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

The Genesis of Englacial Till Along the Shear Planes of Urumqi No. 3 Glacier, Tian Shan

—— Indicated by Grain Size Distributions and Quartz-Grain Surface Features

Minoru Yoshida and Okitsugu Watanabe
(Water Research Institute, Nagoya University Nagoya, 464 Japan)

Abstract

No. 3 Glacier has 4 main shear planes in its lower ablation area, which are accompanied by debris-laden ice 5-40 cm thick. Englacial till was sampled from each area of debris-laden ice to examine its characteristics and genesis.

Boulder shapes of englacial till are extremely angular and the amount of silt and clay is lower than that of till produced by the abrasion process in temperate glaciers. Quartz-grain surface features examined by Scanning Electron Microscope showed that

Ⅰ) All grains have typical 'GLACIAL' features.

Ⅱ) 5—20% of grains show silica precipitation-solution features superimposed on 'GLACIAL' features.

Ⅲ) Signs of subaqueous mechanical action, impact pits and rounding of edges, are rarely observed.

Ⅰ) means that grains were produced by mechanical grinding or crushing. Ⅱ) and Ⅲ) mean that some of the grains were lodged in water after being crushed, but grains were not transported in turbulent water flow.

These results suggest that the englacial till was mainly produced by crushing and/or plucking at the base of No. 3 glacier rather than abrasion. At the base of this glacier where the englacial till was entrained, the temperature is kept or has been kept at melting point but the amount of water is less than that of temperate glaciers.

Ⅰ. Introduction

On the surface of the lower ablation area of Urumqi No. 3 Glacier, Tian Shan, englacial till has been released out of the glacier body at several places. This englacial till is considered to be associated with the thrust systems in the compressive flow zone (Cui, 1981a; Wang and Zhang, 1981).

Watanabe et al. (1983) studied chemical and oxygen isotopic compositions of this debris-laden ice, and stated that debris-laden ice was formed by refreezing of water at the glacier bed. Thus, the englacial till is considered to be entrained at the bed according to the refreezing hypothesis (Weertman, 1961) or regeration + refreezing mechanism

(Boulton, 1970). Boulton (1972) argued that these debris entrainment mechanisms play an important role in the glacial erosion process, so that sub-polar glaciers, which usually have debris-laden ice the same as that mentioned above, have high erosive power compared with pola, and temperate glaciers, in which eroded materials are transported only in the basal traction zone. However, very few field works have been done concerning how and what kind of till is being produced at the base of glaciers with such high erosive power.

The authors sampled basally-derived englacial till from No. 3 Glacier and examined boulder shapes, particle sizes and quartz-grain surface features by Scanning Electron Microscope in order to study the characteristics and genesis of the till.

Ⅱ. Urumqi No. 3 Glacier

At the head of the Urumqi river basin, Tian Shan, China, there exist nearly 60 small cirque glaciers (Cui, 1981b). Urumqi No. 3 Glacier is one of these. It has an area of $0.53km^2$. The height of the terminus is 3,650m a. s. l., and the head is 4,190m a. s. l. As the glacier head extends to the back-wall ridge, the fallen rocks from surrounding valley sides and nunataks scarcely reach to the middle part of the accumulation area.

According to the result of glacier temperature measurement at Glacier No. 1, temperatures below 0℃ were found in the ablation area. So glaciers in this region can be called a' cold' glacier. The mean annual air temperature at the Tian Shan station is about -5℃.

Ⅲ. Characteristics of englacial till

Till samples were taken from the debris-laden ice along the four main shear planes 1－4 (Fig. 1). This debris-laden ice consists of relatively bubble-free clear ice with

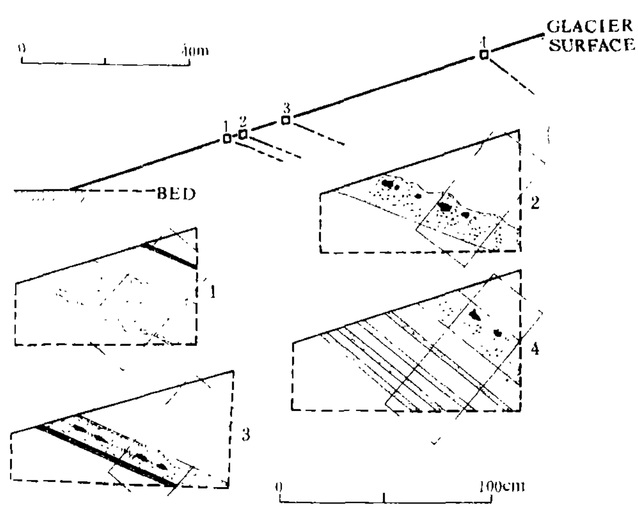


Fig. 1. Structures of debris-laden ice along the 4 shear planes. Dotted part represents debris-laden ice.

englacial till suspended in it. The till content of each sample of debris-laden ice was 1—10% in total weight.

冰川冻土

About 500g of debris-laden ice was sampled from each shear plane to examine the particle size and quartz-grain surface features of the englacial till.

Ⅲ-1. Grain-size distributions

Grain-size distributions of till can be used as an indicator of transport paths through a glacier and of till genesis (e. g. Boulton, 1972). Supraglacial morainic till, debris in the medial moraine and englacial till of extraglacial origin have dominant coarse fraction while basal till has a fine fraction. Furthermore, Boulton (1978) found that, even at the glacier bed, crushing and plucking events produce coarse grains similar to those of extroglacial origin.

Thus the grain-size distributions of shear planes 1—4 were measured and compared with those of till whose transport paths and geneses were known. Fig. 2 shows four

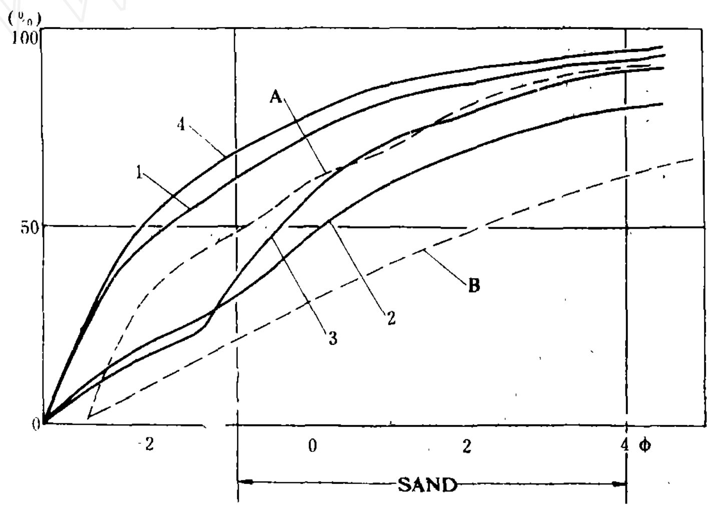


Fig. 2. Particle-size curves of englacial till along the shear planes.

curves of the shear planes and, as typical examples of temperate glacier (after Boulton, 1978), of extraglacial origin (A) and of subglacial origin (B). Grain-sizes were examined every 1/2Φ interval for grains less than 8mm long.

All curves of the shear planes are apparently close to curve (A), although grains of shear plane 2 have relatively fine fraction. The amount of silt and clay in the four shear planes is 5—20%, which is less than those of curve (B) and of other known curves of basal till of temperate glaciers. This result suggests that the englacial till of the shear planes, 1) is derived from the surrounding valley sides and transported englacially, or else 2) consists mainly of the products of crushing and/or plucking events at the base. From the geomorphological fact that rockfalls rarely reach the accumulation area, 2) is a more probable origin of the samples.

Ⅲ-2. Quartz-grain surface features

1) Method

Scanning electron microscopic analysis of quartz-grain surface features has made it possible to discriminate between different sedimentary environments (e. g. Krinsley and Donahue, 1968; Krinsley and Doornkamp, 1973). So far, more than 20 kinds of surface features which are specific to the grains of subaqueous, eolian, regolis + chemical weathering and glacial origins are known. Still, new surface features are being found(e. g. Whalley, ed., 1979), so that the quantitative method for comparison with other worker's studies has not been fully established yet.

In this study, the quartz-grain surface features of four shear planes were classified into the 22 categories (Table 1) of Margolis and Kennet (1971). Categories 1 to 12

Table 1. Surface feature categories of quartz grains described by Margolis and Kennett(1971)

1.	Small scale (< 1μ) imbricate breakage blocks
2.	Small scale (< 1μ) conchoidal fractures
3.	Large scale (> 1μ) breakage blocks
4.	Large (> 1μ) conchoidal fractures
5.	Straight grooves or scratches
6.	Curved grooves
7.	Randomly oriented striations
8.	Semi-parallel step like fractures
9.	Arc shaped steps
10.	Meandering ridges (> 5μ in length)
11.	'V'-shaped irregularly oriented impact pits
12.	Small fractures caused by crack propagation
13.	Sharp angular outline
14.	Rounded outline
15.	Low relief (< 0.5μ)
16.	Medium relief (≈0.5μ and 1μ)
17.	High relief (> 1μ)
18.	Crystallographically oriented etch pits
19.	Irregular finely pitted surfaces
20.	Anastomosing patterns and diagenetic etching
21.	Smooth featureless surfaces (fracture planes)
22.	Crystallographic overgrowths

are mechanical features, 13 to 17 indicate the grain outlines and surface relief, and 18 to 22 are features of chemical origin.

Grains of subaqueous origin have abundant features of 1, 2, 11, 14, 15, 16 and 18; of a eolian origin, 1, 12, 14 and 15; of glacial origin, 3, 4, 5, 8, 9, 13, 17 and 21; of regolith origin, 17, 18, 19, 20 and 22 (Margolis and Krinsley, 1974; Higgs, 1979).

Each feature category was counted when a sample exhibited that feature over at least 10% of its grain surface.

The till samples were put into 10% ammonia water for 10 hours and rinsed in distilled water. Then samples were boiled for 10 minutes in distilled water. After drying well, 25 quartz grains 0.2—2.0mm long were randomly selected with the aid of a stereoscopic microscope from each. Selected grains were stuck onto the mounting stub with double-stick tape and argentum paste. Carbon coating was applied by the sputter-coating method.

JSM—35 Scanning Electron Microscope (JEOL Co Ltd., Japan) was used with an accelerating voltage of 25kv. The tilt angle was generally 10° to 30°.

2) Results

Obseved surface features are summarized in Fig. 3 with the typical 'GLACIAL' features using data from Margolis and Krinsley (1974) and Higgs (1979). Most of the

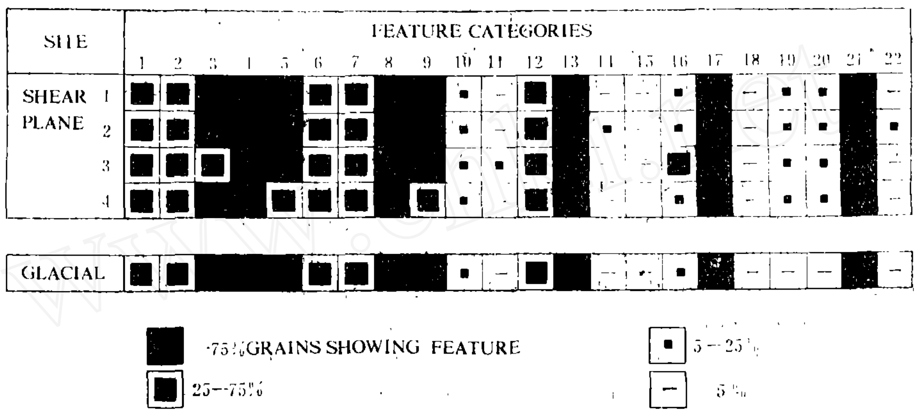


Fig. 3. Quartz-grain-surface-feature characteristics of each englacial till sample. 'GLACIAL' represents the typical surface features of glacial origin compiled using data from Margolis and Krinsley (1974) and Higgs (1979).

grains exhibit the 'GLACIAL' features and the differences between samples of four shear planes are very slight. Plate 1 is an example of SEM photos of grains from shear plane 4. Sharp angular outline, arc shaped steps, large breakage blocks an other typical 'GLACIAL' features are clearly observed. Conchoidal fractures of various sizes and of different directions (Plate 2) indicate that this grain was fractured under high stress. All other grains also exhibit conchoidal fractures, semi-parallel steps like fractures, sharp angular outlines and fresh fracture planes unless they are not covered by chemical weathering features, although large breakage blocks, straight grooves, and arc shaped steps are sometimes not observed.

The notable differences between the samples and the glacial grains are that the former sometimes have features of chemical weathering (Plate 3, 4). 5—20% of the grains show silica precipitation/solution features partially superimposed on the 'GLACIAL' features. In general, such features cover 10—30% of the surface, occasionally up to 80%. Crystallographic overgrowths of silica were also observed in the grain of shear plane 2.

Features of aeolian origin, dish-shaped concavities and rounded grains were not observed. Impact 'V' pits and rounding of the edges, which are abundant features of aqueous origin, were seldom observed.

Ⅳ. Discussion

The coarse fraction of grain-size distributions suggest that the grains were produced by crushing like events. Although it is difficult to determine whether the samples were subglacial origin or periglacial origin only from the results of grain-size analysis, the following results of SEM analysis suggest that the grains were the products of basal crushing and/or plucking events.

The fact that the almost all of the sampled quartz-grain had 'glacial' features, indicates the englacial till was produced by mechanical crushing or fracture. These features are most probably aquired during subglacial erosion process. (Shimizu, 1975; Eyles, 1978). Howerver, supraglacial morainic till of periglacial origin has the similar features (Whalley and Krinsley, 1974).

The fact that 5—20% of the sampled grains had chemical weathering features superimposed on 'glacial' features indicates that the grains were lodged in water after being crushed because the chemical weathering of quartz-grains is active in water (Margolis, 1968; Shimizu, 1980). As the ice and firn temperature of this glacier is below 0 C, the place where the grains were in water was probably at the glacier bed.

Furthermore, the grains rarely show either the rounding of the edges or impact 'V' pits, which means the grains were not grinded nor transported in subglacial turbulent stream. Because the rounding of edges indicates the inter-particle contact in the grinding or abrasion event at the glacier bed if only some edges of each grain are modified, while if all edges of each grain are rounded, the grain is transported in fluvio-glacial stream (whalley, 1978). The 'V' pits are aquired by the collision of the grains during the transportation in turbulent water flow (Margolis and Kennet, 1971).

According to the above results, the sampled till genesis is considered to be followings. Crushing and/or plucking event at the glacier bed produced the fresh grains. The Crushed grains were entrained in the glacier ice imediately or after being lodged in basal water, without being transported in subglacial drainage.

Because all samples from each shear plane showed the similar characteristics, crushing and/or plucking event may play a more important role than abrasion event on erosional process at the base of Urumqi No. 3 Glacier. And the lack of the features of subaqueous origin suggests that subglacial drainage system which is usually in temperate glaciers is not developed in this glacier.

Acknowledgements

This field work was done as a part of China-Japan Cooperative Glaciological Expedition to the Tian Shan. Electron microscope facilities were kindly provided by Dr. Y. Fujii of National Institute of Polar Research (NIPR). We would like to thank Dr. K. Shiraishi of NIPR and Dr. T. Koaze of Meiji University for assistance with their various instruments.

References

[1] Boulton, G. S. (1970): On the origin and transport of englacial debris in Svalbard glaciers. *J. Glaciol.*, Vol. 9, 50,

[2] Boulton, G. S. (1972): The role of thermal regime in glacial sedimentation. In Price, R. J. and Sugden, D. E. (eds) Polar geomorphology, Inst. Br. Geogr. Spec. Pub. 4, p. 1—19.

[3] Boulton, G. S. (1978): Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis. *Sedimentology*, 25, p. 773-799.

[4] Cui, Z. (1981a): Kinds and features of glacial moraine and till at the head of Urumqi River, Tian Shan. *J. Glacial. and cryopedol.* (in Chinese with English abstract), 3, special issue, p. 36—48.

[5] Cui, Z. (1981b): On the glacial cirque at the head of Urumqi River, Tian Shan. (in Chinese with English abstract), *J. Glaciol and cryodedol. 3, special issue*, p. 36—48.

[6] Eyles, N. (1978): Scanning electron microscopy and particle size analysis of debris

from a British Columbian glacier: a comparative study. In Whalley, W. B., ed. Scanning electron microscopy in the study of sediments. Norwich, Geo Abstracts, p. 227-242.

[7] Higgs, R. (1979): Quatrz-grain surface features of Mesozoic-Cenozoic sands from the Labrador and Western Greenland continental margins. *J. Sediment. Petrol.*, 49, p. 599-610.

[8] Krinsley, D. and Donahue, J. (1968): Environmental interpretation of sand grain surface textures by electron microscopy. *Bull. Geol. Soc. Am.*, 79, p. 743-748.

[9] Krinsley, D., Donahue, J. and Doornkamp, J. C. (1973): Atlas of quartz sand surface textures, Cambridge University Press, 91. pp.

[10] Margolis, S. V. (1968): Electron microscopy of chemical solution and mecanical abration features on quartz sand grains. *Sediment. Geol.*, 2, p. 243-256.

[11] Margolis, S. V. and Kennett, J. P. (1971): Antarctic glaciation during Tertiary recorded in sub-Antarctic deep sea cores. *Am. J. Sci.*, 371, p. 1—36.

[12] Margolis, S. V., Kennett, J. P. and Krinsley, D. (1974): Processes of formation and environmental occurrence of microfeatures on detrial quartz grains. *Amer. J. Sci.*, 274, p. 449-464.

[13] Shimizu, F. (1975): Quartz-grain surface features of the glacial deposits in Matsukawa valley, Mt. Shirouma. (in Japanese), in Shiki, M. ed. Problems in glaciation of Japan, Kokin Shoin, Japan, p. 72—87.

[14] Shimizu, F. (1980): Chemical weatering features on quartz-grains in the glacial deposits of European Alps, the Nepal Himalaya and the Japan Alps. (in Japanese with English abstract). Review of Research for Disaster Prevension, Japan, 29. pp.

[15] Wang, J. and Zhang, Z. (1981): Glacial sediment at the head of Urumqi River, Tian Shan, (in Chinese with English abstract), *J. Glaciol. and Cryopedol.* 3, special issue, p. 49—56.

[16] Watanabe, O., Ageta, Y. and Iwata, S. (1983): Some aspects of the glacier structure and moraine characteristics of Glacier No. 3 in the Urumqi river head waters, in this issue.

[17] Weetman, J. (1961): Mechanism for the formation of inner moraines found near the edge of cold ice caps and ice sheets. *J. Glaciol.*, Vol. 3, 30, p. 965-978.

[18] Whalley, W. B. (1978): An SEM examination of quartz grains from sub-glacial and associated environments and some methods for their characterization. *Scanning Electron Microscopy*, Vol. 1, p. 353-360.

[19] Whalley, W. B. ed. (1978): Scanning electron microscopy in study of sediments. Norwich, Geo Abstracts, 303. pp.

[20] Whalley, W. B. and Krisley, D. H. (1974): A scanning electron micro scope study of surface textures of quartz grains from glacial environments. *Sedimentology*, Vol. 21, 1, p. 87-105.

天山乌鲁木齐河源3号冰川沿剪切面内碛的成因

——据粒度分布和石英颗粒表面特征的分析

吉田稔 渡边兴亚
（日本名古屋大学水圈科学研究所）

摘 要

3号冰川消融区下部有4个主要的剪切面，这些剪切面伴随着5—40厘米厚的富含岩屑冰。在每个富含岩屑冰区域采集了内碛样品以便考察它的特征和来源。

冰内碛巨砾具有极其明显的棱角状，泥沙和粘土的含量低于温冰川磨蚀过程产生的冰碛的泥沙和粘土含量。用电子扫描显微镜观察到的石英颗粒表面特征表明：

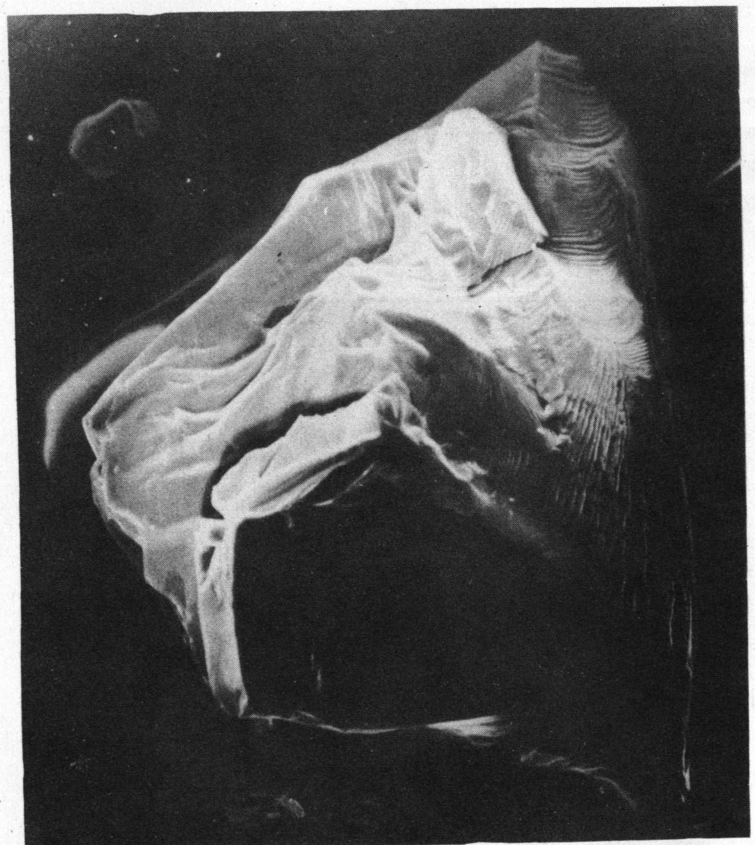
（1）所有颗粒都具有典型的“冰川作用”特征。

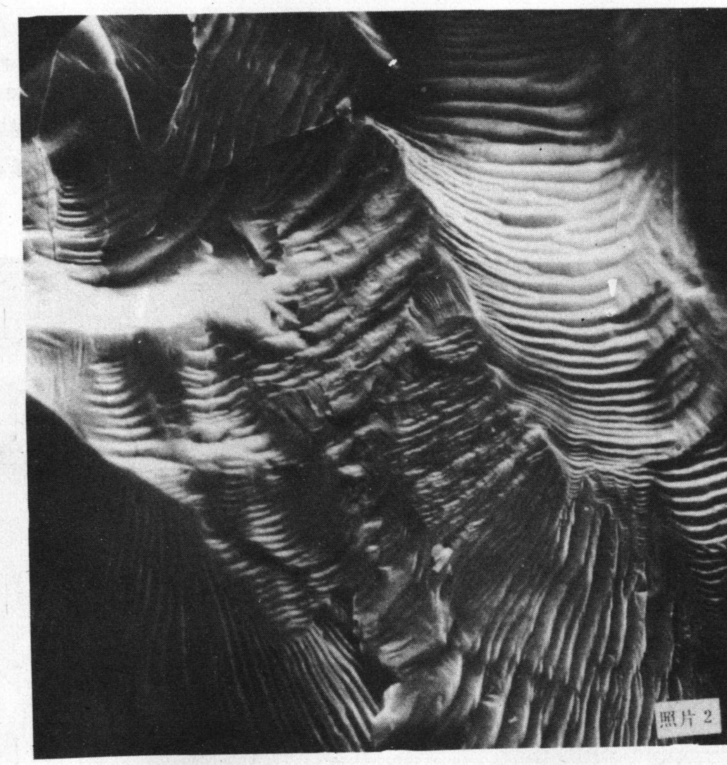
（2）5—20%的颗粒显示出在“冰川作用”特征之上附加有二氧化硅溶解沉淀物特征。

（3）水下机械作用的标志如撞击痕和磨圆现象很少观察到。

(1)意味着石英颗粒是机械研磨或挤压作用的产物；(2)和(3)意味着某些颗粒在被挤压后曾在水中停留过，但颗粒并没有在湍流水流中被搬运。

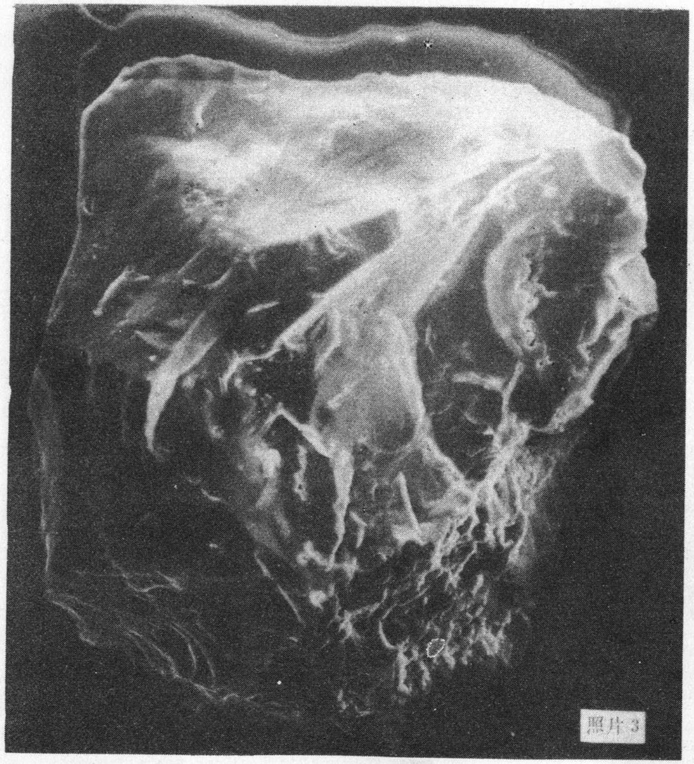
这些结果暗示3号冰川内碛主要是由冰川底部挤压或拔蚀作用所产生，而不是磨蚀作用的产物。在内碛产生的冰川底部，温度一直或以前保持在融点，但水量小于温冰川底部的水量。





照片1　4号剪切面的石英颗粒，显示典型的冰川成因特征。照片2　照片1中颗粒的微观特征,反映不同尺寸的贝状断口和碎块。

Pho. 1 Quartz grain of shear plane 4 shpwing typical glacial origin features. Scale bar represents μm. Pho. 2 Detail of grain in Plate 1 showing conchoidal fractures of various sizes and large breakage blocks (upper left). Scale bar represents 20μm.



照片3　1号剪切面的石英颗粒，化学风化作用部分地改变了其冰川特征。照片4　照片3中颗粒的微观特征，具有不规则下凹的表面和氧化硅沉淀(右上方)。

Pho. 3 Quarts grain of shear plane 1. Glacial features are partially covered by chemical weathering features. Scale bar represents 100μm. Pho. 4 Detail of grain in Plate 3 showing irregular pitted surface and silica precipitation (upper right). Scale bar represents 40μm.