SPECIAL MAP SERIES OF NATIONAL INSTITUTE OF POLAR RESEARCH

NO 1

ANTARCTIC GEOMORPHOLOGICAL MAP OF LANGHOVDE

Explanatory Text of Geomorphological Map
of
Langhovde, Antarctica

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NATIONAL INSTITUTE OF POLAR RESEARCH
TOKYO, MARCH 1984

EDITORIAL BOARD

National Institute of Polar Research
9-10, Kaga 1-chome, Itabashi-ku
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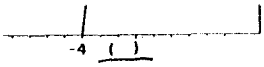
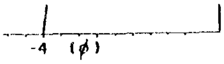
ERRATA

page	line	erratum	correction
cover	9	Masatake	Masamu
title page	5	Masatake	Masamu
27	Fig. IV-7		

EXPLANATORY TEXT OF GEOMORPHOLOGICAL MAP OF LANGHOVDE, ANTARCTICA

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Contents

I. Introduction

As is explained in the following chapter, a geomorphological map is of great value for the detailed study of landforms from both qualitative and quantitative viewpoints. The geomorphological work of the Lützow-Holm Bay region started without any scientific materials other than several air photographs and a small-scale map covering a part of the region, as is often the case in Antarctica. Since that time, the results of field work have been accumulated and topographic and geological mappings have gradually progressed. Large scale aerial color photography has also covered a part of the ice-free areas.

With these results as the background, we attempted to prepare a geomorphological map of ice-free areas in the region for future geomorphological study including the qualitative and quantitative comparison with those in other regions inside and outside the Antarctic.

The work was done as cooperative efforts by researchers from several universities within the framework of the joint studies granted by the National Institute of Polar Research. It consisted of discussions on legend and representations, air photograph interpretation, morphometric measurements, and compilation of results of field work. This geomorphological map is the first issue of the special map series published by the National Institute of Polar Research.

Langhovde is an ice-free area situated on the Sôya Coast, the eastern coast of Lützow-Holm Bay, in East Antarctica. It is the second largest of the ice-free areas on the Prince Harald and Prince Olav Coasts and has an area of about 52 square kilometers.

Lützow-Holm Bay is bounded by the NNW-SSE protruding Riiser-Larsen Peninsula on the west and by the ENE-WSW extending Prince Olav Coast on the east. The bay was discovered by reconnaissance flight in the Norwegian Expedition in 1932 (Isachsen, 1932). The Norwegian Expedition in 1937 also made oblique air photography on the coastal region of the bay (Christensen, 1939). The map of this region on a scale of 1:250,000 was prepared by Hansen (1946) on the basis of these oblique air photographs as a part of Antarctic Map Series of Norway. The Langhovde area was drawn with 100 m interval contour lines in this map, and Norwegian place names were introduced (Fig. I-1). Langhovde means a long rounded peak and seems to describe properly the glacially scoured landscape of this area. Other place names are Hamna (harbor), Dokkene (dock), and Hovdebukta (rounded peak bay) for embayments, Hamnenabben (harbor knoll) for a detached hill, and several names for islets near the coast.

The Langhovde area was first visited by the summer party of the first Japanese Antarctic Research Expedition (JARE-1, Table I-1). On the basis of the geomorphological work during this short visit, Yoshikawa and Toya (1957) pointed out the following geomorphic features of the area: 1) Langhovde is hilly mountains extending along a coast of the ice sheet, and its northern half and a part of the southern half are separated by a glacier (named Langhovde Glacier afterwards) from the ice sheet, 2) The mountains are divided into two parts by glacial troughs in the central part, where the crescent-shaped moraine suggests one stage of standstill of the ice sheet shrinkage, 3) the northern part of the mountains consists of low-lying hilly land with quarried surface and isolated dome-like peaks, 4) the southern part forms plateau-like mountains having summits of comparatively similar altitude, 5) the mountains were once covered completely with the ice sheet in the past as evidenced by glaciated landforms with scattered erratic boulders, 6) during the shrinkage of the ice sheet, some cirques were formed by mountain (cirque) glaciers at places where the depressions along structurally weak lines in gneissic bedrock were shaped by selective erosion of the ice sheet, 7) raised beaches containing fossil molluscs are distributed in some places along the coastline, indicating the crustal uplift of about 20 m after deglaciation, and 8) nivation, exfoliation and wind erosion are actively modifying the present topographic features.

The JARE-1 wintering party made geological work in the coastal ice-free areas, and described some characteristic features of the glaciated landforms and weathering phenomena in

Langhovde (Tatsumi and Kikuchi, 1959a). Recent minor shrinkage of the ice sheet was suggested by them on the basis of the fact that bedrock surface along the ice margin is not subjected to substantial weathering compared with that in other places and erratic boulders near the ice margin have not been altered since their settlement on bedrock.

On the basis of field work by the JARE-6 and of air-photo interpretation, Koaze (1964) discussed the landforms along the

Table I-1. Field work in earth sciences of Langhovde.

Expedition	Year	Investigator (S): summer party member (W): winter party member	Items of investigation		
			Geomorphology	Geology	Glaciology
JARE-1	1957	Yoshikawa (S) Tatsumi, Kikuchi (W)	*	*	
JARE-4	1960	Kizaki, Y.Yoshida, Ishida (W)		*	*
JARE-5	1961	Fujiwara (W)			*
JARE-7	1966	Maegoya (W)			*
JARE-8	1967	Y.Yoshida (W)	*		*
JARE-9	1968	Fujiwara, Yanai, Endo (W)	*	*	*
JARE-10	1969 1970	Omoto, M.Yoshida, Naruse, Ageta (W)	*	*	*
JARE-11	1970	Watanabe, Yoshimura (W)			*
JARE-12	1971 1972	Yamada, Nakao (W)			*
JARE-13	1972	Moriwaki (S) Ishikawa (W)	*	*	
JARE-14	1973	Omoto, Shiraishi, Naruse, Yokoyama (W)	*	*	*
JARE-15	1974	Yanai, Moriwaki (W)	*	*	
JARE-16	1975	Hayashi, Matsumoto (W)	*	*	
JARE-17	1976	Nogami (S)	*		
JARE-18	1977	Suzuki (S)		*	
JARE-22	1981	Y.Yoshida (W)	*		
JARE-24	1983	Motoyoshi, Matsubara (S)		*	

Sôya Coast including those in Langhovde. He pointed out that strandflat in the Langhovde area might have originated from piedmont surface in preglacial age. He also described selective erosion by the ice sheet and characteristics of periglacial phenomena, and inferred the mode of the ice sheet shrinkage.

Yoshida (1970) described raised marine features such as marine boulder pavement and probable wave-cut bench after field work by the JARE-8. He reported also peculiar thermal water stratification of Lake Nurume. Geochemical properties of saline lakes in Langhovde were analyzed by several researchers (Torii and Yamagata, 1973; Murayama, 1977; Sano *et al.*, 1977).

Since the JARE-9, geomorphological work of the Langhovde area including sounding of submarine topography have been conducted on several occasions. Moriwaki discussed raised beach topography together with its radiocarbon age (1974) and some characteristics of glacial and periglacial landforms (1976) in the northern part. Ishikawa (1974), in his detailed geological work, discussed the glaciated landforms, raised beach deposits and mechanical weathering. Omoto (1977) made a detailed survey of raised beaches and presented the schematic topographic cross section of them with radiocarbon dates. Nogami (1977) also discussed the characteristics of the raised beach topography.

Submarine geomorphology around Langhovde was studied by Fujiwara (1971) and by Omoto (1976). The topographic features of glaciated continental shelf with complicated rises and depressions were revealed and discussed in relation to geologic structure and past glacial flow.

Yoshida (1983a) summarized the geomorphic characteristics of the Langhovde area with a geomorphic map on the basis of the above studies and air-photo interpretation. Yoshida (1983b) added the result of supplementary field work on fluviogalcial deposits.

On the other hand, since the first investigation by Tatsumi and Kikuchi (1959b), regional geology of the Langhovde area has been studied repeatedly. Ishikawa (1974) presented the detailed description of geology, and compiled the geological map with other researchers (1976). Geologic structure was also discussed by several researchers (*e.g.* Ishikawa et al., 1976; Yoshida, 1978; Matsumoto *et al.*, 1979).

The first glaciological investigation in Langhovde was the icefabric studies on the Hamna Icefall (Kizaki, 1962). Then, measurements of movements of glaciers around Langhovde were carried out (Fujiwara and Yoshida, 1972; Shimizu *et al.*, 1975).

On place names given by JARE:

During repeated field work in Langhovde, many place names were proposed by researchers mainly for the convenience of description of scientific results, and thirty-seven place names were approved by the Japanese Antarctic Research Expedition Headquarters according to recommendations by the Antarctic

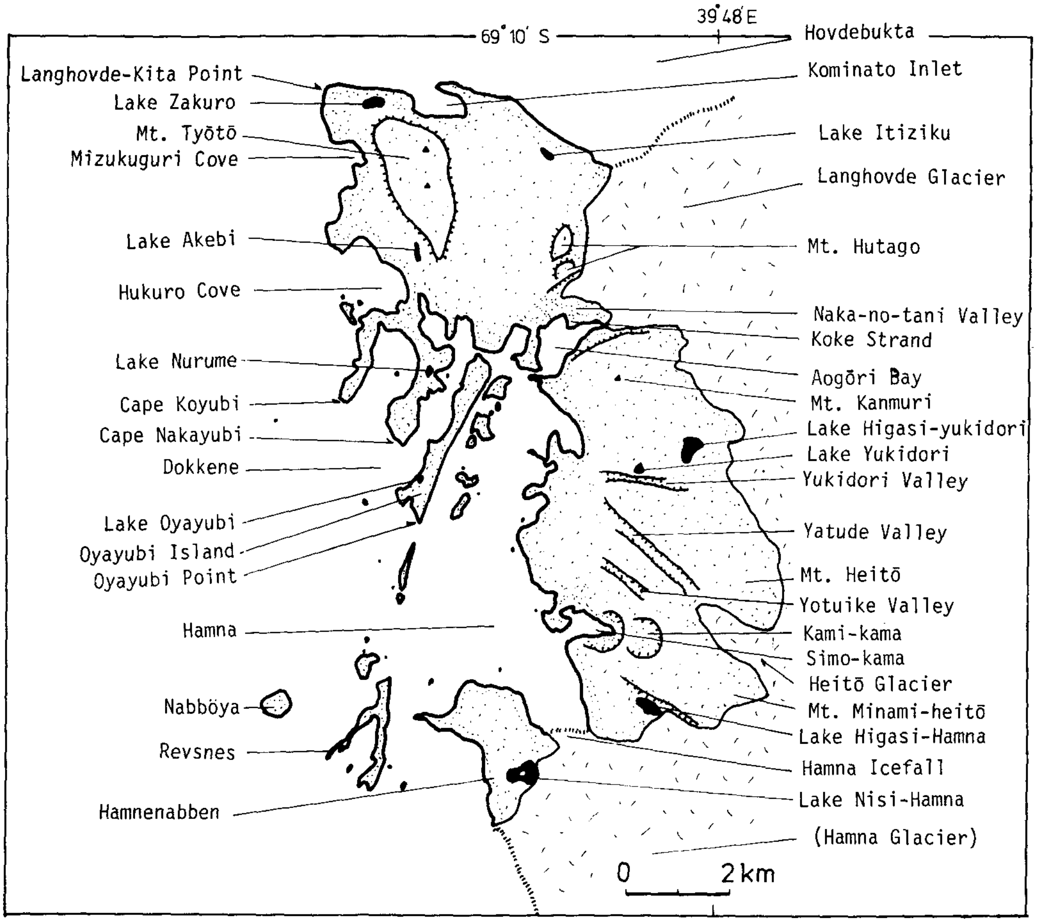

Fig. I-1. Place names of the Langhovde area.

Place-Name Committee of Japan, National Institute of Polar Research (Fig. I-1). Some names were derived from topographic features as exemplified by Mt. Heitô (flat-topped mountain) and Mt. Tyôtô (long-head mountain), and some from topographic situation as Naka-no-tani Valley (central valley) which divides Langhovde into two parts at the central place. A name of a glacier is usually derived from the place name of the neighboring ice-free area such as Langhovde Glacier. Yukidori Valley and Lake Yukidori represent fertile breeding of snow petrels (yukidori) in this area. Kami-kama is a circular depression on land and Simo-kama a partly drowned, semi-circular depression next to Kami-kama. Three lakes have names derived from fruit names, indicating that their shapes are more or less circular or oval. On the other hand, Lake Nurume was named according to its unusual thermal water stratification. Nurume means a pool at a corner of a paddy field which is used to warm irrigation water temperature by solar radiation. The name Lake Nurume suggests that its unusual thermal stratification is caused by solar radiation. Other place names were derived from various sources, for example, according to sea ice condition ((Aogôri (blue ice) Bay)), as a memory of scientific activity ((Mizukuguri (diving) Cove)), etc.

II. Concepts of the geomorphological maps

The purpose of the geomorphological maps is the accurate graphic representation of landforms of an area and the indication of the wide range of influences, both past and present, that have made it what it is (St. Onge, 1968). Since the 1950's, geomorphological mapping systems have been developed mainly in European countries such as France, West Germany, Poland and U.S.S.R. Among them, France and West Germany have developed most the systems of mapping indipendently by their detailed and systematic ways of representation of landforms and related phenomena. The preparation of the detailed geomorphological map of such kind in Antarctica was attempted for the first time by the authors. Therefore, we discussed repeatedly the mapping system for the geomorphological map of Langhovde, taking the regional characteristics of Antarctica in comparison with those of other regions into consideration. As a result, we tried to make the best use of different merits of both the German and the French systems. French and German mapping systems are both highly sophisticated and very useful, but they are different from each other in several points. The principles of the French and German systems of mapping are summarized as follows:

1. French system

In France, the geomorphological mapping has been attempted since 1953, especially by the Centre de Geomorphologie Applique de Strasbourg. The geomorphological maps on different scales, 1:50,000 and 100,000, were published (Tricart, 1959, 1961). In the 1960's, the principles of mapping systems were established (Joly, 1962; Tricart, 1965). Since 1962, many sheets of the detailed geomorphological maps ("cartes geomorphologiques detaillees") have been published on a scale of 1:25,000 for various areas not only in France but also in other parts of the world.

The principles of the French system of geomorphological mapping (in large scale, especially 1:25,000) are as follows:

(1) Solid colors indicate lithology.

(2) Each landform is represented by a symbol which is overprinted on lithological colors. The symbol itself has a different color according to a different morphogenesis which is linked to each landform: for example, symbols representing glacial landforms are colored in purple; fluvioglacial landforms are in green, periglacial landforms are in lilac.

(3) Age of landforms is indicated by a difference of the darkness in colors of the symbols.

(4) Geomorphic processes presently operating in the area such as torrents, slope wash, solifluction and so on are represented by special symbols having the corresponding color of morphogenesis.

In short, the advantages of the French system exist in its clarity and legibility. One can easily grasp the lithological control on the landforms and the distribution of distinctive erosional and depositional forms made by different processes. But there remain the following disadvantages:

(1) Morphometric data are much less represented than in the German system: for example, slope curvature is not mentioned in the French system.

(2) Although each symbol represents the morphogenesis, the space between the symbols bears no information on the morphogenesis, for it is colored according to the lithology.

2. German system

In West Germany, since 1976 a research project on geomorphological mapping on a scale of 1:25,000 and 1:100,000 has been carried out with the financial support of the Deutsche Forschungs Gemeinschaft. There are a series of papers not only on the project itself but also on the mapping system (Barsch, 1976; Barsch and Mäusbacher, 1978; Stäblein, 1978; Barsch and Liedtke, 1980). Several sheets and explanatory texts were already published (*e.g.* Leser, 1979; Galbas *et al.*, 1980).

According to these papers, the principles of the geomorphological map on a scale of 1:25,000 are as follows:

(1) Mapping and representation of data on the description and explanation of the relief, including the geomorphological processes.

(2) Mapping and representation of current geomorphological processes, including all parameters of special ecological importance.

(3) Representation in a form, which allows an easy application to other works in geosciences and various kinds of planning.

The information contained in the geomorphological map is, therefore, divided into five main groups (Barsch *et al.*, 1978): 1) topography, 2) morphography/morphometry, 3) surface and subsurface materials/geology, 4) hydrography and 5) morphogenesis (geomorphological processes and their areal distribution).

1) Topography is printed in dark gray.

2) Relief is supplemented by morphographical (mostly morphometric at the same time) data regarding the curvature of slope segments, steps or scarps, form of small valleys, minor landforms, surface roughness, etc. They are represented in black without any morphogenetic interpretation.

3) The surface material is mapped according to its genesis (loess, moraine, bog,...) and grain size classification (sand, clayey sand, silt,...) used in soil science. Rocks are mapped only when they form the surface, or when lithology is especially important to understand relief conditions (*e.g.* limestone). This sort of information is printed in brownish red.

4) Hydrological data (springs, perennial creeks, swampy areas,..) are given in blue.

5) The most important decision during mapping has to be taken on the registration and delimitation of process areas, presented by colors. As there is no logically consequent hierarchy of geomorphological processes, a hierarchical system of decision was developed (Barsch and Mäusbacher, 1979). In this respect the process areas are presented by the process which was responsible for the latest significant shaping of the respective parts of relief. Polygenesis is only mapped in an exceptional case and at most by two colors.

Special symbols stand for singular or actual geomorphological processes such as rock fall, land slide, soil creep, solifluction and so on, because they are considerably important for interpretations of all geomorphological and geoecological phenomena. They are represented in red when they are active, and in black when they are no longer active. Further discussions are necessary to be referred to the explanatory text.

3. Principles of the geomorphological map of Langhovde

The basic idea for the mapping system of Langhovde is to prepare the map which is easy to read and yet carries geomorphic information as much as possible. The principles (basic points) of the map are as follows:

(1) Almost whole the area consists of glacially erosional features which are strongly controlled by geological structure and lithology. Therefore, lithology and geological structure should be represented by an easily readable way in line with the French system. They are, however, placed at the lower order in the arrangement of the legend, because the map is not a geological map.

(2) Morphographic and morphometric elements are represented fundamentally according to the German system whose representation is more detailed than that in the French system. Slope classification, however, is not printed on the main map as the German system but on the separate overlay, in order to avoid the poor reading.

(3) The geomorphic processes, or their geomorphic traces which do not form conspicuous topography, are symbolically represented.

(4) The area of geomorphic processes is represented by color representation according to types of geomorphic processes as the German system, in order to indicate the extent and nature of such process.

III. Mapping system for Langhovde area

1. Topographic map and bathymetric map

The base map for the geomorphological map of Langhovde is the topographic map of Langhovde (1:25,000), which was published in 1968 by the Geographical Survey Institute, Japan. Plotting of the topographic map was based on vertical aerial photographs taken in January 1962 (JARE-6) and geodetic data obtained by control survey in October 1966 (JARE-7) and in October 1967 (JARE-8) (Yoshida and Kakinuma, 1963; Inbe, 1967; Tables III-1, 2). Aerial photographs of the Langhovde area were taken further by JARE after the JARE-6 (Table III-2, Fig. III-1).

Plotting of the eastern part of the Langhovde Glacier was carried out by the authors with Wild B8S stereoplotter of the

Table III-1. Records of aerial photography of the Langhovde area.

Expedition	Year	Camera	Focus (mm)	Scale	Remarks
JARE-1	1957	Fairchild, K-17C	153	1:12,000	
JARE-6	1962	RMK 11.5/18	115.02	1:26,000	
JARE-10	1969	"	"	"	
JARE-11	1970	"	"	1:5,000	
JARE-12	1971	RC-9	88.43	1:16,000	
JARE-16	1975	"	"	1:10,000	Color
	"	"	"	1:34,000	
JARE-23	1982	RC-10	88.05	"	

Table III-2. Control survey of Langhovde.

Expedition	Year	Control survey
JARE-4	1960	Distance measurement.
JARE-7	1966	Control point survey and pricking, 8 stations.
JARE-8	1967	Distance measurement of base line.
JARE-12	1971	Control survey between West Ongul I. and Langhovde.
JARE-13	1972	Traverse survey (Padda-Skallen-Skarvsnes-Langhovde).
JARE-14	1973	Distance measurement (East Ongul I.-Langhovde-Skarvsnes).

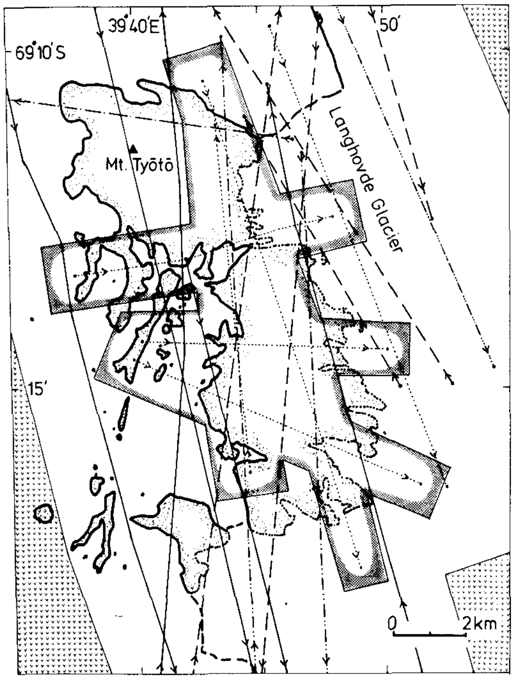

Fig. III-1.
Flight courses of aerial photography.

National Institute of Polar Research on aerial photographs by the JARE-16. The authors corrected some parts of the coastline in the topographic map, using photographs taken by the JARE-10 and the JARE-16 which show less snow cover compared with those by the JARE-6.

Field work in geoscience carried out from the JARE-1 to the JARE-24 in Langhovde are shown in Table I-1.

A bathymetric map near Langhovde was drawn first by Fujiwara (1971). It is based on echo-sounding data obtained by the icebreaker "Fuji" in shore polynya along the northern part of the Sôya Coast in the summer season of the JARE-9. Omoto (1976) carried out echo-sounding from the surface of sea ice at intervals of 500 m in the winter season of the JARE-14 and produced a detailed bathymetric map around Langhovde. The bathymetric contours in the geomorphological map of Langhovde were re-drawn by the authors using additional data (Table III-3). Submarine topography is represented by contour lines at intervals of 50 m. Sounding points and depth are expressed as

Table III-3. Echo-sounding near Langhovde.

Expedition	Year (S): summer (W): winter	Area	Method	Investigator
JARE-9	1968 (S)	West of Langhovde	From ship	"Fuji"
"	" (W)	North of Langhovde	From surface of sea ice	Fujiwara
JARE-10	1969 (S)	West of Langhovde	From ship	"Fuji"
JARE-14	1973 (W)	Around Langhovde	From surface of sea ice	Omoto
JARE-15	1974 (W)	Kominato Inlet	"	Moriwaki

figures in the map. Most of these data were quoted from Omoto (1976).

2. Morphography and morphometry

Data on morphography and morphometry were obtained by interpretation of air photographs on the scale of 1:26,000 and 1:10,000, which are listed in Table III-1 (Fig. III-1; Photos 1, 2). The morphography was represented in principle according to German system, although it was often difficult to obtain the morphometric information such as height and width of cliffs, radii of curvature of convex and concave slopes and so on. This map represents the following morphographic features: (1) axes of curved slope segments; (2) steps and cliffs; (3) ridges; (4) valleys (smaller than 100 m in width); (5) hillocks and depressions; (6) minor landforms and roughness. All morphographic symbols are printed in black color.

3. Geomorphological processes and their traces

Individual geomorphological processes and their traces are represented on the basis of field observations and air-photo interpretations. They are presently operating ones except erratic boulders, glacial striae and fossil shells. They are indicated by symbols on the map in red color at localities where they are active or found.

4. Inland water

Glaciers, snow drifts, lakes and streams are classified as inland water.

5. Area of geomorphological processes

Areas of geomorphological processes are represented by different colors: glacial (purple); periglacial (lilac); fluvioglacial (green); eolian (yellow); and marine - littoral (greeny blue). In principle, the darker color indicates the area of deposition and the lighter color the area of denudation. In the depositional area of fluvioglacial processes, the difference of the darkness in color also represents the ages of deposition.

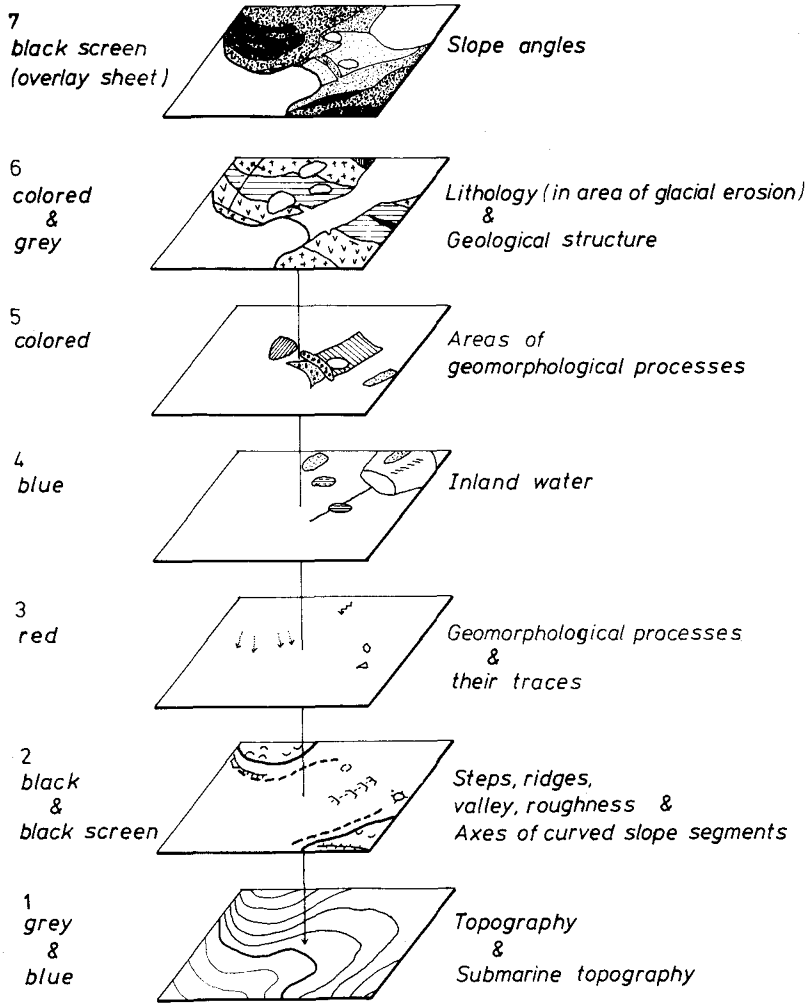

Fig. III-2. Layers of information in the geomorphological map of Langhovde.

According to the German system, all terrains of exposed bedrocks in Langhovde might be colored either in purple (glacial forms) or in reddish brown (rock-controlled structural forms), since these areas have been totally subjected to areal scouring of the ice sheet on one hand, and they constitute rock controlled structural forms on the other. As the glacial erosion itself works selectively on different rock types, it is difficult to distinguish glacial forms from structural ones in this region of Antarctica. Furthermore, if the exposed bedrock areas are colored either in purple or reddish brown, the color could no longer be used to represent each type of lithology which is the most important factor for the landform evolution of this area through a differential erosion. Only in this point, which is especially the case in the Antarctic region where the nearly total area is included into the denudational area of glacial processes, the German system is not suitable. Therefore, we adopted the French system for the lithological representation and the denudational area of glacial process was not colored.

In order to show the distribution of each area of geomorphological processes in Langhovde, a separate map of smaller scale was drawn at the right side of the main geomorphological map.

6. Lithology

Lithology of bedrocks represented in the geomorphological map is based upon the geological map published in 1976 (Ishikawa *et al.*, 1976).

The Langhovde area is mainly composed of various sorts of gneiss of Precambrian and Cambrian ages (Ishikawa, 1974), which were classified into six petrographic units in the geological map. In the geomorphological map, they are grouped into the following three units to avoid an overburden of the map:

1) Garnet gneiss and garnet-bearing granitic gneiss.
2) Hornblende gneiss and pyroxene gneiss.
3) Garnet-biotite gneiss, porphyroblastic gneiss and microcline granite.

This grouping is made not from a petrographical but from a geomorphological viewpoint; these three units are arranged in descending order of their apparent resistance against the subglacial and subaerial denudation.

Besides, metabasite, which is mostly exposed as narrow bands intruded into the garnet gneiss and pyroxene gneiss, is represented, because it bears characteristic features shaped by differential erosion.

7. Slope classification map

Slope values are represented in a separate small-scale map and an overlay sheet to avoid the overburden of the geomorphological map. The slope angle is classified into the following four categories: 0-3°, 3-15°, 15-40° and 40-90°. They correspond to gently sloping, moderately sloping, steeply sloping and very steeply sloping conditions, respectively.

Other characteristics of slope are interpreted from contour lines and morphographic symbols.

IV. Explanation of legend

1. Morphography

1) Axes of curved slope segments

It is very important to understand characteristics of slopes to classify those into concave and convex segments (Fig. IV-1). The axes of these two types of slopes are represented in this map. If curvatures of both concave and convex slope segments are considerably large, and the axes of neighboring slopes are situated closely to each other (ca. 100 m), it is very difficult to distinguish such slope forms from steps or cliffs. In case that a horizontal distance of both axes is less than 100 m, the concave and convex segments are represented as steps and scarps, respectively.

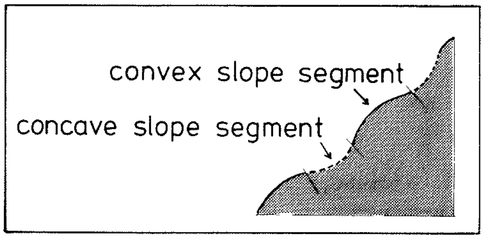

Fig. IV-1.
Schematic profile of curved slope segments.

2) Steps and cliffs

Steps and cliffs are classified into two groups according to relative height; higher than 100 m and lower than 100m. The latter group should preferably be subdivided into some groups on the basis of its height and width. But it was not attempted due to defect of its morphometric data.

3) Ridges

Ridge topographies with the basal width less than 100 m in cross section are classified into the following four types (Fig. IV-2): (1) asymmetric ridge; (2) flat-topped ridge; (3) knife ridge and (4) asymmetric knife ridge. It was sometimes very difficult to distinguish asymmetric ridges from asymmetric knife ridges or scarps. In the Langhovde area, asymmetric ridges develop mostly controlled by homoclinal structure of geology.

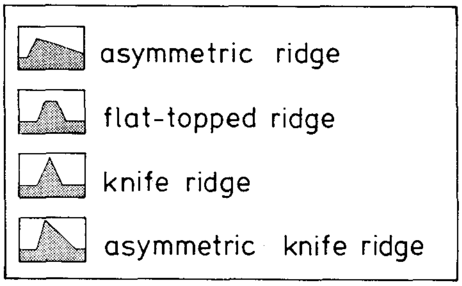

Fig. IV-2.
Schematic cross sections of ridge forms.

4) Valleys

Valleys less than 100 m in width between upper edges in cross section are classified into three types: (1) a trough-shaped valley with gently sloping concave walls; (2) box-shaped and (3) V-shaped valleys. Larger valleys are represented by using other symbols (steps and cliffs) of morphography. In the Langhovde area, all valleys are strikingly controlled by geological structure such as joint and foliation of gneiss.

5) Hillocks and depressions

A lot of hillocks and small depressions are characteristically developed in the mapped region. They could be subdivided into two or three groups, on the basis of the width and the radius of curvature at their margins. But we mapped them without such subdivision. In most cases, they are larger than 100 m in diameter.

6) Minor landforms

As very small hillocks and depressions can not be individually indicated, they are symbolically represented as hillocky- and pitted-surfaces, only in case of their considerable extention. They indicate, therefore, a rough rocky surface. A talus cone, which is also too small to be individually represented, is mapped as the minor landform with a special symbol.

2. Geomorphological processes and their traces

1) Rock fall

The process of rock fall is strongly controlled by slope form and lithology. Rock falls are observed on glaciated steep walls mostly composed of garnet-biotite gneiss and garnet gneiss. Talus cones and talus aprons (Photo 5) which are formed by rock fall develop more extensively in the southern part than in the northern part of Langhovde.

2) Solifluction

Solifluction is not a conspicuous process in this area because of poor distribution of unconsolidated materials and deficiency of soil water.

Gelifluction lobes are found on the moraine field 1 km northwest of Lake Higasi-Hamna where the ice sheet has retreated rather recently and the moraine is probably ice-cored. Gelifluction lobes are found on the fluvioglacial deposits of the Yukidori Valley and in a depression 300 m south of Lake Yukidori. These areas are covered by considerably thick deposits.

3) Patterned grounds

Sorted polygons are developed on glacial till, especially on recessional moraines close to ice-free areas facing the Langhovde Glacier.

Sorted stone circles with mean diameter of 1 m are situated on moraines near the northwestern part of the Langhovde Glacier (Photo 3), in the Naka-no-tani Valley and east of Lake Higasi-yukidori. Poorly developed stone circles are found on fluvioglacial deposits in the Yukidori Valley. Small stone circles with diameter of 40-50 cm are developed in the intertidal zone of a pocket beach of Dokkene (Photo 4).

Stone stripes are observed on the glacial till northwest of Lake Higasi-Hamna.

4) Frost cracks

Frost cracks are found at such places as raised beaches, moraines and fluvioglacial terraces; the south of the Hukuro Cove, the mouth of the Yatude Valley, Naka-no-tani Valley and Yukidori Valley. They are not so well-developed as to form polygonal nets. They are linear cracks of 5 to 30 cm wide and 5 to 10 m long. They are often filled up by gravel up to the depth of 20 to 30 cm. No ice was seen within them during summer. They have been probably formed by soil contraction under the present climatic conditions.

5) Ventifacts

Ventifacts are found often on the surfaces of till at valley bottoms and near the coast (Ishikawa, 1974). It seems that they are produced by the easterly katabatic wind in summer, when the ground surface is free from snow cover (Moriwaki, 1976). Indicated ventifacts are only those identified in the field work.

6) Honneycomb-weathered rocks

Honneycomb weathering is active in various places not only on the surface of bedrock but also on that of boulder on till. Honneycomb-weathered rocks often develop in a specific layer of gneissic banding (Photos 6, 25) and face to various directions independently of the direction of prevailing wind. In the map honneycomb-weathered rocks are shown only in areas where the field work was carried out.

7) Erratic boulders

Most of gravels in glacial till are composed of rocks of the same kinds as those in the Langhovde area. But some exotic gravels, such as hornfels and basalt, are distributed in various places of the Langhovde ice-free area (Ishikawa, 1974; Ishikawa *et al.*, 1976). An erratic boulder mapped in the east of Mt. Tyôtô is basalt.

8) Glacial striae

Glacial striae are distributed not only on bedrock surfaces near the glacier in the northern part, but also near the coast detached from the glacier in the southern part of Langhovde (Yoshida, 1973; Ishikawa, 1974; Moriwaki, 1976). Glacial striae north of Mt. Hutago have been protected from exfoliation by thin cover of till (Photo 7). Their directions trending west differ from the flow direction of the Langhovde Glacier in spite of being located close to the west margin of the glacier. SW-trending shallow glacial grooves exist west of the Naka-no-tani Valley.

Directions of glacial striae suggest that the past ice flowed generally from east to west not only in the Langhovde ice-free area but also in the Langhovde Glacier area.

9) Fossil shells

Fossil shells are often contained in raised beach deposits lower than 10 m in this area. They are mainly shells of *Adamussium colbecki* and *Laternula elliptica* which live in shallow sea at present. Fossil shells of *Laternula elliptica* seem to be autochthonous, because they occur in erect posture shutting their shells (Ishikawa, 1974; Nogami, 1977; Photo 8). They were dated by the ^{14}C method, as shown in Table V-1 (p.41). Their ages can be classified into two groups, those before 20,000 yr. B.P. and those after 10,000 yr. B.P.

3. Areas of geomorphological processes

1) Area of glacial processes

The Langhovde area was once completely covered by continental ice sheet up to the summits of mountains. Conspicuous landforms are of glacial origin such as troughs, cirques and roches moutonnées.

Most of troughs are located close to snouts of the present outlet glaciers such as the Heitô and Hammna Glaciers. They are relatively short in length (1.8 - 3.0 km) and narrow in width (usually less than 250 m except the Naka-no-tani Valley (Photo 9) which is 1 km wide). Trough direction is mainly from east to west or from southeast to northwest. It coincides with the directions of joints (Figs. IV-3, 4). The trough walls are steep and high (150 - 220 m), but often develop only along one side of valleys; some on north-facing slopes and others on south-facing slopes. Therefore, trough forms are often asymmetric in cross section. High cliffs which dominate the coastal lowland and limit the northern and western margins of Mt. Tyôtô are another special form of trough walls which stand without any corresponding valley wall at the opposite side (Photos 5, 10).

The most marked cirques are located in Kami-kama and Simo-kama, southern Langhovde (Photo 11). The former is about 1 km wide and 750 m long with a steep headwall of 250 m high. The latter is 1 km wide, 500 m long with a headwall of 200 m high. The cirque bottom of Kami-kama bears a small tarn, while that of Simo-kama is under the sea level. These two cirques form stepped cirques facing to the west.

Small cirques are found in the southeast of Mt. Tyôtô in the northern Langhovde area (Photo 12) and in the north of Mt. Kanmuri in the southern Langhovde. Both are shallow and have a terminal moraine ridge.

Roches moutonnées are mainly distributed on trough bottoms. Mammilated peaks and undulating hilly land of the Langhovde area form a stoss-and-lee topography of large scale, and notable mammilated peaks such as Mt. Tyôtô can be regarded as a giant roche mountonnée (Koaze, 1963).

The area of glacial deposition is divided into two parts: ground moraine fields and terminal and lateral moraine ridges. Ground moraine fields are scattered on relatively flat surfaces, especially in small depressions and hollows (Photo 13). They develop more extensively in the south than in the north. Terminal and lateral moraine ridges are located in a marginal part of the present ice sheet and outlet glaciers. They are also better preserved in the south than in the north: (1) on the south of Lake Higashi-Hamna and around Hamnennabben, two or three ridges

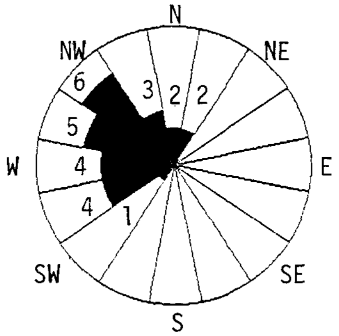

Fig. IV-3. Frequency of directions of glacial troughs. T=27.

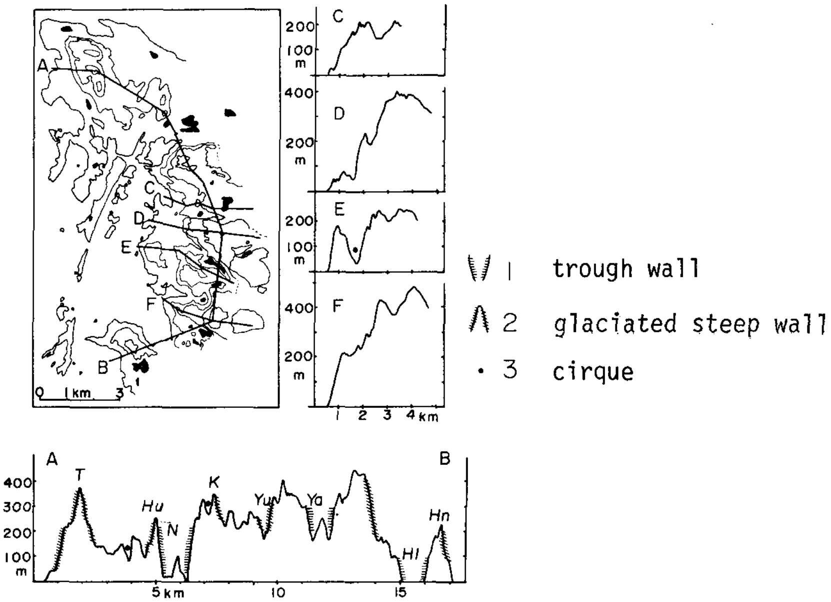

Fig. IV-4. Topographic sections of Langhovde.
T: Mt. Tyōtō, Hu: Mt. Hutago, N: Naka-no-tani Valley,
K: Mt. Kanmuri, Ya: Yatude Valley, Yu: Yukidori Valley,
HI: Hamna Icefall, Hn: Hamnenabben.

of terminal moraine are found; (2) at the snout of the Heitô Glacier, a terminal moraine ridge divides a lake into two parts; (3) at the snout of Hamna Icefall, a lateral moraine, extending along the southern margin of the glacier, is composed of till which contains marine shells. Most of moraine ridges in the Langhovde area are small (less than 5 m in height) and relatively short and narrow (less than 500 m in length and less than 100 m in width).

2) Area of fluvioglaical processes

An area of fluvioglacial processes is almost completely covered with fluvioglacial deposits. It is distributed only in the southern Langhovde, particularly in the Yatude and Yukidori Valleys (Photo 1). It is divided into the older and the younger deposits. The older deposit forms one or two levels of fluvioglacial terraces; the younger is the present bed of meltwater channels. They consist of sand and gravel of various sizes. Gravels are more or less rounded. The uppermost part of terrace deposits is somewhat weathered.

Fluvioglacial terraces are developed well in the lower reaches of the Yatude Valley. Terraces of 3 to 5 m in relative height extend several tens of meters along the valley. They consist of large boulders larger than 2 m in maximum diameter. At the mouth of the Yatude Valley, fluvioglacial terraces are found at two different levels: 17 m high in the north and 10 m high in the south (Fig. IV-5; Photos 1, 14). These appear to be

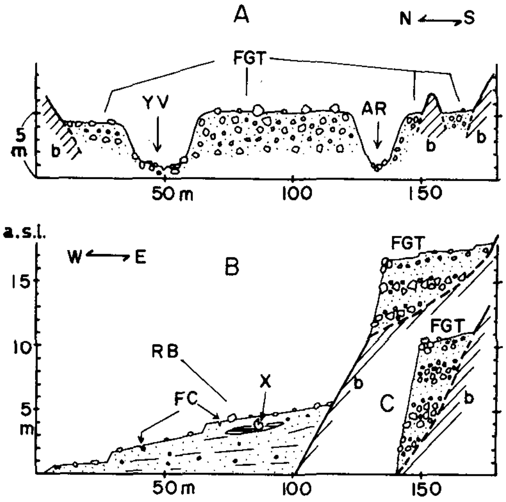

Fig. IV-5.
Schematic profiles of fluvioglacial terraces in Yatude Valley, A: lower part of Yatude Valley, B: northern side, C: southern side of mouth of Yatude Valley.
AR: abandoned river channel, b: bedrock, FC: frost crack, FGT: fluvioglacial terrace, RB: raised beach, X: fossil shells dated 5,330±120 yr. B.P.

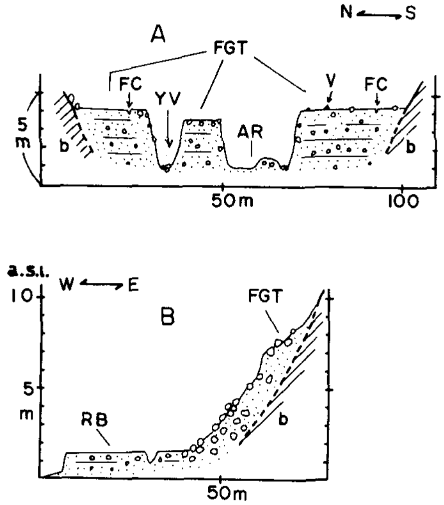

Fig. IV-6.
Schematic profiles of fluvioglacial terraces in Yukidori Valley,
A: lower part of Yukidori Valley,
B: mouth of Yukidori Valley.
AR: abandoned river channel, b: bedrock, FC: frost crack, FGT: fluvioglacial terrace, V: ventifact, RB: raised beach, YV: Yukidori Valley.

the remnants of dissected small deltaic fans which are composed of slightly bedded boulders and gravels.

In the lower reaches of the Yukidori Valley about 20 m in altitude, fluvioglacial terraces 20 to 30 m in width stand 2 to 3 m high above the present channel bed (Fig. IV-6). These flat terraces consist of rather fine sand and gravel (Photo 15). They seem to be correlative to the remnant of the lower dissected deltaic fan at the mouth of the Yatsude Valley, judging from the altitudinal and topographic dispositions.

The younger fluvioglacial deposits form the present channel bed of intermittent streams which are fed by meltwater during the summer season only. As the meltwater of the Yatude Valley which is supplied by a small hanging glacier has the greatest quantity in the area, the present channel floor is wide and exceeds 100 m in width in the lower reaches of the Yatude Valley. The bed materials are similar in composition to those of the terraces.

A long and narrow levee of fluvioglacial deposits extends horizontally on an upper slope of a semi-circular depression 700 m north of Simo-kama. This might have been formed at the margin of a small ice mass which had once occupied the depression, judging from its characteristic distribution (Yoshida, 1983b; Photo 16).

3) Area of periglacial processes

The ice-free area of Langhovde is undoubtedly subjected to periglacial environments. However, periglacial processes in this area do not seem to produce effectively any characteristic periglacial landform except talus cones and some tors.

Talus cones and talus aprons are located at the foot of precipitous trough walls or cirque walls (Photos 5, 11). These features are formed by a combination of periglacial and gravitational processes. In the northern Langhovde, a talus apron 500 m wide fringes a northernmost foot of Mt. Tyôtô (Photo 5). In the southern part, talus is distributed more extensively. Small talus aprons and talus cones are located (1) at the foot of the southern trough wall of the Naka-no-tani Valley, (2) around Lake

Yukidori, (3) in the upper reaches of the Yatude Valley, (4) at the foot of cirque walls of Kami-kama and Simo-kama (Photo 11) and (5) in Hamnenabben.

Talus deposits are loose and not so thick. They are composed of angular to subangular boulders which partly contain erratics or morainic deposits.

Tors develop on the undulating surface of hilly land, but it is difficult to discriminate them from other projecting microforms by aerial-photogrammetry. Therefore, tors are included in the hillock or the hillocky surface (IV-1, 5, 6) in this map, and their characteristics are described later (V-3). Other periglacial microforms such as patterned grounds and frost cracks are shown being included in other legends (IV-2).

4) Area of eolian processes

As the ice-free area of Langhovde is under arid condition, eolian processes such as wind erosion and deflation are fairly active. Small conical drifts of eolian sand are found at some places in the northern Langhovde. They are located (1) on the western slope of Mt. Tyôtô (Photo 17), (2) in narrow depressions at the northeast and the southwest of Mt. Tyôtô and (3) on the southwestern side of small ridges north of Lake Itiziku. Judging from eolian sand accumulating on the lee side of a ridge, the prevailing wind in this area is easterly and northeasterly. This corresponds to the direction of katabatic wind (Moriwaki, 1976).

In the southern Langhovde, conical drifts of eolian sand are not found in spite of the presence of facetted pebbles. This does not always mean the weakness of wind but suggests that a wetter condition prevails here because of abundant meltwater.

Eolian sand is composed of abundant quartz, feldspar and garnet grains with small amounts of biotite, hornblende and pyroxene grains, reflecting the lithology of the Langhovde area. Eolian sand is well sorted and its roundness is high (Fig. IV-7).

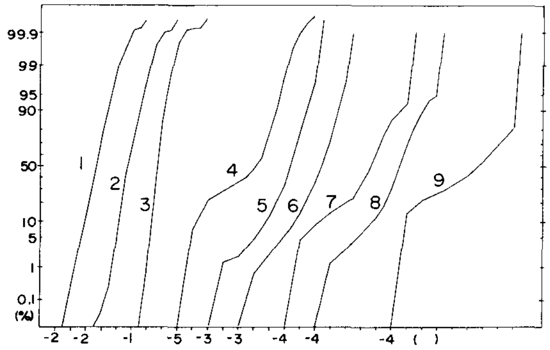

Fig. IV-7.
Cumulative curves of grain size. 1-3: eolian sand (1: southwest of Mt. Tyōtō, 2: west of Mt. Tyōtō, 3: southeast of Mt, Tyōtō), 4-8: fine materials of beach deposits (4: south of Mizukuguri Cove, 5: south of Kominato Inlet, 6: east of Kominato Inlet, 7: north of the mouth of Yatude Valley, 8: north of Simo-kama), 9: fine materials of a lateral moraine west of Hamna Icefall.

5) Area of marine processes

Raised marine features are distributed along the coast. Most of them are raised beaches below the height of 13 m on pocket beaches occupying depressions (Photo 18), and consist of sands and gravels derived from glacial drifts, sometimes including fossil shells. Several step-like berms are formed on many raised beaches, but their features and height are not always similar to each other (Nogami, 1977; Photo 19).

Elevated marine-boulder pavement is found in a valley crossing the headland between the Mizukuguri Cove and the Hukuro Cove (Yoshida, 1983a; Photo 20). It contains many round gravel. Its lower part below 7 m above sea level composed of boulderly deposits is steep.

A set of low cliff and small flat surface lower than 13 m exist north of Lake Oyayubi. They seem to be a sea cliff and a wave cut bench (Yoshida, 1970; Ishikawa *et al.*, 1976). Flat surfaces lower than 15 m on peninsulas and on small islands such as "skjaergard" of Dokkene were possibly formed or modified by marine agency.

4. Lithology and geological structure

1) Lithology

(1) Garnet gneiss and garnet-bearing granitic gneiss

Garnet gneiss: leucocratic and massive rocks including spot-garnet; weak foliation; quartz content from 30 to 40 %; potassium feldspar is generally more abundant than plagioclase. Garnet bearing granitic gneiss: characterized by pink colored potassium feldspar; bedded; weak foliation.

(2) Hornblende gneiss and pyroxene gneiss

Hornblende gneiss: medium- to coarse-grained gray rocks with large quantity of quartz and plagioclase. Pyroxene gneiss: medium-grained dark brown and gray rock with feldspar and quartz; faint gneissose structure.

(3) Garnet-biotite gneiss, porphyroblastic gneiss and microcline granite

Garnet-biotite gneiss: reddish brown colored rock with abundant garnet; distinct foliation with a leucocratic layer of biotite and a melanocratic layer of quartz and feldspar. Porphyroblastic gneiss: characterized by porphyritic potassium feldspar; generally bedded with garnet-biotite gneiss; mainly occurring in Hammenabben. Microcline granite: fine- to rather coarse-grained rock with pink-colored potassium feldspar; mainly occurring around the Hukuro Cove.

(4) Metabasite: medium to coarse-grained rock; usually black in color; in garnet gneiss, showing a continuity as a thin bed, often with boudinage; composed of hypersthene, diopside, hornblende, biotite and plagioclase.

2) Geological structure

Geological structure of the Langhovde area is different between the northern and southern parts. In the northern part, the folding structure is well developed. A complicated folding structure develops around Mt. Tyôtô; an anticline axis runs in the Kominato Inlet, and another overturned anticline extends in the NW-SW direction in a northeastern wing of that anticline. A syncline is located between Mt. Tyôtô and Langhovde-Kita Point. Its axis trends SE-NW, and shows isoclinal folds in the south of Mt. Tyôtô (Photo 2).

In the southern part of the Langhovde area, a monoclinal structure striking N 10°E and dipping to the east is characteristic. A fault is inferred along Aogôri Bay, bounding the northern and southern Langhovde areas of different geological structures.

In every gneissose rock, a foliation structure notably develops, except for massive pyroxene gneiss and hornblende gneiss. In the metabasite, a boudinage structure is commonly observed.

5. Inland water

1) Saline lakes

Distribution of saline lakes is confined in the northern part of Langhovde. Saline lakes are classified into two groups, the one which was once a part of the sea after deglaciation, and the other which has not been connected with the sea. The former comprises Lake Zakuro, Lake Oyayubi and Lake Nurume, where marine sediments or raised beaches can be observed in and around their basins. Chemical composition of their water is similar to, but more concentrated than, that of sea water (Murayama, 1977). Deposits in the circumference of Lake Zakuro and Lake Oyayubi contain fossil shells and other marine organic remains. The threshold between Lake Zakuro and the sea is 6 m high above sea level. Inflow of sea water to Lake Oyayubi seems to happen occasionally in spring tides (Murayama, 1977). Lake Nurume whose threshold to the sea is about 1 m high above sea level has the structure of two water layers. Concentration of major dissolved components in the upper layer is nearly the same as that of sea water, but that in the lower layer is 1.5 times greater than that in sea water (Sano *et al.*, 1977). Sano *et al.* (1977) suggest that the two-layer structure was formed by twice repeated transgressions and regressions after deglaciation. Lake Itiziku is a nearly disappearing lake and its bottom is covered by salt pan (Photo 21). It is not clear whether Lake Itiziku has connected with sea or not.

Lake Akebi whose threshold to the sea is about 45 m high above sea level belongs to the latter group. Origin of its water is not probably sea water because of the difference of the Ca/Mg ratio from that of sea water (Murayama, 1977). Lake Akebi was fed by meltwater from the retreating ice sheet, and then the inflow to the lake decreased with deglaciation. Consequently evaporation of lake water has exceeded inflow, lake level gradually lowered, and water became more saline (Murayama, 1977; Yoshida, 1983a).

2) Fresh water lakes

Many fresh water lakes exist in the southern part of Langhovde. In the northern part, only one fresh water lake exists in a col between two peaks of Mt. Hutago. This lake seems to be a kettle lake, because it exists on glacial till and has no inflow of water (Moriwaki, 1976). Fresh water lakes in the southern part are nourished by abundant meltwater from drift snow or the ice sheet in the summer season (Photo 22). Most of those lakes have drains. In Lake Higasi-yukidori with no drain the concentration of ion in water is slightly increasing due to evaporation (Murayama, 1977).

Some fresh water lakes occur in depressions on the surface of the Langhovde Glacier in summer. Since major surface morphology of glacier depends on the relief of bedrock, locations of these lakes scarcely changed during the period from 1962 to 1982 in spite of the movement of the glacier.

3) Meltwater streams

Many small meltwater streams are found in the ice-free area in summer. Those having distinct channels are shown in the geomorphological map. The Yukidori Valley and the Yatude Valley of the southern part are typical examples. Flash floods caused by collapses of snow dams seem to happen occasionally in the Yatude Valley (Ohyama, 1984). In the northern part, meltwater streams appear in a short term, mostly forming no distinct channels, even on the surface of glacier. Their channels are formed almost in the same locations every summer.

4) Glaciers

Judging from its surface configuration, the Langhovde Glacier can be traced upstream for about 10 km from its present snout. Several ridges and furrows about 10 m in relative height are formed along flow lines on it. Numerous crevasses also occur, especially on ridges. The Langhovde Glacier flows nearly toward NNW at a rate of about 40 m/year in the upper part and about 170 m/year in the lower part (Fujiwara and Yoshida, 1972; Shimizu *et al.*, 1975; Table IV-1). Judging from its longitudinal profiles, its lower part seems afloat and its grounding line is situated 3.5 km upstream from the snout (Fig. IV-8).

Depth d of the bottom of floating ice below sea level is calculated by the following equation:

$$d = h \cdot \rho i / (\rho w - \rho i),$$

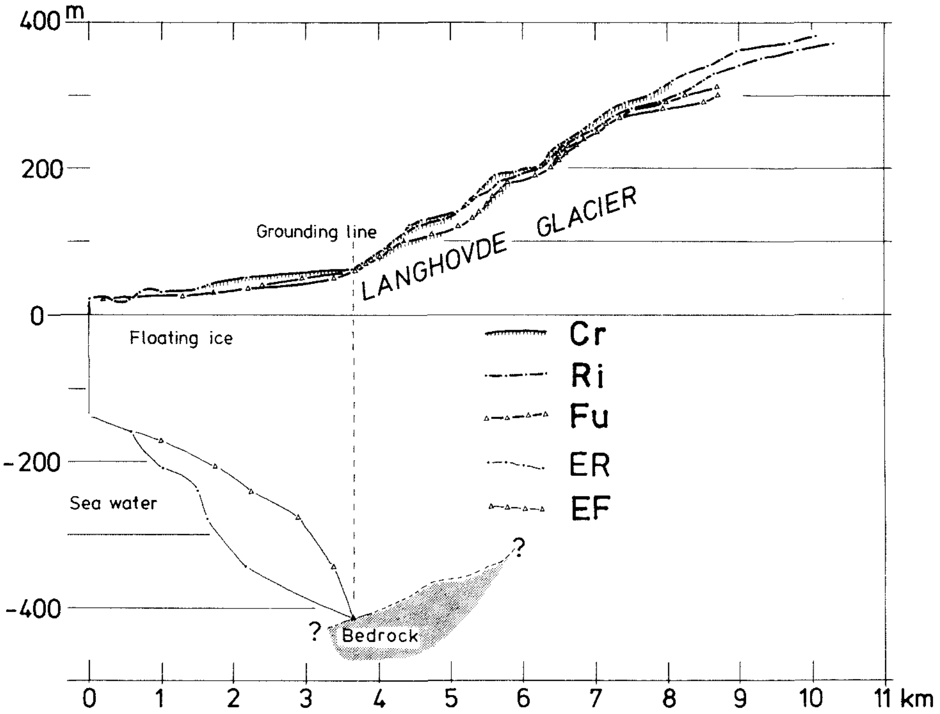

Fig. IV-8. Projected longitudinal profiles of the Langhovde Glacier along the line of N30°W.

Cr: zone of crevasses, Ri: profile of ridge, Fu: profile of furrow, ER: estimated profile of the ice bottom under ridge, EF: estimated profile of the ice bottom under furrow.

where h is the surface height of floating ice above sea level, ρi (0.90 g/cm^3) and ρw (1.03 g/cm^3) are the density of glacier ice and sea water, respectively. Near the grounding line h is 60 m, therefore the depth of the bottom of floating ice tongue is calculated at 415 m. This means that there is a depression more than 415 m deep. This depression joins the submarine trough in the Ongul Strait deeper than 600 m (Fujiwara, 1971).

The Heitô Glacier seems to be a glacier composed of an outlet glacier and a drift glacier, judging from its surface features and ice movement (Shimizu *et al.* , 1975). It has two small end moraines, the one existing closely to its north snout at the head of the Yukidori Valley and the other existing a little apart from its snout at the head of the Yatude Valley. It seems to be a stagnaut glacier because of its very slow movement (Table IV-1).

The Hamna Glacier (provisional name) has a few ridges and furrows along flow line, but it moves not so fast as the Langhovde Glacier (Fujiwara and Yoshida, 1972; Table IV-1).

5) Snow drifts

Snow covers considerable parts of the ice-free area in winter, but disappears almost completely by evaporation and melt in summer. Snow drifts accumulate mainly on leeward slopes and at the foot of windward slopes by northeasterly blizzards and easterly katabatic winds.

Perennial snow drifts are distributed on shady southward-facing slopes in E-W tending valleys and on the ice sheet. Snow drifts in the Naka-no-tani Valley and at the heads of the Yukidori Valley and Yatude Valley seem to be drift glaciers.

6) Crevasses

Crevasses on the Langhovde and Hamna Glaciers are plotted in the map by the authors using aerial photographs taken by the JARE-16 (1:34,000) and the JARE-10 (1:26,000), respectively. Numerous crevasses occur on ridges along flow line and on convex slopes in longitudinal profiles of glaciers. Their locations and shapes scarcely changed during the period from 1962 to 1982 in spite of glacier movement, judging from air-photo interpretation.

7) *Flow vector of glacier*

The movement of glaciers was measured by Fujiwara, and Shimizu and others (Table IV-1). Fujiwara measured on 10 May 1961 and 12 September 1961 (at an interval of 135 days) on the lower part of the Langhovde Glacier (Fujiwara and Yoshida, 1972). Shimizu and others measured on 15 September 1970 and 11 March 1971 (at an interval of 158 days) on the upper part of the Langhovde Glacier, and on 9 February 1970 and 10 February 1972 (at an interval of 732 days) on the Heitô Glacier (Shimizu et al., 1975).

Table IV-1. Flow velocities of glaciers estimated from the measurements by Fujiwara and Yoshida (1972) and Shimizu *et al.* (1975).

Langhovde Glacier		Hamna Glacier	Hamna Icefall	Heitō Glacier
Lower part	Upper part			
63∿86 m/yr. 172 m/yr.*	22∿40 m/yr.	5.2 m/yr.	2.6 m/yr.	0+ ∿ 2.0 m/yr.

* estimation by Fujiwara and Yoshida (1972).

V. Characteristics of landforms

1. Structural landforms

The relief of the Langhovde area is strongly controlled by lithology and geological structure. The boundaries between depressions and protrusions, combs and ridges, and lowlands and hilly lands always correspond to lithological boundaries. As gneissose rocks composing the ice-free area of Langhovde are dipping to the east by 30-60°, homoclinal ridges are well developed along relatively resistant rocks (Photo 23).

In the northern Langhovde area, depressions and protrusions run conformably with the folding structures of gneiss. The most conspicuous protrusion, Mt. Tyôtô, is mainly composed of massive pyroxene gneiss without marked foliation. This rock also constitutes a rather flat lowland of 20-40 m high to the northeast of the summit of Mt. Tyôtô where narrow and long ridges are formed along garnet-bearing granite gneiss, metabasite and the pegmatite dykes (Photo 24). On the other hand, depressions develop along garnet-biotite gneiss which surrounds the mass of pyroxene gneiss of Mt. Tyôtô (Photo 17). The steep cliff (trough wall) bordering the western margin of Mt. Tyôtô was formed along the boundary of garnet-biotite gneiss and pyroxene gneiss.

In the southern Langhovde area, homoclinal ridges develop well, for the zonal arrangement of each lithological unit is more distinct than in the northern part. Two cliffs were formed along the boundaries (1) between garnet-biotite gneiss and garnet gneiss and (2) between garnet-biotite gneiss and hornblende gneiss. The former separates a relatively flat surface around 200 m high from the lowland and the latter intervenes between relatively flat surfaces around 200 m and higher than 400 m. A relatively flat surface higher than 400 m extends from the west of Mt. Heitô to the south of the Yukidori Valley. This surface is composed of massive hornblende gneiss without distinct foliation. The cirque wall of Kami-kama was formed along the boundary of garnet biotite gneiss and hornblende gneiss (Photo 11). The cirque wall of Simo-kama was formed along the boundary of garnet biotite gneiss and pyroxene gneiss. As in the northern Langhovde, depressions occur in areas composed of garnet biotite gneiss (Photo 2). On the other hand, narrow bands of metabasite often form narrow depressions in areas of garnet gneiss in the southern part, while they constitute narrow ridges in areas of pyroxene gneiss in the northern Langhovde.

The resistance of each lithological unit against denudational processes is in the following order from the strongest to the weakest:

(1) garnet gneiss, (2) garnet-bearing granitic gneiss, (3) metabasite, (4) pyroxene gneiss and hornblende gneiss, (5) porphyroblastic gneiss and microcline granite, (6) garnet biotite gneiss.

However, the differences of resistance between (1) and (2), and that of (5) and (6) are not so clear. Therefore, in the geomorphological map, they are grouped together, respectively. The resistance to denudation of each rock is controlled by the following three factors: (1) degree of foliations, (2) amount of quartz and (3) amount of biotite. Rocks of higher resistance show weaker foliation, and contain greater amount of quartz and lesser amount of biotite. All of these factors seem to affect chemical weathering which is usually dominant under the temperate or tropical climatic conditions. Many closed small depressions ("alvéols") on a relatively flat surface in the southern Langhovde seem to support this idea. These small depressions are usually less than 100 m in diameter and 10-20 m deep. They are semicircular to elliptical in form and sometimes bear small ponds in bottoms. They are always situated at junctions of two or three joints systems of different directions (Photo 1).

Joints play an important role in the development of landforms in the Langhovde area. Not only trough and major valley systems but also linear and narrow valleys or depressions, together with cirques and coastlines, are defined by joints which run NW-SE, WNW-ESE, E-W and WSW-ENE. Cirques and depressions are located at intersections of two or three joints (Photo 11). Linear and narrow valleys in the southern Langhovde

(Yoshikawa and Toya, 1957) were formed along the foliation of gneiss which runs N-S, nearly perpendicular to joint systems.

The coastal lowland in the northern Langhovde was described to be a strandflat (Koaze, 1963). On the flat surface of coastal lowland lower than 40 m, there are neither weathering products nor glacial deposits (Photos 5, 24). Several pegmatite dykes rise above the surrounding flat surfaces by 20-40 cm (Ishikawa, 1974; Photos 24, 25). This feature was interpreted as a result of weathering which operated after glacial scouring of this area (Ishikawa, 1974; Moriwaki, 1976). However, as scouring by ice sheet acts on bedrocks selectively, it cannot be denied that such a small protrusion was formed under the ice sheet. The coastal lowland in Langhovde was probably formed by areal glacial scouring of preglacial erosion surfaces, and may be similar in origin to strandflats which develop extensively in Norway (*e.g.* Peulvast, 1978).

As stated above, landforms of the Langhovde area have been evolved by differential erosion including chemical weathering. Although preglacial forms were more or less modified by glacial scouring, it is inferred that structural landforms of Langhovde were shaped mainly in preglacial times.

2. Glacial landforms

The total area of Langhovde, once completely covered by ice sheet, has experienced glacial scouring, as indicated by mammilated peaks and stoss-and-lee topography on hilly lands, where glacial striae are still preserved. Judging from the direction of striae, the ice sheet flew over the hilly lands of Langhovde from east, nearly perpendicular to the present coastline (Yoshida, 1973; Ishikawa, 1974; Fig. V-1A). However, several ice streams in directions different from that of the ice sheet flew being controlled by preglacial landforms. Furthermore, it is probable that the basal parts of the ice sheet flew in directions different from that in its upper part (Yoshida, 1983a; Moriwaki and Yoshida, 1983). One major basal ice stream from SSE to NNW was inferred from the existence of glacial trough about 600 m deep in the Ongul Strait, north of the Langhovde Glacier (Fujiwara, 1971; Fig. V-1A).

When the ice sheet flew over hilly lands of the Langhovde area, preexisted valleys served for these ice streams as passways. Ice streams in ice sheet exerted selective linear erosion to transform preglacial valleys into glacial troughs. Conspicuous cliffs along the northern and the western margins of Mt. Tyôtô were formed by the ice stream which was confined by a rise of bedrocks on one side, and by the sluggish ice sheet on the other side (Yoshida, 1983a).

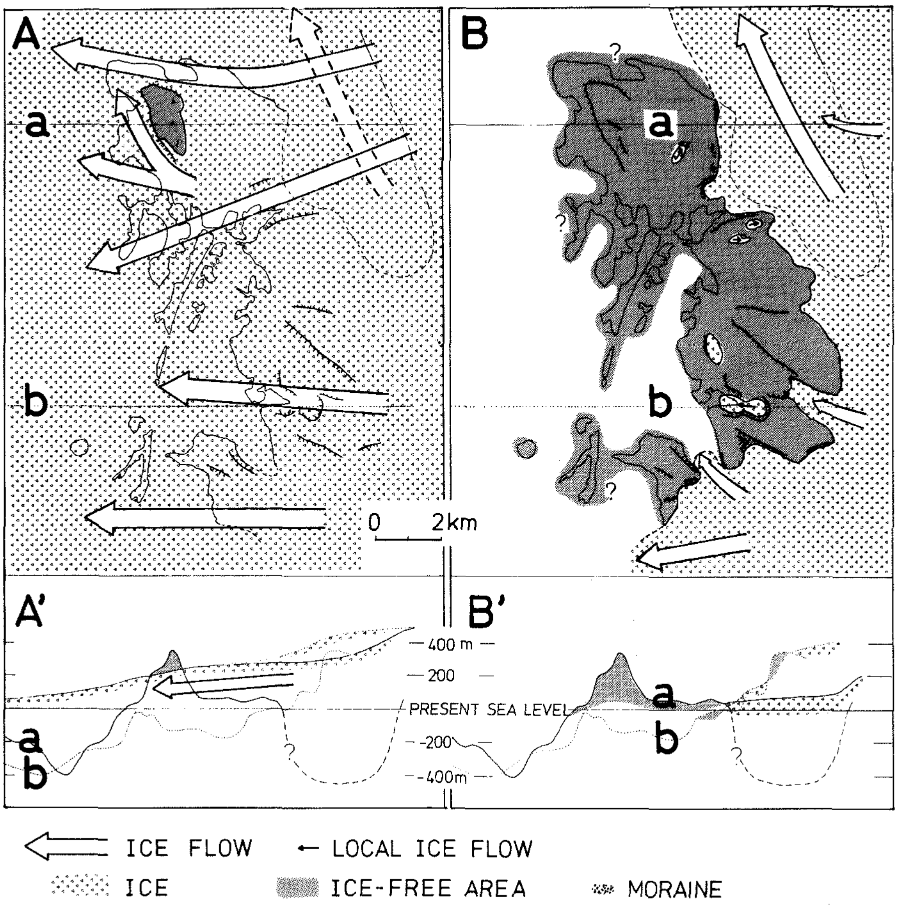

Fig. V-1. Schemata of changes of the ice sheet and ice flows.
A: when the Langhovde area was covered almost by the ice sheet.
B: when the Langhovde area was freed from the ice sheet.

It is difficult to say when the ice sheet retreated finally from the hilly lands of the Langhovde area. But radiocarbon dates of *in situ* organic remains in the raised beach deposits which were not modified by glacial action suggest that the ice sheet receded from the main part of Langhovde, at the latest, prior to 30,000 yr. B.P. (Yoshida, 1983a). During the retreat of the ice sheet, several detached glacial bodies occupied depressions in the hilly lands of Langhovde and survived for a while as small cirque glaciers (Fig. V-1B). Kami-kama, Simo-kama and the cirques in the northern Langhovde were formed in this stage, although their initial topography had been prepared either under the ice sheet or before the invasion of the ice sheet.

Weathering of ground surface is more intense in the northern Langhovde than in the southern part. This suggests that the northern Langhovde became free from the ice sheet earlier than the southern part (Yoshida, 1983a).

It is also difficult to judge whether there was a re-advancing stage during the general shrinkage of the ice sheet in this region. But several fresh terminal and lateral moraine ridges near the snout of outlet glaciers in the Naka-no-tani Valley, Heitô and Hamna, suggest a re-advance of glaciers in rather recent times. Fluvioglacial terraces and associated deltaic fans at one or two levels in several outlet valleys in the southern Langhovde were probably formed in this glacial re-advance.

On the other hand, well-developed sorted stone circles with mean diameter of 1 m, located on a flat terminal moraine close to the Langhovde Glacier, are now partly covered with snow and ice. This suggests that the ice sheet retreated from the present glacial margin or, at least, snow accumulation was less than at present in the near past (Yoshida, 1983a).

3. Periglacial landforms

Soil temperature measurement at Syowa Station 20 km north of Langhovde (Moriwaki, 1976) shows that an active layer reaches the depth of 40 to 60 cm in this region. The distribution of patterned ground, however, is limited in area in Langhovde. Sorted circles and contraction cracks are found only on moraines near the Langhovde Glacier and at a few places in intertidal zones. Their occurrence, therefore, seems to be controlled by ground moisture which is fed by meltwater. Present conditions of Langhovde appear to be too much dry for the formation of patterned ground near the ground surface. No sand wedge, however, has been found in Langhovde.

Tors develop on undulating surfaces of hilly lands or on gentle mountain summits. They show an isolated and projecting hillock topography and seldom exceed 10 m in height and 20 m in width. They are found (1) around a small peak south of the Hukuro Cove (Photo 20), (2) on the ridge northeast of Lake Itiziku (Photo 26), (3) in the lowland between the Yukidori and Yatude Valleys, (4) on the valley bottom of Naka-no-tani and (5) on the flat top of Mt. Minami-heitô.

Glacially rounded surfaces remain on tops of some tors, surrounded by frost-riven steep slopes. A small amount of blocks is often found on lower parts of cliffs. It indicates that freeze-thaw process on glaciated surfaces has worked selectively at intersecting points of joint system or gneissic foliation.

Tatsumi and Kikuchi (1959a) suggested that mechanical weathering, probably frost shattering, was active down to the depth of 30 cm in the central part of Langhovde. Talus aprons and talus cones at the foot of free surfaces indicate that frost shattering operates to some extent. Periglacial landforms are not so notable, although periglacial processes such as frost action are presently active all over the ice-free area of Langhovde.

The dry condition in the Langhovde area favors eolian activity. Wind-blown sand is found on snow drift which evidences the eolian process operates actively at present. Many ventifacts are found in linear and narrow valleys due to strong wind along their direction (Ishikawa, 1974). As for valley walls, north-facing valley walls are usually subjected to honeycomb weathering, while south-facing walls are polished by wind abrasion. It might be explained by the fact that north facing walls usually cut foliation planes of bedrocks and are less resistant to wind abrasion (Moriwaki, 1976).

4. Littoral landforms

Lützow-Holm Bay is extensively covered by fast ice almost all the year round. Flaw leads separating pack ice zone from fast ice area usually occur offshore near the outer margin of the continental shelf in the summer season. Artificial satellite images of NOAA-6 suggest that the flaw leads are sometimes formed also in the winter season in the same area. The western part of the bay is covered by thick multi-year ice, but the fast ice in the eastern part is comparatively thin, suggesting that breakout of fast ice often takes place in the east. Along the 50 km coastline of the Sôya Coast from the Ongul Strait through the Langhovde area to the northern part of the Skarvsnes ice-free area, a shore polynya is frequently formed from February to May or even to July. The polynya extends occasionally over 100 km towards south near the head of the bay. Maximum thickness of first-year ice ranges from 90 to 150 cm near Langhovde. The frequent formation of shore polynya around Langhovde seems to be favored in part by formation of blue (bare) sea ice near the coast and scattering of wind-blown sand on it. This would increase the chance of wave action on the coast of Langhovde than on other ice-free areas.

Features and trends of the coastline of Langhovde are controlled by the geologic structures. The greater part of the coastline is rocky and bounded by steep slopes of mountains in the southern part and by low cliffs 10 to 20 m high fringing flat surfaces 20 to 40 m high above sea level in the northern part. Raised marine features are distributed below the height of 13 m in pocket beaches, marine-boulder pavement and wave-cut benches along the coast. Yoshida (1983a) summarized characteristics of raised marine features in the region of the Prince Olav Coast and the Sôya Coast as follows: (1) wave-cut bench and sea cliff develop only in very limited places, as wave action has been very weak, (2) most of raised beaches consist of sand and gravel derived from glacial drifts deposited in rather sheltered places as ground moraines, (3) beach deposits often contain fossiliferous sand and silt, (4) wave-washed features such as marine-boulder pavement develop better on the Prince Olav Coast than on the Sôya Coast, (5) raised beaches are often marked by stepped topography composed of berm-like steps and beach faces, indistinct beach ridges, or ice-pushed ridges, (6) raised beach topography has not been subjected to ice sheet erosion, and (7) pitted beaches are rarely found, and there is no beach resting on ice slab (ice-foot), but perennial drift-snow ice covers raised beaches in some places.

In Langhovde, raised beach deposits often contain organic remains such as shells of *Adamussium colbecki* and *Laternula elliptica* below the height of 10 m above sea level. *Adamussium colbecki* was found to live even on a few centimeters-deep sea bottom close to the beach of East Ongul Island in 1981. *Laternula elliptica* lives on shallow sea bottom 5 to 30 m deep (National Institute of Polar Research, 1982).

Table V-1. The results of radiocarbon datings of marine organisms in beach deposits of Langhovde.

Locality	Elevation above sea level (m)	Sample	Age (yr. B.P.)	Code No.	Collector	Date of sampling
Shore of Kominato	5 ∿ 6	*Laternula elliptica*	23,830±910	Gak-4148	Moriwaki	Feb. 1972
"	5.1	*Laternula elliptica*	4,570±120	Gak-	Nogami	Jan. 1976
"	4.7	*Adamussium colbecki*	5,310±105	N-2603	Hayashi	May 1975
"	3.0	*Laternula elliptica*	3,120±110	TH-186	Omoto	Nov. 1973
"	1.5	*Adamussium colbecki*	3,305±130	TH-044	"	"
"	1.5	*Adamussium colbecki*	4,290± 90	Gak-4151	Moriwaki	Feb. 1972
East of L.Zakuro	6	*Adamussium colbecki*	10,250±210	Gak-4150	"	"
"	6	*Laternula elliptica*	33,400<	Gak-4149	"	"
North of L.Zakuro	-3.4 (6)	*Laternula elliptica*	31,700<	Gak-	Nogami	Jan. 1976
"	-4.6 (6)	*Adamussium colbecki*	33,200<	Gak-	"	"
North of C.Koyubi	5.5	*Laternula elliptica*	3,730±220	Gak-	"	"
"	1.4	*Laternula elliptica*	1,030±100	Gak-	"	"
South of L.Oyayubi	2	Fragments of molluscan shell	2,000±220	Gak-3668	Yoshida	Oct. 1967
Mouth of Yatude V.	4	*Laternula elliptica*	5,330±125	N-2605	Hayashi	May 1975
Shore of Simo-kama	1.5	*Laternula elliptica*	3,170± 90	N-2604	"	"
"	1.5	*Laternula elliptica*	3,840± 90	Gak-4850	Ishikawa	1972

Results of radiocarbon datings of fossil shells obtained from raised beach deposits of Langhovde are shown in Table V-1 and in Fig. V-2. Radiocarbon dates are sometimes problematical, especially in Antarctica. For instance, living marine animals in Antarctic waters are known to be dated not modern but old ones by radiocarbon method (Yoshida and Moriwaki, 1979). Omoto (1972) pointed out that sea water in the Ongul Strait contains carbon with low concentration of C . Omoto (1977) also pointed out the possibility of large counting error in measuring radioactivity of old samples. In spite of some shortcomings of radiocarbon datings, some inferences can be drawn from dates and raised beach topography. Abundance of samples make up for these defects to some extent. Radiocarbon dates obtained from Langhovde and its neighboring ice-free areas can be classified roughly into two groups; the one belongs to the "postglacial" age younger than 10,000 yr. B.P., and the other ages older than 20,000 yr. B.P. (Yoshida, 1970, 1983a). This means that marine transgressions had occurred twice at least before 20,000 yr. B.P. and after 10,000 yr. B.P. Furthermore, the fact that fossil shells of the older group remain *in situ*

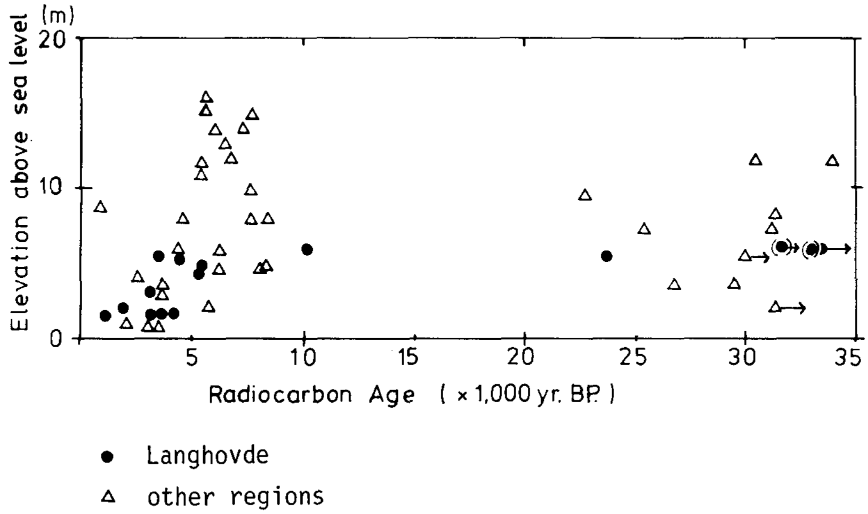

Fig. V-2. Relationship between elevations and ^{14}C ages of marine organisms in the coastal areas of the Sōya Coast and the Prince Olav Coast.

indicates that some of them were not disturbed by marine agency during the latter transgression. On the other hand, marine-boulder pavement and wave-cut benches in projecting parts into the sea suggest that those projecting areas were attacked by somewhat strong wave in the past.

Many steps occur where raised beach deposits accumulated on bedrocks continuously from the upper to the lower slopes near the strand-line. The steps must have been formed successively from the upper to the lower levels during the last relative lowering of sea level (Photo 19). It is difficult, however, to estimate whether sea level was stagnant repeatedly during its lowering, because the number and height of steps are not always same among different beaches.

The coastal lowland lower than 40 m a.s.l. in the northern Langhovde is regarded as a strandflat and many islets around Langhovde are regarded as "skjaergard" (Photos 7, 24). They seem to have been formed mainly by areal scouring of the ice sheet, though they might have been subjected in part to marine agency.

Summarizing the above argument, the following geomorphic sequence concerning the raised marine features is inferred (Yoshida, 1983a). After the ice sheet receded from the coastal region, some land areas emerged from the ice and were partly covered by sea water. Morainic materials were reworked by weak marine agency to some extent to form glacial marine features. Marine organisms were deposited on glacial marine sediments before 20,000 yr. B.P. Then, emergence of ice-free areas took place after 20,000 yr. B.P., resulting in the formation of "older" raised beaches. Sometime prior to 10,000 yr. ago, sea level began to rise again, probably by the eustatic rise of sea level during the "postglacial" period. On the other hand, the land mass which had emerged from the sea was uplifted by crustal rebound caused by unloading of ice. But the rate of uplift was lower than that of sea level rise at least between 10,000 and 6,000 yr. B.P. The preexistent raised marine sediments were reworked weakly, and some clastics together with marine organisms were deposited with rise of sea level. After the eustatic rise of sea level culminated "recent" raised beach topography below the level of 13 m high was formed by isostatic uplift of land mass. It is inferred from raised marine features that sea ice and snow were once less than at present (Yoshida, 1970, 1983a).

5. Submarine forms

The sea floor off the Langhovde area becomes deeper abruptly near shore and bears many depressions. Most of the depressions, including those deeper than 400 m (Fujiwara, 1971; Omoto, 1976), are circular and arranged in parallel with the direction of nearly N-S along the foliation of gneissic bedrocks. They run in three rows; the one is from the north of Langhovde-Kita Point to the west of Nabböya (island), the second from the east of Cape Koyubi to the west of Revsnes (island), and the other from Aogôri Bay to the south of Hamnenabben (Fig. V-3). Each

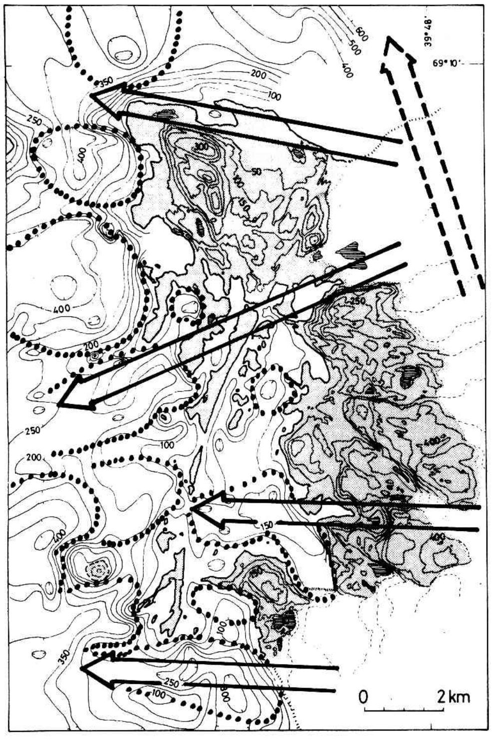

Fig. V-3.
Submarine circular depressions (dotted lines) and past ice flows (arrows) near the Langhovde area.

depression has a cirque shape having a steep wall in the east and a gentle slope in the west. Some depressions continue to a drowned glacial trough or another depression through a low threshold (Fujiwara, 1971; Fig. V-3). The ice flowed obviously from east to west sometime in the past expansion of the ice sheet, judging from glacial striae and glaciated landforms on land. The depressions were formed by plucking of bedrocks in places where ice moved across foliation structure (Fujiwara, 1971; Moriwaki and Yoshida, 1983).

The conspicuous drowned glacial trough deeper than 600 m extends in the north-south direction off the Langhovde Glacier (Fujiwara, 1971). This shows that the ice flowed not only from east to west but also from south to north in expansion time of the ice sheet. It appears that the flow direction of the basal part of the ice sheet was different from that of the upper part at that time (Moriwaki and Yoshida, 1983).

Acknowledgments

The authors wish to express their hearty gratitude to Professor T. Koaze, Meiji University, Mr. T. Iozawa, Director of Iozawa Institute, Mr. M. Ito and Mr. K. Matsuoka, the University of Tsukuba and Mr. H. Yagi, Tohoku University, who discussed many problems with us and gave invaluable advice for this work. The authors also wish to thank Professor T. Yoshikawa, Tokyo University of Agriculture, who read critically the final draft of the text.

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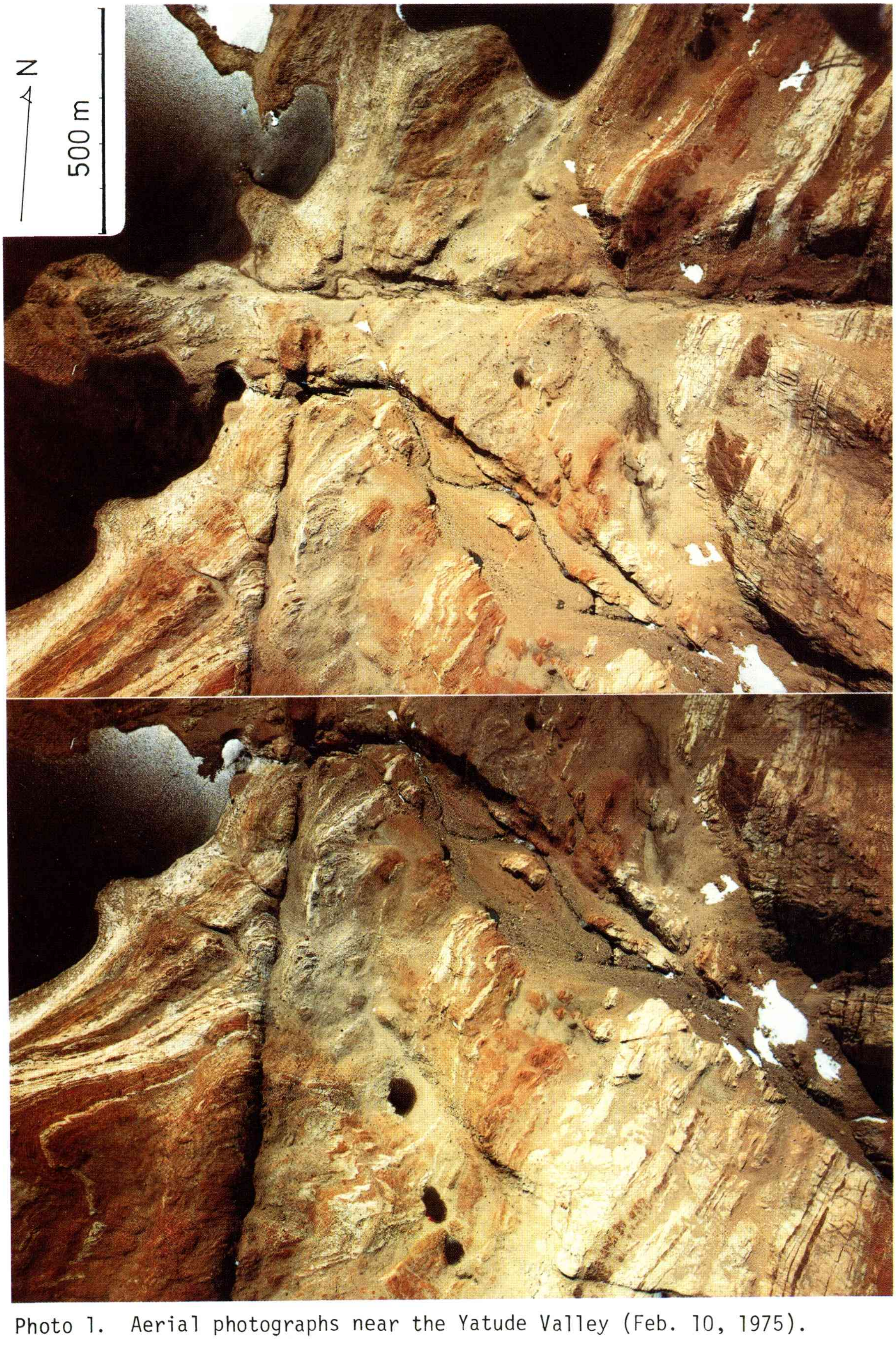

Photo 1. Aerial photographs near the Yatude Valley (Feb. 10, 1975).

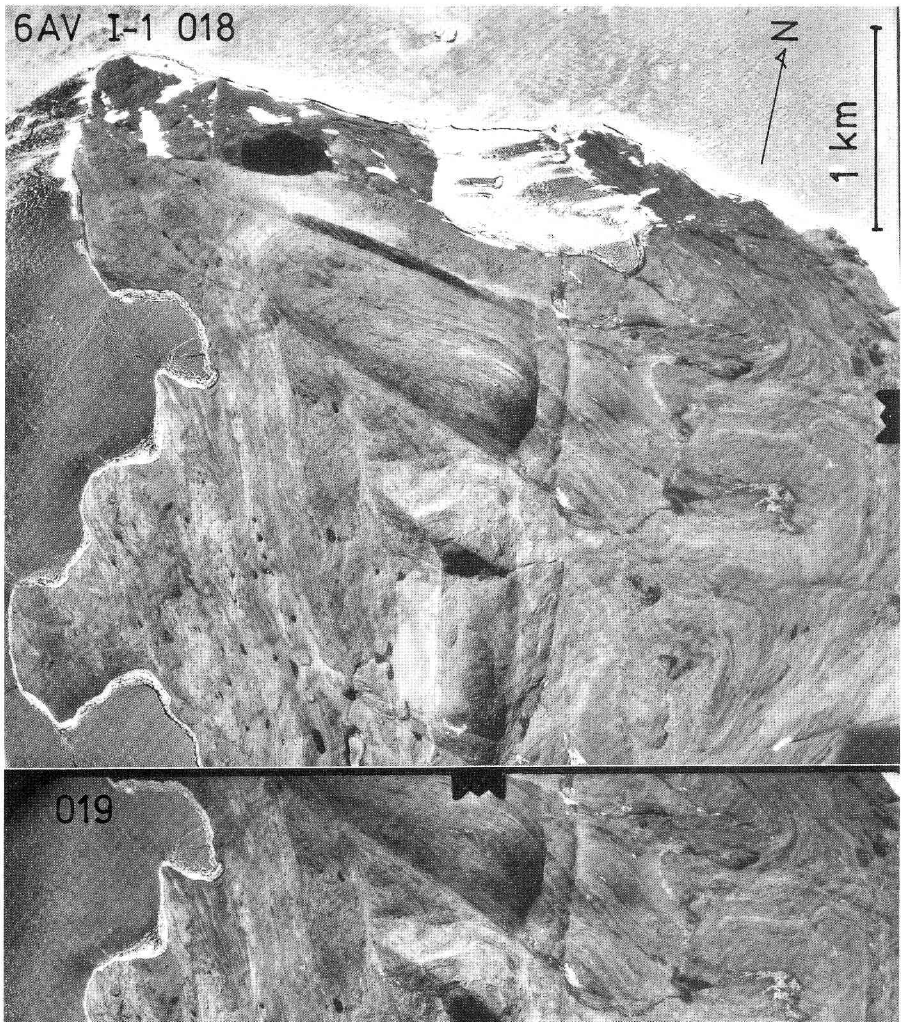

Photo 2. Aerial photographs near Mt. Tyōtō (Jan. 15, 1962).

Photo 3. Sorted polygons on the moraine near the northwestern part of the Langhovde Glacier.

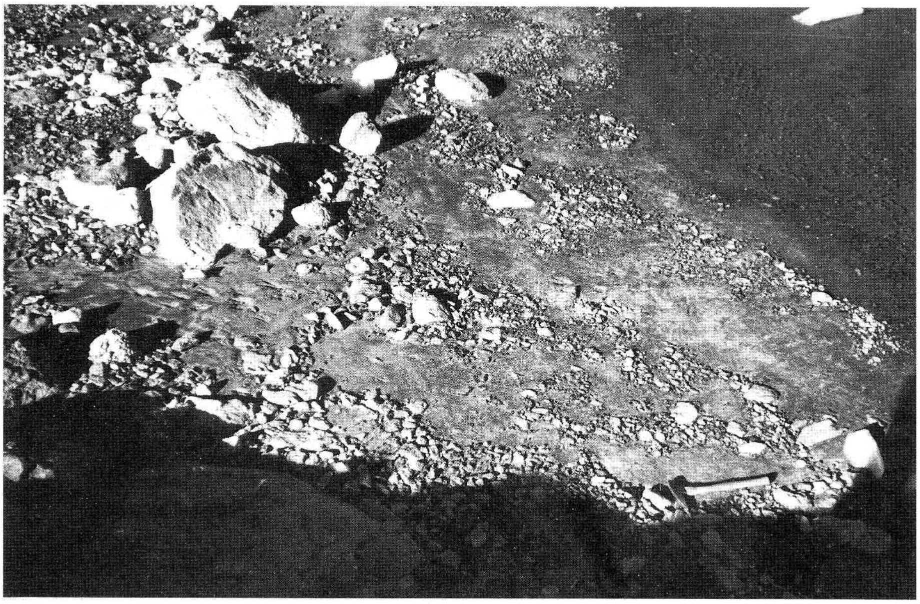

Photo 4. Stone circles in the intertidal zone of pocket beach facing the "Dokkene".

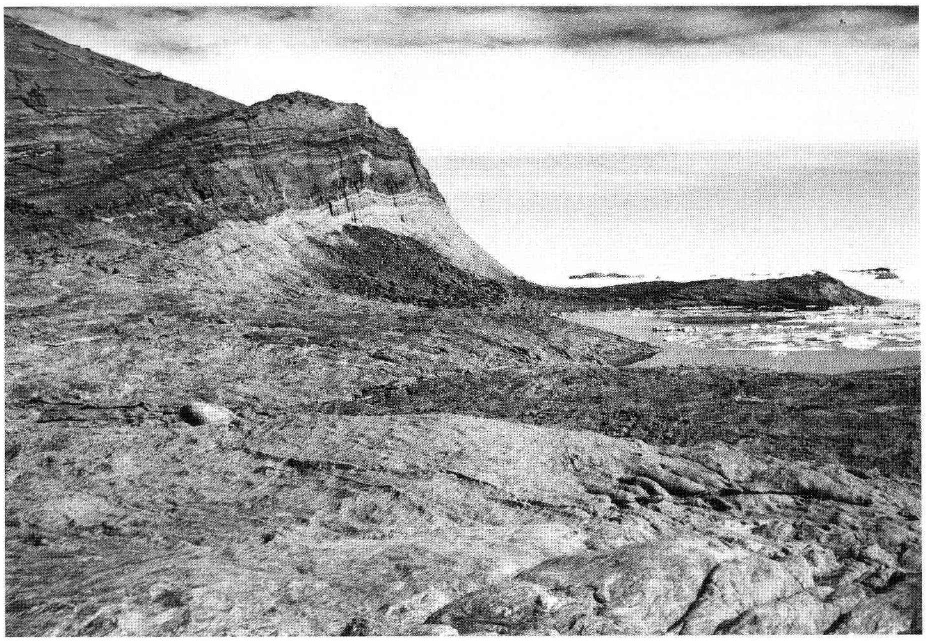

Photo 5. Talus apron at the foot of the north wall of Mt. Tyōtō and the coastal lowland (strandflat) around Kominato Inlet.

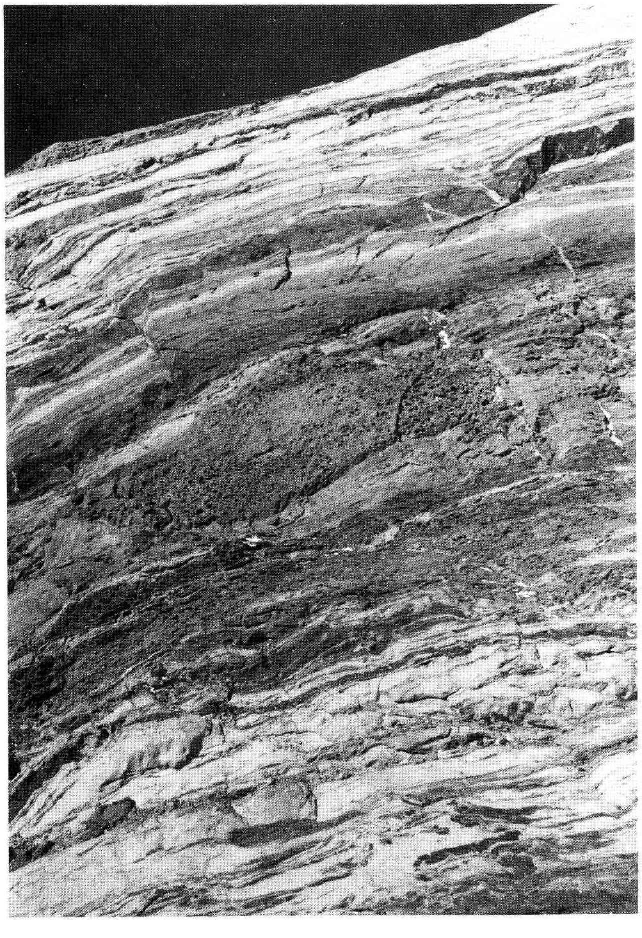

Photo 6.
Honneycomb weathering in a band of pyroxene gneiss on the south wall of the Naka-no-tani Valley.

Photo 7.
Glaciated surface facing the Langhovde Glacier, the north-eastern part of Langhovde. Arrows indicate the directions of glacial striae.

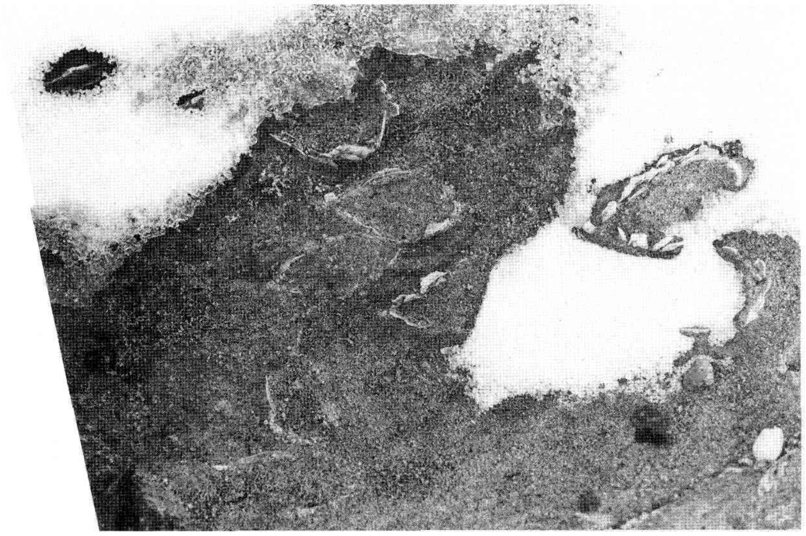

Photo 8. Fossil shells of *Laternula elliptica* showing autochthonous occurrence, which were dated at older than 33,400 yr. B.P. The locality is at the threshold between Kominato Inlet and Lake Zakuro.

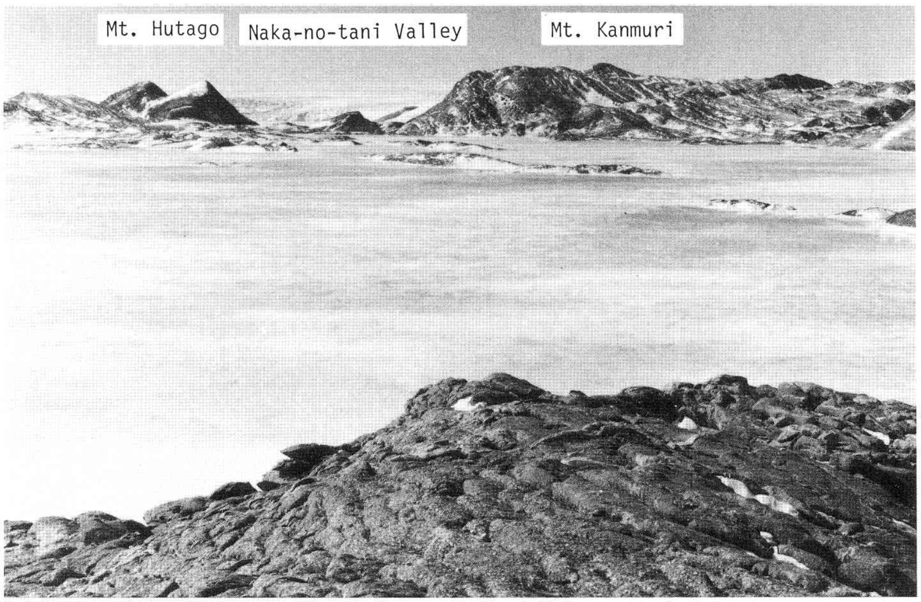

Photo 9. Mt. Hutago, Naka-no-tani Valley and Mt. Kanmuri viewed from Nabböya (island).

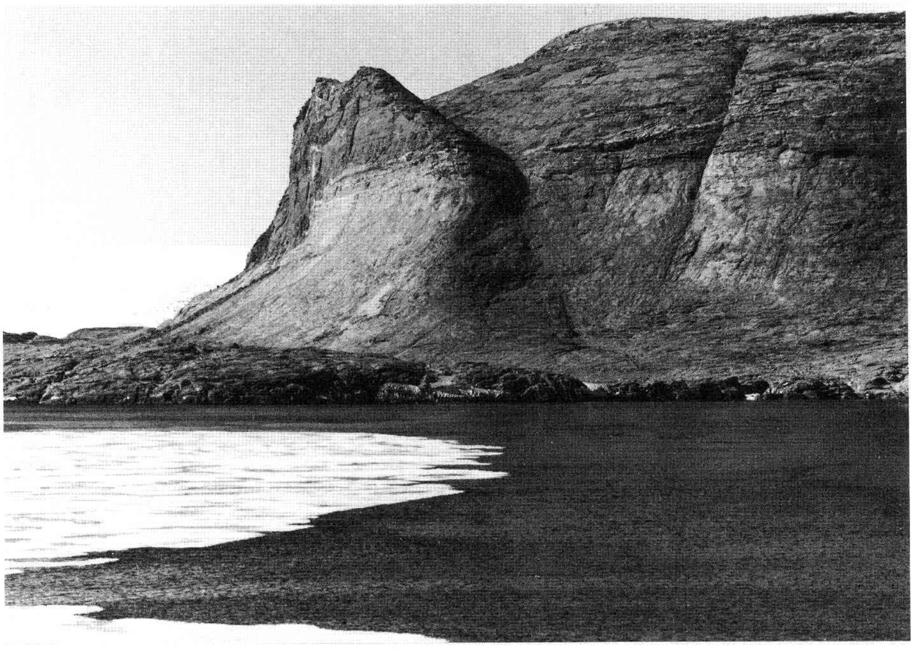

Photo 10. North wall of Mt. Tyōtō stands without a corresponding valley wall on the opposite side, viewed from the Mizukuguri Cove.

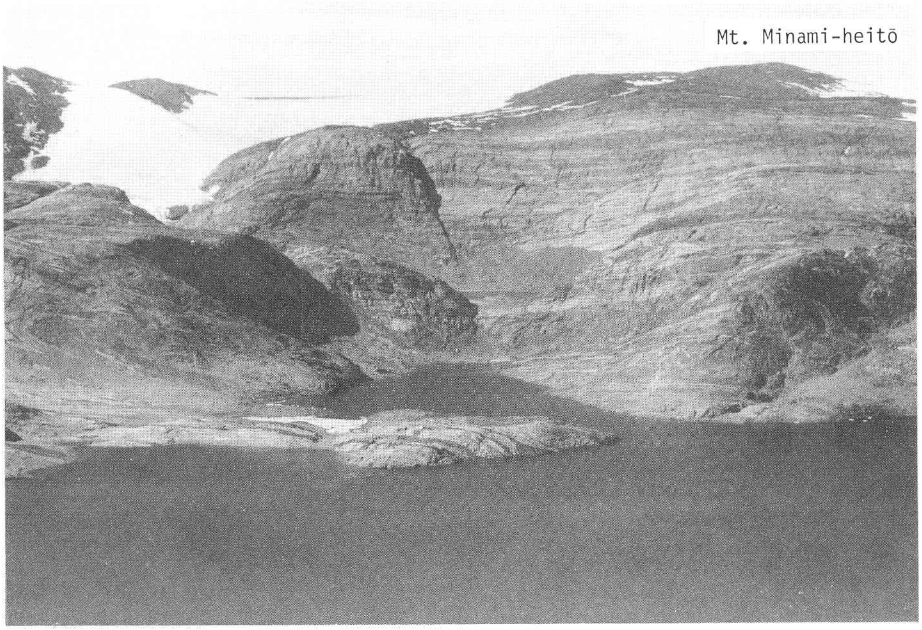

Photo 11. Kami-kama and Simo-kama (cirques), and a flat top of Mt. Minami-heito. Talus apron in Kami-kama and several joint systems of gneissic rocks are shown.

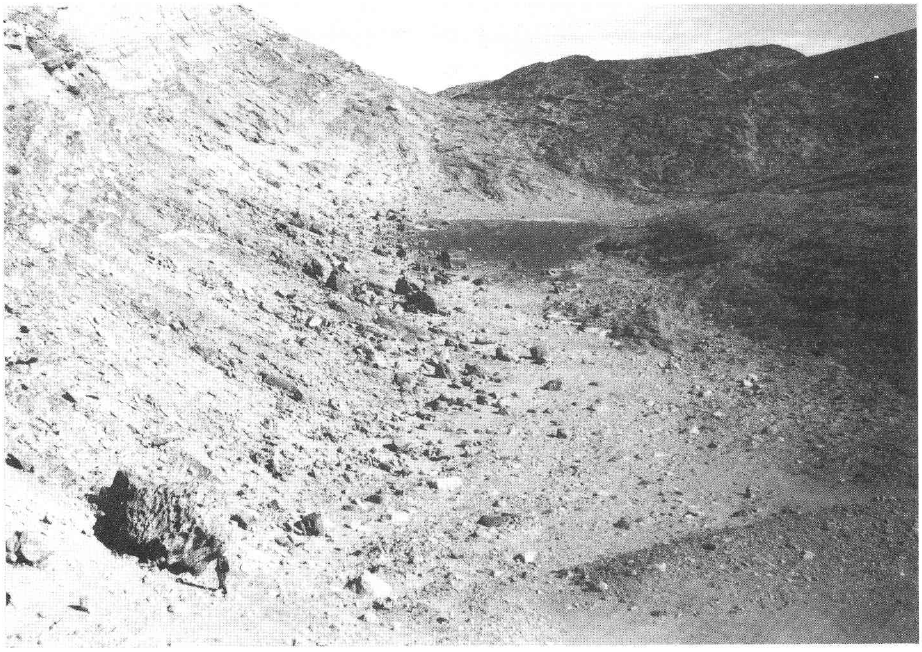

Photo 12. One set of a cirque and a terminal moraine southeast of Mt. Tyōtō. A boulder suffering honneycomb weathering is shown on the left-hand side.

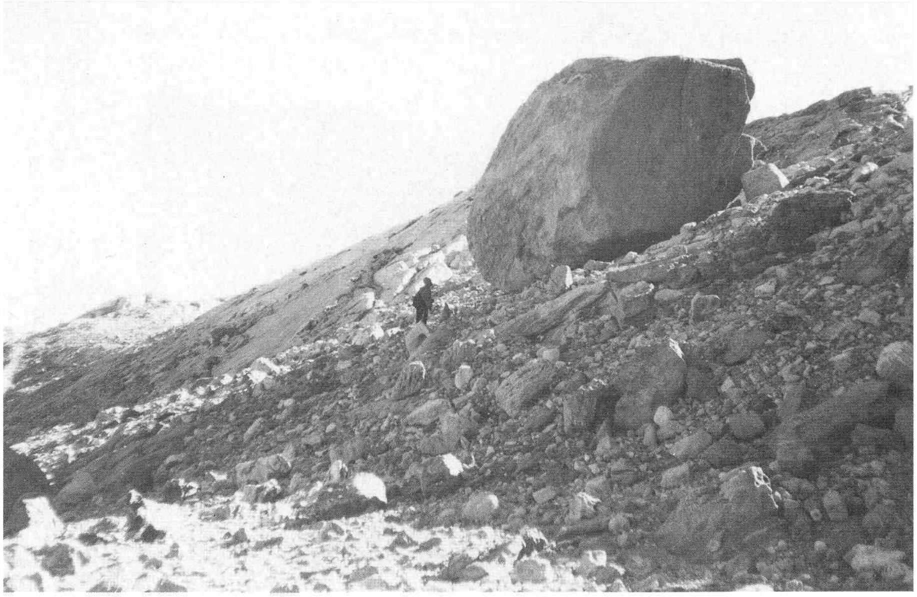

Photo 13. Glacial drift in a valley west of Mt. Hutago.

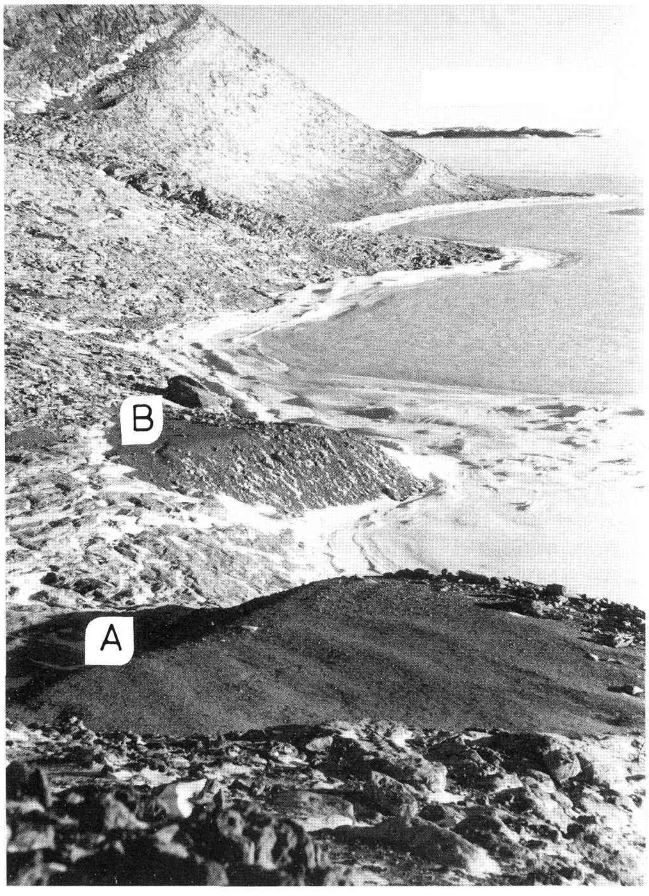

Photo 14.
Dissected deltaic fans at the mouth of the Yatude Valley. The height of A and B is 17 m and 10 m above sea level, respectively.

Photo 15. A fluvioglacial terrace in the Yukidori Valley.

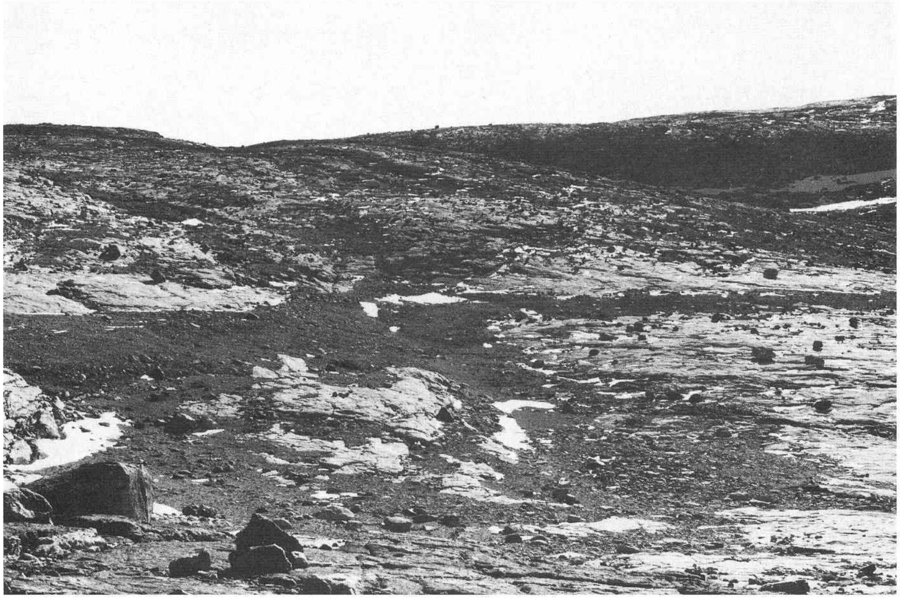

Photo 16. A long and narrow bank of fluvioglacial deposit in a circular depression north of Simo-kama.

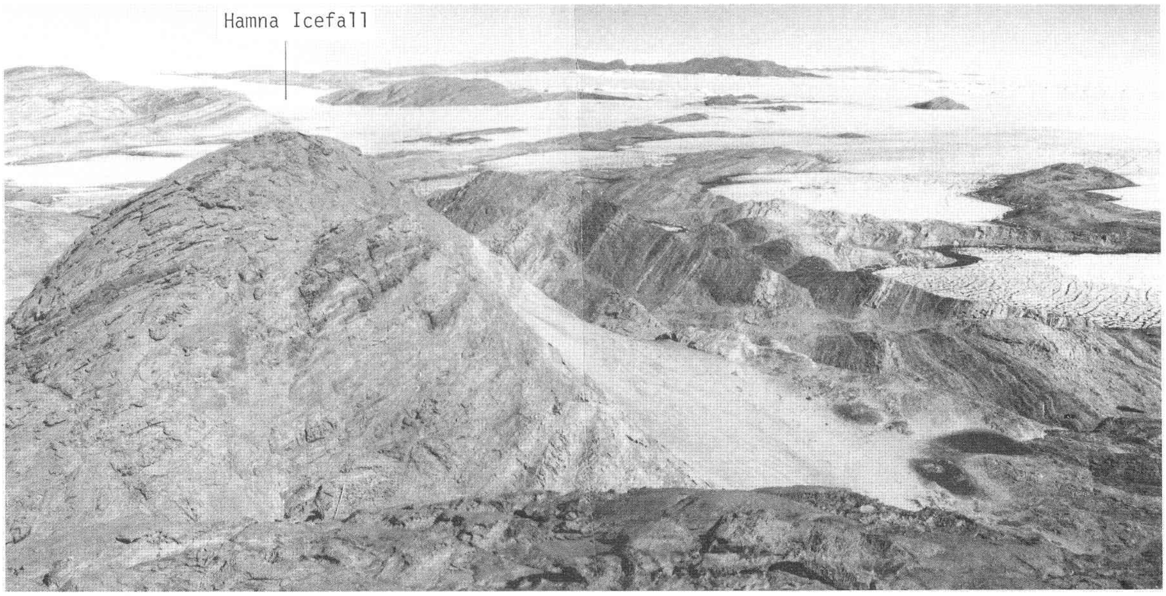

Photo 17. A conical drift of eolian sand on the western slope of Mt. Tyōtō and homoclinal ridges west of Mt. Tyōtō.

Photo 18. Pocket beaches and the coastal lowland facing the Mizukuguri Cove.

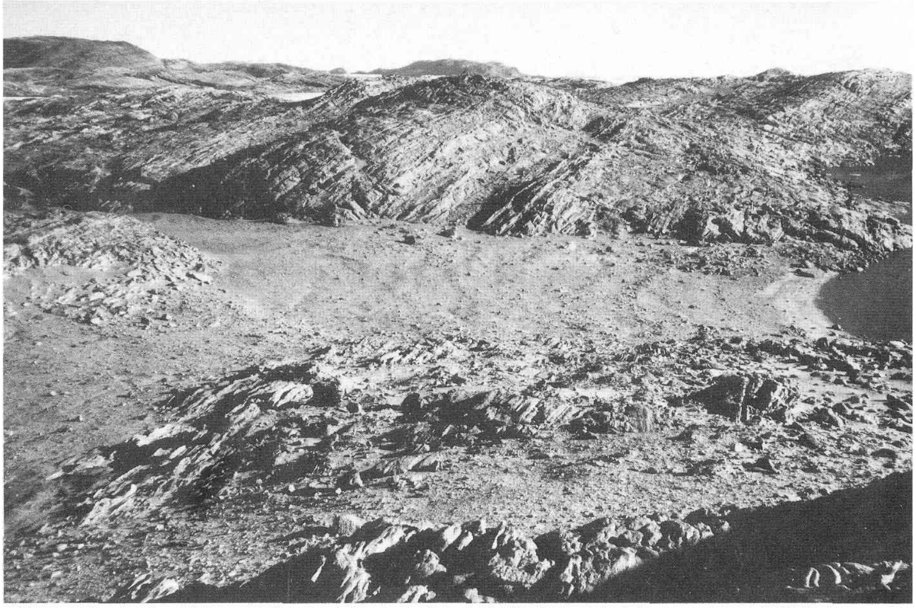

Photo 19. The stepped topography on the raised beach west of Lake Nurume.

Photo 20. The elevated marine boulder pavement viewed from Mizukuguri Cove. A knife ridge and tors are seen in the background.

Photo 21. The salt pan in the empty bottom of Lake Itiziku.

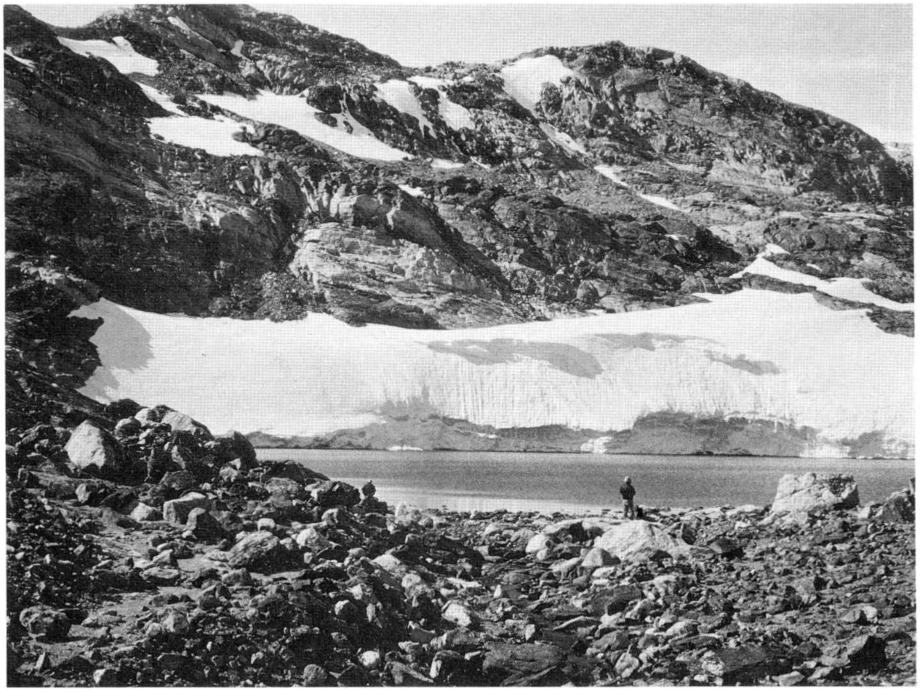

Photo 22. A snow drift and glacial drifts around Lake Yukidori.

Photo 23. Homoclinal ridges and subsequent valleys developed along the gneissic foliations and joint systems viewed from Mt. Hutago.

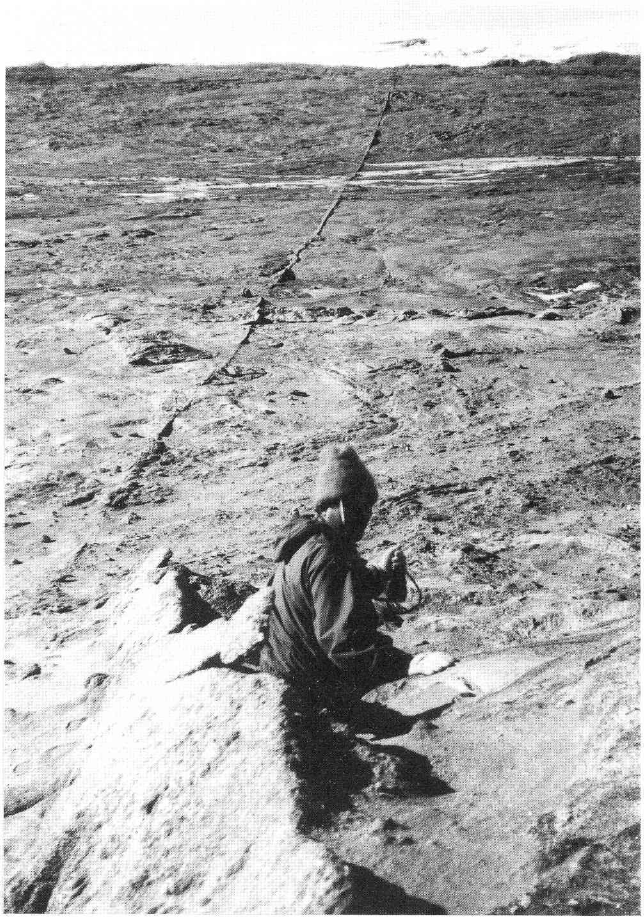

Photo 24.
Protrusion of pegmatite dyke on the "strandflat" east of Mt. Tyōtō.

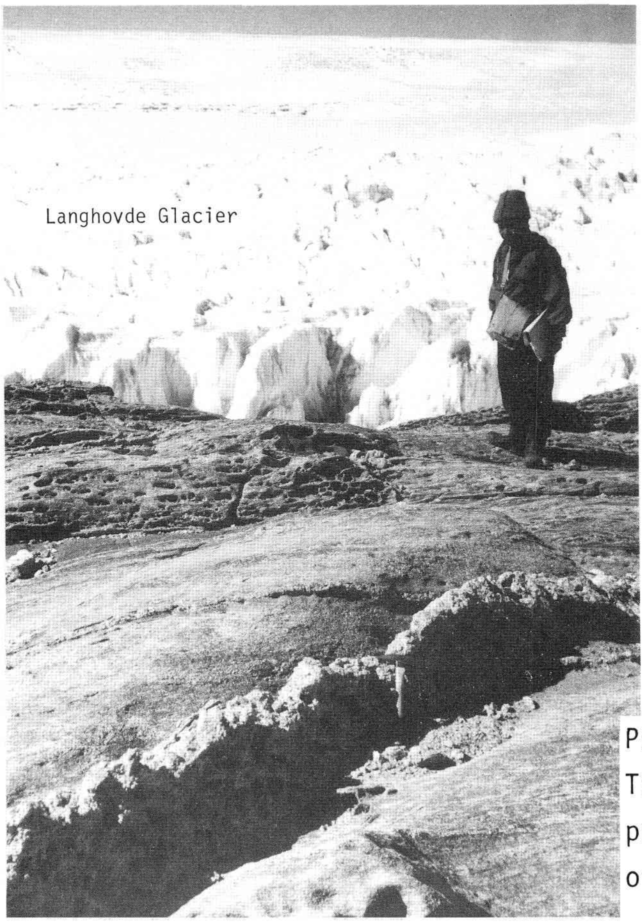

Photo 25.
The honneycomb-weathered rock and a protrusion of pegmatite dyke west of the Langhovde Glacier.

Photo 26. Tors of granitic gneiss on the ridge northeast of Lake Itiziku.