Cryopedology*, Vol.3, No.2, p.32—40, (in chinese with an English abstract).

东天山博格达峰地区四工河源冰川的粒雪特征

渡边兴亚* 上田 丰** 任贾文***
(*日本名古屋大学水圈科学研究所；**日本山口大学教育学部；***中国科学院兰州冰川冻土研究所)

摘　要

1981年夏天对东天山冰川进行了粒雪层研究。

本文系通过对从冰川上取得的雪-冰岩芯进行分析来解释长期气候变化的初步研究。粒雪岩芯取自博格达峰北坡D-4冰川和乌鲁木齐河源1号冰川西支，深度为表面以下2—6米，工具为手摇钻。

对冰雪样品进行了地层学描述和物理性质测量，还做了氧同位素含量分析。应用这些资料，试图就年层的估算和附加冰的形成给予地层学解释。在D-4冰川几个不同点上，发现年净平衡约在1000毫米附近变动，和以前在邻近冰川区得到的降水量相比是一个意外的值。

用花杆法在D-4冰川上测量了物质平衡，发现在最暖季节，该冰川的物质平衡与海拔高度之间具有线性关系。