Structural Observations of the Glaciers on the North Slope of Mt. Bogda, Tian Shan

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Abstract

Preliminary structural glaciological studies of the glaciers on the north slope of Mt. Bogda were carried out during July-August, 1981.

The distributions of structural elements, such as depositional and dynamical structures and also structures resulting from glacier fluctuations, were observed on the surface of Glaciers D-4 and D-5 and structural maps of both of glaciers were made.

In contrast to the structure of Glacier D-4, which is simple and monotonous, that of Glacier D-5 is more complicated. Clarification of the inner structure of Glacier D-5 is attempted.

The surface ice movement and the occurrence of the debris laden layer were observed on both glaciers. Surface deformation and the change of terminus position were measured on Glacier D-5. Mean daily velocities are on the order of several cm per day and the glacier terminus retreated about 1 to 3 meters per month in late summer, 1981.

Ⅰ. Introduction

Mt. Bogda (5,445m a.s.l.) is located about 2,400km from the nearest coast (Fig. 1). Therefore, glaciers in this area belong to the continental type (Shi and Li, 1981).

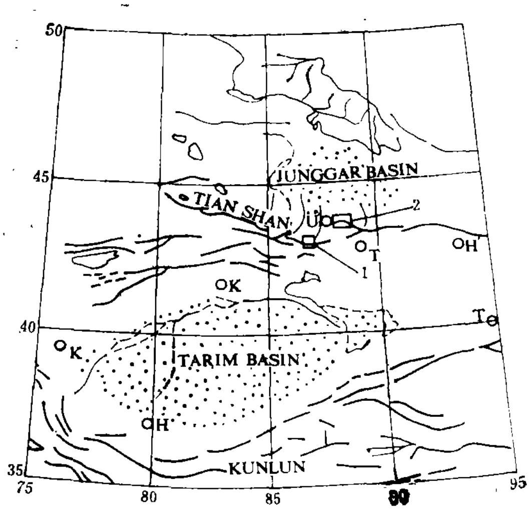

Fig. 1. Location of observation area in Tian Shan 1: Area of Urumqi river headwaters; 2: Mt. Bogda area

On the north slope of Mt. Bogda, isolated and compound types of cirque and cirque-valley glaciers are developed in reflection of the climatic and geographical situation.

Steep accumulation slopes and relative flat glacier tongues are topographic characteristics of glaciers in this region. Well-preserved multi-formed end moraines pushed out during the neoglaciation period indicate glacial fluctuation due to the climatic change.

This is a preliminary study of the structural characteristics of glaciers and their variations relating to the glacier fluctuations in this region. Another purpose of this investigation is to clarify the relation between the glacier structures and the distribution of isotopic and chemical composition of glacier ice in connection with the process of water and material circulation within a glacier. This investigation was performed as cooperative work under the China-Japan joint expedition to the Tian Shan during July-August, 1981.

Ⅱ. Glaciological setting of Glaciers D-4 and D-5

The distribution of glaciers on the north slope of Mt. Bogda is shown in Fig. 2. For the glacial structural investigation, two of these glaciers were selected. One is a glacier

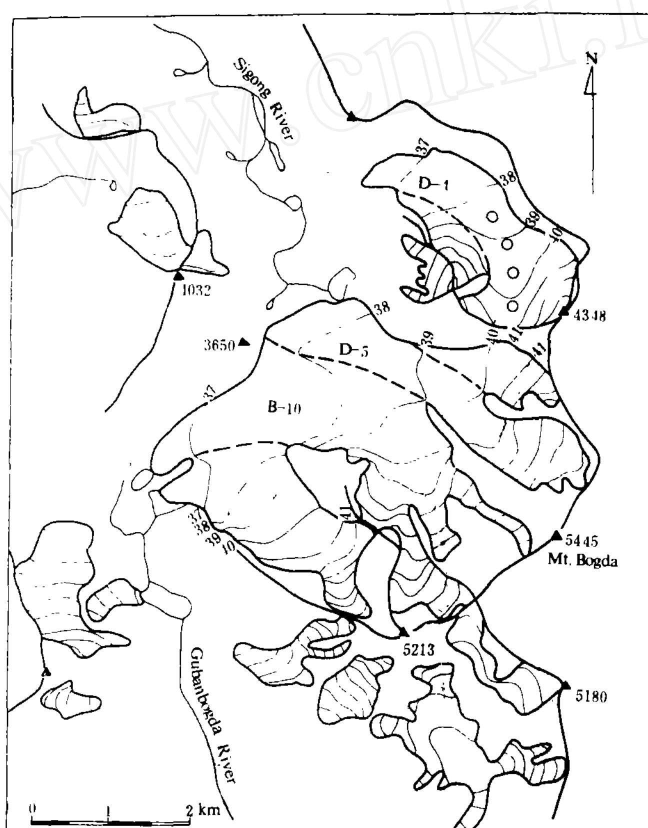

Fig. 2. Distribution of glaciers on the north slope of Mt. Bogda (Contour lines on glaciers are at 100m intervals)

located in the headwaters of the Sigong river, catalogued as number 5Y725 D-4, and another is a fan-shaped diffluence glacier, the largest in the Bogda region, consisting of 4 ice flows. In this report, the former is tentatively named Glacier D-4 and the latter to the Sigong river is named Glacier D-5.

Glacier D-4 is a compounded cirque-valley glacier with an area of 2.96km². The accumulation area of this glacier has a simple basin surrounded by two peaks and a col between them, with altitudes of 4,348m, 4,304m and about 4,100m, respectively. The lower part of the glacier has a form of the valley glacier type with gentle slope of 5-10°. The altitude of the terminus is 3,600m.

Glacier D-5 is a large cirque glacier with an area of 3.3 km², with its edge directly contacting that of the next ice flow in the fan-shaped diffluence glacier. Altitudes of the peaks and ridges which are the highest limit of the glacier are above 5,000m a.s.l.. From the altitude of 4,000m to those peaks and ridges, the slope is steep with an average inclination of around 40—50°, and many avalanches carry much snow down to the foot of the wall. On the other hand, the glacier surface in the part lower than 4,000m has a wide and gentle slope with an inclination of around 5—10°. The lower part of the glacier flow toward Sigong river with a terminus altitude of 3,630m, showing a form of the piedmont type.

Ⅲ. Structural investigations in Glaciers D-4 and D-5

Ⅲ-1. Methods of mapping

For positioning of structural data observed, relatively large scale topographic maps are not available for scientific usage so that the base points for the identification of location on the glacier were surveyed by means of the simple compass method. On Glacier D-4, the base line through the center of the glacier and the base points (1—10) on the line were set up as shown in Fig. 3. The highest point, No. 10, is located above the firn line, at an altitude of 4,030m a.s.l.. On Glacier D-5, one closed traverse line and several open traverse lines were set up as shown in Fig. 4. Topographic observations were made on both of the glaciers as follows:

1) Measurements of horizontal and vertical positions at various points on the glacier;

2) Mapping of topography of the end moraine;

3) Descriptions of glacial topographic features, such as the direction of the maximum slope at the glacier snout, location and shape of the glacier edge and mounds and depressions on the glacier surface.

Ⅲ-2. Surface features of structural elements and the descriptive method

Various structural elements are seen on the surface. Surface structures such as crevasses, cracks, and foliation and lineation are related to the stress field of the glacier.

On the other hand, glacier structures originating from the glacier fluctuation, such as stagnant and fossil ice, and disposition and the orientation of moraines on the glacier, are also seen.

Structural elements related to the origin of the glacier can be classified into the following three categories:

1) Depositional structures (stratification, ablation surface);

2) Dynamical structures (bubble lineation, foliation, crack, crevasses and transparent

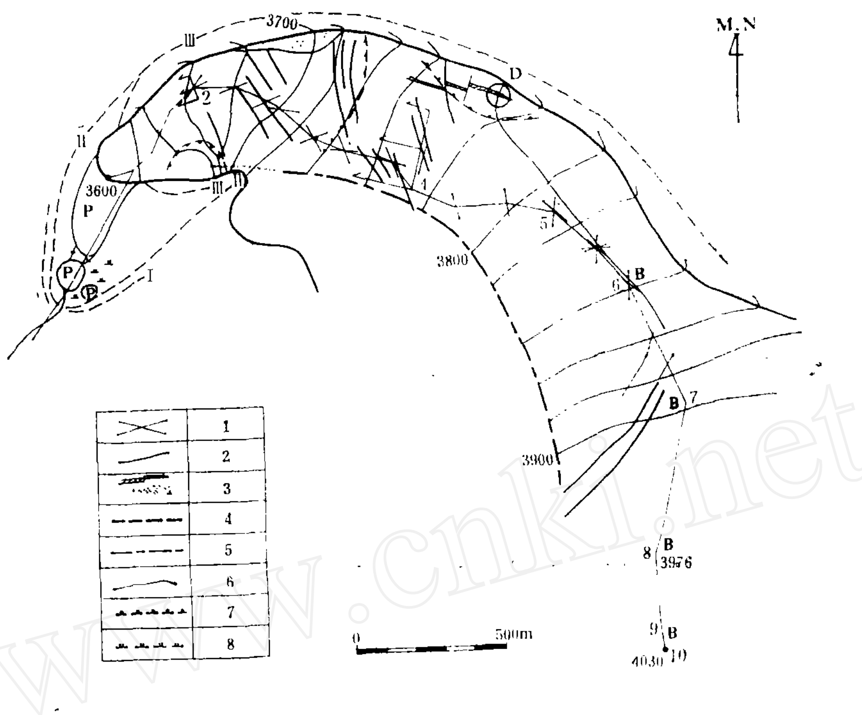

Fig. 3. Structural map of Glacier D 4

1: crack; 2: crevasse; 3: debris laden layer; 4: moraine ridge-advance phases I—III; 5: boundary of ice flows; 6: surveying line; 7: ice escarpment; 8: grassland
B: ice boring site; D: observation site for debris laden layer. P: pond;
4030: elevation in meter above sea level

bands);

3) Structures resulting from glacier fluctuations (fossil ice, stagnant ice and various aspect of supra-glacial moraines).

The ogive structure and debris laden layer seen in these glaciers are not included here because of the uncertainty of their origin in these glaciers. The term ogive' is descriptive of the form of a series of bands of various origins seen on the glacier and resembling an architectural form (Glacier Bands, 1953).

From the detailed observation of the ogives, the banding structures seem to be a stratification defined by the form of a series of dirt layers. The word ablation surface' also should be used for this stratification. The descriptional symbols used in the structural maps are tabulated and explained in the figure captions.

III. 3. Structure of Glacier D 4

The distribution of structural elements observed on Glacier D 4 is shown in Fig. 3. As easily visualized from the figure, the distribution of the structural elements on the

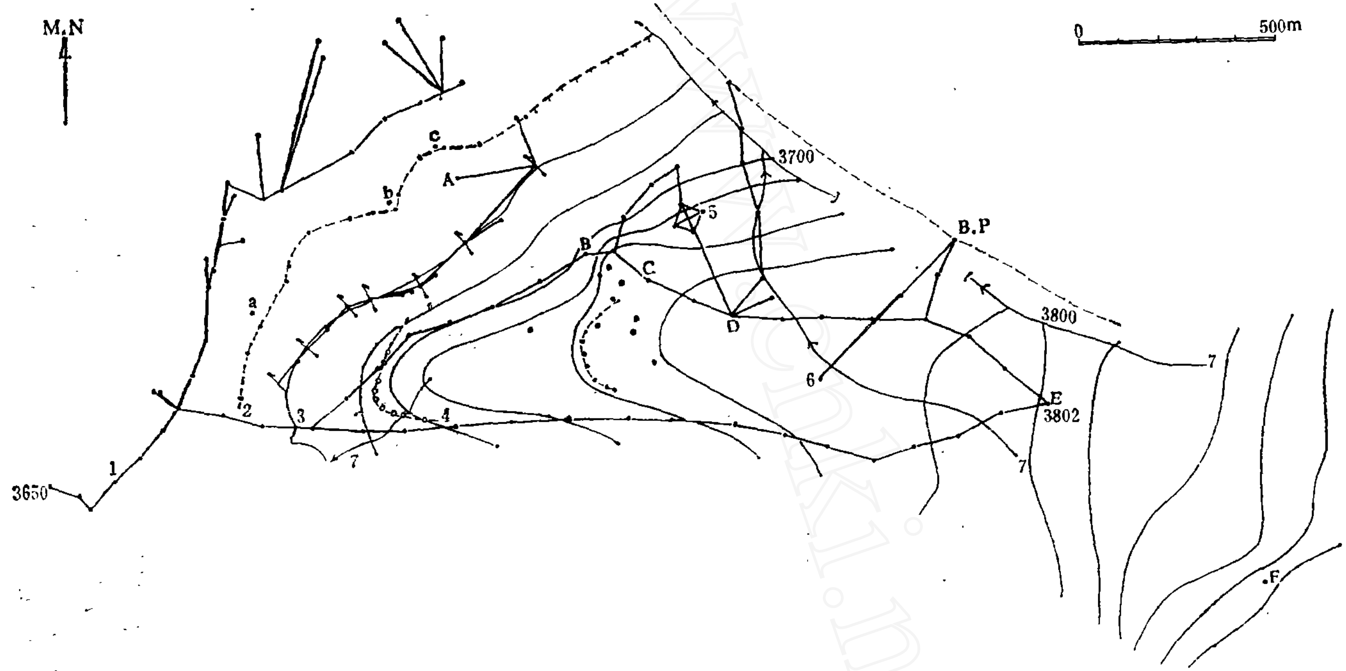

Fig. 4. Topographic map of the lower part of Glacier D-5 with the survey plan. Surveying lines for: 1: topography of the snout area; 2: glacier edge; 3: maximum slope direction of the ice; 4: ogive structure; 5: surface strain; 6: surface ice movements; a, b, c: base points for measurements of change of terminus position; A B C ···· F: points for mass balance measurements and meteorological observation (at D) 7: Stream

surface is too simple to reveal much about the inner structure. One set of cracks, appearing to be open and closed, and transverse crevasses smaller than 100cm in width are distributed in the lower and middle part of the ablation area. However, there is no clear evidence of occurrence of foliation and any other banding structure of dynamical origin on the surface.

According to measurements of surface movement, mentioned in a later section, the dynamical condition of Glacier D-4 is active, not stagnant, so that the lack of such dynamical elements as foliation and alternating of bubbly and bubble-free bands is inconsistent with our present knowledge of glacier structure.

On the right bank of the middle part, the debris laden layer is seen being cut by shearing crevasses (point D in Fig. 3). Results of detailed observations on this structure will be described in a later section.

Glacial fluctuation during the neoglaciation left multiformed end moraines (Phases I-III in Fig. 3). At present, the glacier is advancing beyond end moraine III.

In the accumulation area of this glacier, the structure is very simple and monotonous.

III-4. **Structure of Glacier D-5**

In contrast to the structure of Glacier D-4, that of Glacier D-5 is more complicated, as shown in Fig. 5. Among the various types of dynamical structural elements,

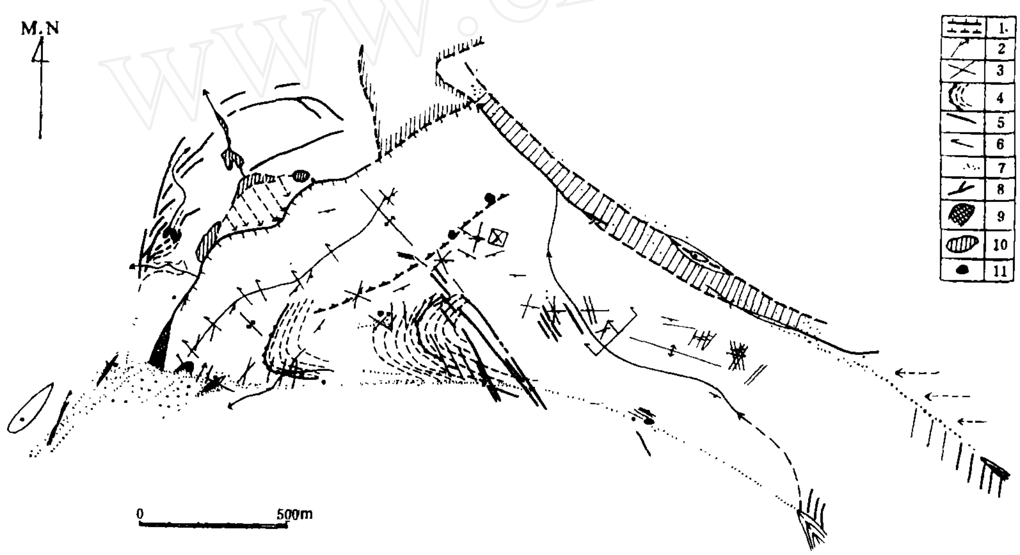

Fig. 5. Structural map of the lower part of Glacier D-5
1: *edge of the glacier;* 2: *dip and strike of foliation;* 3: *crack;* 4: *ogive structure;* 5: *crevasse;* 6: *direction of maximum slope;* 7: *moraine* 8: *terminal moraine ridge;* 9: *area of stagnant ice;* 10: *pond;* 11: *erratic boulder*

there is one dominant arcuate system, concave upward and extending across half side of lower part of Glacier D-5.

This arcuate system can be considered as a kind of ogive system. According to close observation of this ogive, this banding is composed of a series of layers represented by appearance of dirt layers at relatively regular intervals (about 2 meters).

Over the area, this ogive feature turns out to be invisible, and development of the foliation defined by alternating layers of bubbly and relatively bubble-free ice are dominant.

The system of foliation is related to the stress field of the glacier , and as obvious from Fig. 5, the system separates into two parts: one has a concave shape and another has a convex shape.

These appearances and occurrences are very similar, whereas, judging from origin of the banding and areal tendency of the dip and the strike, these two systems cannot be considered to be equivalent structurally. The strike of foliation in the middle of the lower part of the glacier is parallel to the flow direction with steep inclination toward the center line, and then turns perpendicular to the flow direction.

The crevasse system of this glacier is simple. A distinct zone with the direction of NW-SE is seen in the lower and middle part of the glacier. This crevasse zone may reflect the base rock topography, and coincide with the boundary lying between the foliation systems.

A cromplicated system of multi-formed terminal moraines pushed off during the neoglaciation period is developed and well-preserved. And rapid retreat of the present glacier front is indicated by a recently formed fluted moraine near the snout.

Ⅲ-5. Results of some observations

(1) Observations of glacier movements

Measurements of surface ice movement were made across the ablation areas of both glaciers. The positions of the stakes were determined by the straight line method from the base point on bed rock.

On Glacier D-4, two straight lines with 3 measuring points in each were set out on 26 July and remeasured on 6 Aug. and 20 Sep..

On Glacier D-5, one straight line with 3 measuring points was set out on 2nd Aug. and remeasured on 7 Aug. and 18 Sep. The locations of these measurements are shown in Fig. 3, 4 and 5. Results are shown in Fig. 6 .

Maximum daily velocities of 14.4cm in the upper line (across St. 4R, M and L), 5.6cm in the lower line (across St. 2R, M and L) on Glacier D-4 and of 10.8cm on Glacier D-5 were recorded. Mean daily velocities are around a range of 5-10 cm per day.

(2) Observation of surface deformation

Assuming the presence of different dynamical conditions in the lower part of Glacier D-5, Measurements of surface deformation were attempted at the right side of the lower part of the glacier (No. 5 in Fig. 4) using square stake patterns of 50m on one side.

The obtained results are shown in Fig. 7 for detailed studies in future, though errors of the measurements may be large comparatively to the change of the sides length. The elongated deformation can be seen from Fig. 7 on the direction perpendicular to flow direction.

(3) Measurements of the terminus position

To clarify the present condition of glacier fluctuation due to climatic conditions and

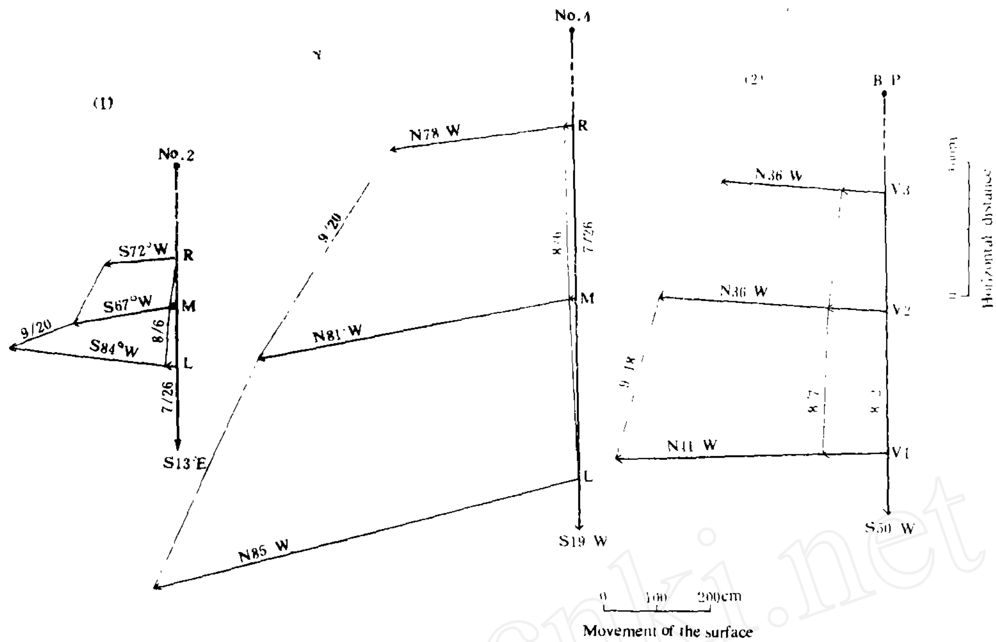

Fig. 6. Surface ice movement vectors of the Glaciers D-4 and D-5
(1): vectors at stations No. 2 and No. 5 on Glacier D-4; (2): vectors on Glacier D-5
thick arrow: direction of the base line of measurement; thin arrow: vector of surface ice movement; 9, 30 and so on: date of the measurements

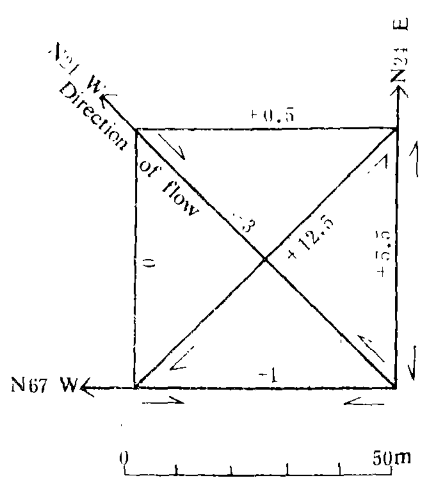

Fig. 7. Changes of sides lengths of the square (in cm) from 2Aug. to 8 Sept. at the lower part of Glacier D-5
one set of vectors indicates a compressive (→←) or tensile (← →) strain on each side of the strain grid

ablation characteristics in that year, measurements on the change of the terminus position were made along the terminus edge of Glacier D-5.

Positions of measuring points on the edge were determined by the distance and azimuth method from base points on glacier-free ground. On Glacier D-5, these base points (a, a′, b and c) are indicated in Fig. 4 and the results obtained on 4 Aug. and 7 Sep. are tabulated in Table 1.

Table 1. Change of the terminus position of Glacier D-5 during 4 Aug. and 7 Sep., 1981.

Base points	Direction	Distance between B. P. and the terminus (cm)		Retreat (cm)
(B. P.)	(magnetic)	(A) 4 Aug.	(B) 7 Sep.	(B) − (A)
a	S18°E	1540	1670	130
a′	S40°E	690	790	100
b	S42°E	2370	2490	120
c	S25°E	890	1170	280
	S10°E	840	1100	260

During this one month, the terminus of Glacier D-5 retreated about 1 to 3 meters.

(4) Observations of the debris laden layer

Investigation of the debris laden layer is important to clarify the mechanism of glacier erosion at the base and transportation of rock in the sub-glacial moraine.

Different appearances of occurrence of debris laden layers are seen in these glaciers; one is a layering parallel to glacier flow in Glacier D-4 (D in Fig. 3) and another is layering perpendicular to that in Glacier D-5.

Structure of debris laden layer with data of isotopic and chemical composition are shown in Fig. 8 and 9 and Table 2. The restricted spatial distribution of debris

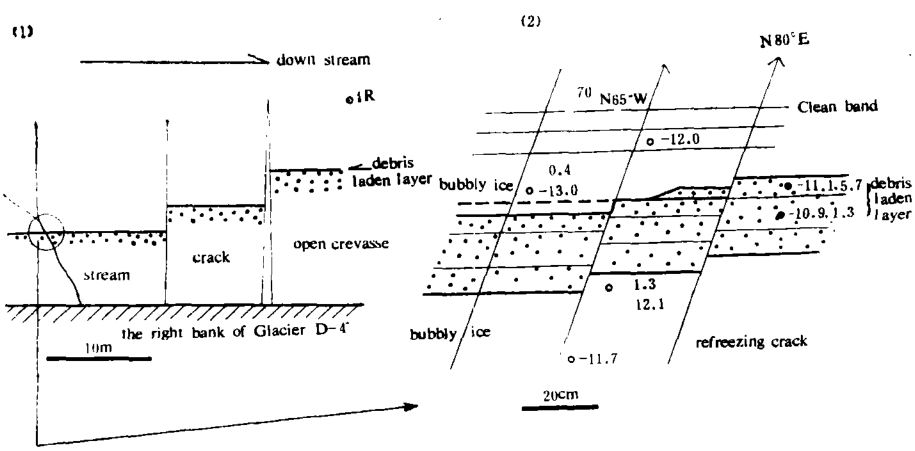

Fig. 8. Horizontal structure of debris laden layer on the middle stream of Glacier D-4 (1) *occurrence of the debris laden layer;* (2) *detailed structure of the layer and distribution of oxygen isotopic content* (‰) *and chemical composition* (Ca^{2+}, mg/l)

and irregular size distribution of debris ranging from a few cm to larger than 1m on Glacier D-5, may imply that these rocks originated from deposition of fallen rock in a high accumulation basin.

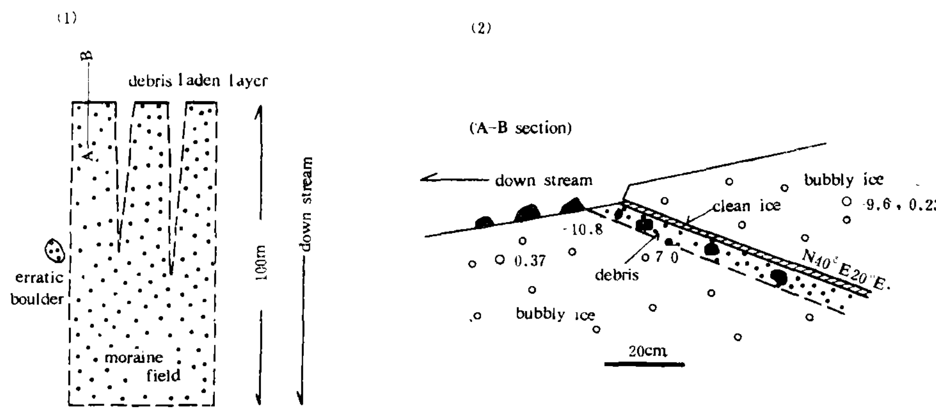

Fig. 9. Debris laden layer in the snout area of Glacier D-5
(1) horizontal distribution of the moraine released from the layer;
(2) vertical structure of the debris laden layer with oxygen isotopic content (‰) and chemical composition (K^+, mg/l)

Table 2. Comparison of chemical composition between the debris laden layer and the adjacent layer (mg/l)

	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}
A_1	0.007	0.18	0.045	0.08	0.11	0.13	0.85	0.12
B_1	0.016	0.13	0.259	0.12	0.20	0.35	3.5	0.63
B_2/A_2	2.3	0.7	5.8	1.5	1.8	2.7	4.1	5.3
A_2	0.005	0.23	0.052	0.051	0.098	0.13	0.30	0.072
B_2	0.011	0.19	0.051	0.30	0.24	0.16	7.0	0.13
B_1/A_1	2.2	0.8	0.98	5.6	2.4	1.2	23.3	1.8

A_1, B_1: *average chemical compositions* (mg/l) *of debris laden layer* (A_1) *and the adjacent layer* (B_1) *of Glacier* D-4,
A_2, B_2: *those of Glacier* D-5
A/B: *ratio between* A *and* B

(5) Relation between the structure and the distribution of oxygen isotopic composition in Glacier D-5

As a conclusion to this preliminary study of the structural characteristics in these glaciers, the relation between the structure and the distribution of oxygen isotopic composition of glacier ice is examined here.

A conceptual structural map of the lower part of Glacier D-5 is illustrated in Fig.10 as an explanation of the distribution of the structural elements on the surface. According to this conceptual figure, the ice stream of Glacier D-5 can be separated into two stream, and the left stream fans out near the relatively steep slope of the snout. On one side, the right stream looks like to be forced out to the right bank, and movement of this side seem to be relatively slow and inactive compared to that of the left stream.

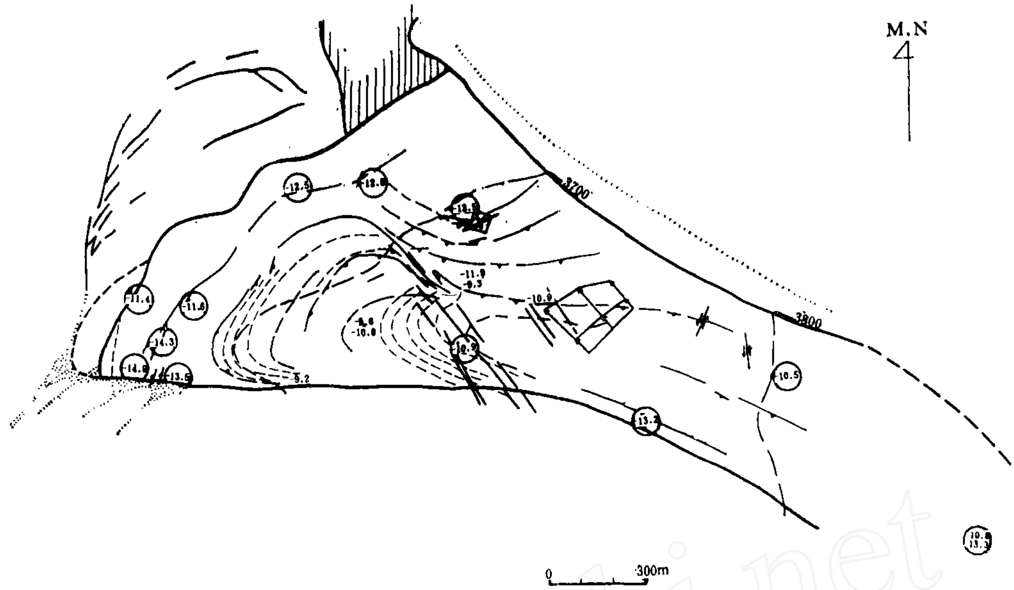

Fig.10. Conceptual structural map of the lower part of Glacier D-5 *with distribution of oxygen isotopic content of glacier ice* (‰)

If this conceptual explanation of the structure and movement of the glacier is reasonable, the origin of a particle path appearing on the same contour line is different depending on the structural domain. For instance, a particle originating from a given place in the accumulation area appears at a lower place in the left stream than in the right stream.

In Fig.10 oxygen isotopic composition sampled from various places are shown and the general trend of the composition agrees with the idea mentioned above, that light oxygen composition (O^{18}-poor) indicates that glacier ice flows down from a higher accumulation area and relatively heavy oxygen isotopic composition (O^{18}-rich) indicates the opposite.

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天山博格达北坡冰川结构观测

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摘 要

1981年7月至8月，我们对博格达北坡冰川进行了初步的结构冰川学研究。

结构要素、诸如沉积和动力结构以及冰川波动所造成的结构，分别在4号和5号冰川的表面做了观测，并绘制了这两条冰川的结构图。

4号冰川结构简单，而5号冰川则比较复杂。我们对5号冰川的内部结构分类做了尝试。

观测了这两条冰川的冰面运动和冰层中岩屑的产生。测量了5号冰川表面变形和末端位置的变化。该冰川平均日变化速度5—10厘米，从1981年的8月初到9月初其末端后退约1—3米。