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ANTARCTIC GEOMORPHOLOGICAL MAP OF MOUNT TYÔ, YAMATO MOUNTAINS

Explanatory Text of Geomorphological Map

of

Mount Tyô, Yamato Mountains, Antarctica

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EXPLANATORY TEXT OF GEOMORPHOLOGICAL MAP OF MOUNT TYÔ, YAMATO MOUNTAINS, ANTARCTICA

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I. Introduction

The Yamato Mountains are situated at about 71.5°S, 35.7°E, 200 km south-southwest of Lützow-Holm Bay and were first visited by members of the traverse party of the fourth Japanese Antarctic Research Expedition (JARE-4) in 1960. They carried out preliminary geomorphological and geological field work as well as geodetic surveying (YOSHIDA, 1961; KIZAKI, 1965). Since then, several field parties have conducted investigations of geology, glaciology, and meteorite search in and around the mountains. Aerial photography was made by JARE-10 (1968–70) and JARE-16 (1974–76), and ground control points for large-scale mapping were established by JARE-14 (1972–74) and JARE-16 in the mountains. Eleven sheets of 1:25,000 topographic maps were published by Geographical Survey Institute in 1981. The geomorphological work, however, has been done on very limited occasions.

The Yamato Mountains consist of many nunataks, seven larger ones which can be called massifs and the other smaller ones, rising 50 to 800 m out of the surrounding surface of the ice sheet. These massifs, tentatively named A, B, C, D, E, F, and G Groups from south to north, with the summit heights of 2100 to 2400 m extend over 60 km in north-south direction, conformably with the trend of the major geological structure. The ice sheet flows from south-southeast to north and to west through and around the mountains. The bare ice surface named Meteorite Ice Field stretches over 4000 km^2 near the mountains and toward further south.

The bedrock of the mountains consists of high grade metamorphic, syenitic and granitic rocks (SHIRAISHI *et al.*, 1983). The mountains are considered to be geologically block mountains uplifted during the Tertiary period (SHIRAISHI and KIZAKI, 1979). This seems to be supported topographically by geomorphic characteristics, subglacial bedrock elevations around the mountains, the similarity of topographic situations and relationship to the Sør Rondane Mountains to the west (YOSHIDA, 1983).

The mountains would have been covered completely by the ice sheet in the period of its maximum inundation (YOSHIDA, 1983). Since then, the ice sheet lowered its surface elevation by at least 400 m (upstream-side) to 800 m (downstream-side) to the present level. As a result, a variety of glacial landforms can be seen as glaciated undulating surfaces, glacial troughs through the mountains, small cirques with cirque glaciers, and moraine fields.

Mt. Tyô is one of the peaks of the C Group in the central part of the Yamato Mountains. The mapped area covers most of the C Group which is composed of a NW-SE trending row of small nunataks, Syôzi, Tuitate and Maku Rocks, and the main massif of Mt. Tyô. The northeastern part of the group consists of medium-grained, coarse-grained, or porphyritic syenites, while the southwestern part mostly of granitic gneiss (YANAI *et al.*, 1982). A conspicuous thrust fault cuts the bedrock in the south of Mt. Tyô, but this fault scarcely influences topography. On the other hand, a probable fault-line scarp rectangular to the main NW-SE trend of the massif can be found on the moraine-covered surface in the southwest of Mt. Tyô.

The undulating gentle slopes supposed to be remnants of old erosional surfaces are distributed in some places, and precipitous cliffs abut on these slopes. In general, the northern part of the mountains shows more rugged topography than the southern part.

Syôzi and Tuitate Rocks which are steep-sided nunataks without gentle slopes and Maku Rock on which rather gentle slopes remain are separated by the Gosiki outlet glacier from the main massif. Gentler surfaces develop on the main massif, part of it showing the cirque-like topography. In particular, a moraine-covered surface stretches over 3 km between Mimi Rock and the southwestern foot of Mt. Tyô. Two small cirque glaciers are formed on Mt. Sentyô and between Mt. Sentyô and Mt. Tyô. They are fed by drifted snow, but the western one has a shrinked terminus. The conspicuous cirque, Tyô-no-kubo, cuts the southwestern part of Mt. Tyô. The glacier surface in it consists entirely of flat bare ice which slightly inclines inversely and is covered partly with thin moraine.

The Gosiki outlet glacier flows northwestward and the ice sheet west of the massif flows north-northwestward at present. But chatter marks which remain at a very limited place indicate that the former ice sheet had flowed westward, overriding the massif.

II. Concepts of Geomorphological Mapping

Landforms have many different aspects such as morphologic, geologic, chronological, genetic, and dynamic ones. Comprehensive description of landforms may necessitate dealing with the above five aspects at least. Therefore, in preparing a multipurpose geomorphological map, these aspects must be mapped and represented. In other words, a geomorphological map must give information about the appearance (morphology), the dimensions and slope values (morphometry), the materials (geology), the origin (morphogenesis) and the age (morphochronology) of each form. Representation of all such information on a single map sheet brings many troublesome problems. The use of many symbols and colours on a single sheet is an extremely complicated problem: difficulty increases furthermore when lithology and other geological information have to be added to the geomorphological aspects. Of the various legends provided for detailed geomorphological mapping, very few meet all the foregoing requirements.

Many countries develop their own systems of geomorphological mapping. Morphological mapping presented in the United Kingdom is based on precise mapping of slopes with special attention to slope discontinuities. Primitive morphometric and simple morphological classification on hillslopes are made in hilly or mountainous lands by national and local governments of Japan. Genetic and chronological aspects are emphasized particularly in the Polish and French systems. In the French system, one can easily obtain the geological information from the map as well as morphogenesis. The German system includes all elements of landforms using many symbols and colours, and in particular, it emphasizes both morphology and current and past geomorphological processes. As a result of too abundant information, the map losts the clarity and legibility. Even if we adopt any of the mapping systems mentioned above, we cannot compile a complete geomorphological map.

The basic idea for the mapping system of Mount Tyô is to prepare the map which represents the five aspects of landforms as morphology, geology, chronology, genesis, and dynamics. It is very difficult, however, to carry out the mapping completely at the present stage, because different from the coastal area along Lützow-Holm Bay, no intensive field work on geomorphology have been conducted in the Yamato Mountains,

mainly because of their remoteness. The present geomorphological map series is not a final result of the geomorphological research, but the purpose of the map is to provide the basic data for future research in geomorphology, geology, glaciology, and engineering. Therefore, our mapping system is inevitably conformed with our present state of knowledge on geomorphology in the area.

The basic points of the mapping are as follows:

(1) Morphographic and morphometric aspects are represented by basic relief lines which divide the relief into unit slopes. This is based on the concept that most of the land surface in the hilly and mountainous land is composed of individual slopes. The Yamato Mountains show distinct alpine landscapes which are constituted by larger slopes, whereas the coastal Langhovde area is composed of smaller irregular, smooth unevenness produced by areal erosion of the ice sheet. The Langhovde area was mapped by HIRAKAWA *et al.* (1984) in a slightly different manner.

(2) Materials which constitute the subaerial terrain are divided into unconsolidated sediments and bedrock. The types and features of the sediments may be interpreted from genetic classification of landforms and/or distribution of geomorphological processes. Bedrock lithology is represented only in the bedrock area, but geologic structures are not represented on the map because the bedrock topography does not seem to be strongly controlled by them.

(3) Genetic classifications of depositional landforms are mapped on the main map, and areal distribution of geomorphological processes is shown in a separate map.

(4) Actual processes and their geomorphic traces, e.g. patterned ground, are mapped on the basis of limited field observations and areal photograph interpretation.

(5) It is impossible to illustrate the chronological classification of the landforms on the map, because our present knowledge on this topic is very limited due to the lack of time markers in sediments and of information on the rate of weathering and slope processes. Geomorphological development is briefly discussed in relation to the deglaciation of the ice sheet in the explanatory text.

III. Mapping System for Mount Tyô

Mapping and representation systems of the present sheet is nearly similar to the Antarctic geomorphological map of Langhovde (HIRAKAWA *et al.*, 1984). Groups of information on the geomorphological map and their representation are illustrated in Fig. 1.

1. Topographic map

The base map for the geomorphological map of Mount Tyô is the topographic map of Mount Tyô (1:25,000), which was published in 1981 by the Geographical Survey Institute, Ministry of Construction, Japan. The map was plotted with vertical aerial photographs taken on Jan. 27, 1969 and Dec. 17, 1975 by JARE-10 and 16, respectively. The photogrammetry was controlled by triangulation points established in 1973 (JARE-14) and 1975 (JARE-16). Topography in ice-free areas and ice- or snow-covered areas is represented by grey and blue contour lines at intervals of 10 m, respectively.

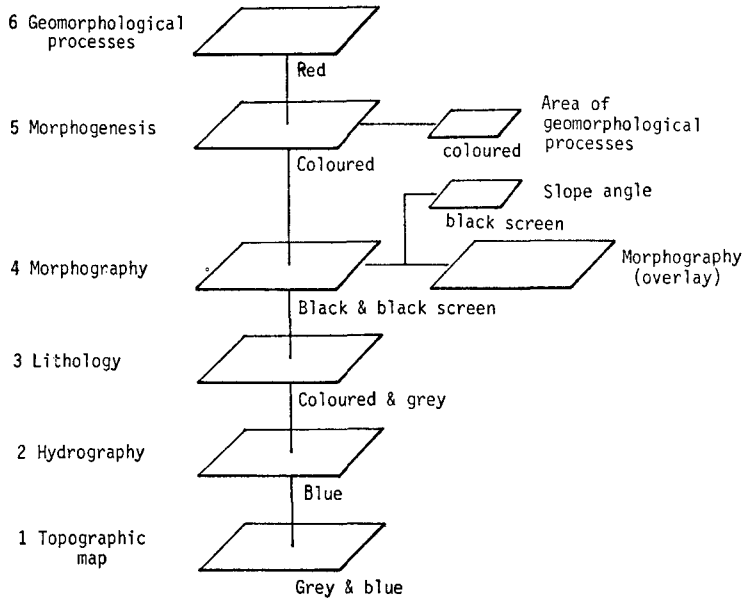

Fig. 1. Layers of information in the geomorphological map of Mount Tyô.

2. Hydrography

Information on glaciers, snow, and inland water is classified and mapped as hydrography. They are mainly painted in bluish or greenish colours.

3. Bedrock lithology

Geological information represented in the geomorphological map is mainly based on the geological map published in 1982 (YANAI *et al.*, 1982). Bedrock lithology is represented only in exposed bedrock areas with yellowish and greyish colours.

4. Morphography and morphometry

Data on morphography and morphometry were obtained by interpretation of aerial photographs on the scale of 1:20,000 and 1:50,000, which are listed in Table 1 and topographic map on the scale of 1:25,000.

Morphographic elements are represented by basic relief lines which divide the relief into some uniform unit slopes larger than 100 m in length and width. The procedure is as follows:

Table 1. Records of aerial photography of the area around Mt. Tyô, Yamato Mountains.

Expedition	Year	Camera	Focus (mm)	Scale
JARE-10	1969	RMK 11.5/18	115.02	1:20000
JARE-11	1970	RMK 11.5/18	115.02	1:16000
JARE-16	1975	RC-9	88.43	1:25000
JARE-23	1982	RC-10	88.05	1:28000 Colour

1. Trace ridge lines and valley axes;
2. Trace discontinuities of slope profiles;
3. Trace discontinuities of horizontal curvature of slopes;
4. Classify the unit slopes bounded by basic relief lines into nine geometric forms of hillslopes (e.g. RUHE, 1975, p. 100).
5. Measure mean angles of the individual unit slopes and classify them into the following four categories: 0–3°, 3–15°, 15–40°, and 40–90°.

Small landform units less than 100 m in extent are designated with symbols for morphological typology, such as ridge, valley, dome, hollow, and cliff.

These lines and symbols are printed on a separate overlay, and major basic relief lines such as ridge crest and valley axes are also indicated on the main sheet. All morphologic symbols are printed in black.

Distribution of slope angles is also represented in a separate small-scale map. This was made from the 1:25,000 contour map by using moving-interval method (e.g. DENNESS and GRAINGER, 1976). The slopes are classified into four categories: flat (0–3°), gentle (3–15°), steep (15–40°), and precipitous (40–90°).

5. Morphogenesis and area of geomorphic processes

Morphogenetic mapping has been undertaken on the basis of field observations and aerial photograph interpretations. Genetic classification of depositional landforms is mainly represented on the main map in different colours and symbols. That of erosional landforms, however, cannot be shown in the main map, except some special landforms such as cirque and trough edges, and roches moutonnées, because the lithology is printed in colour.

Areas of geomorphic processes on the subaerial terrain including the moraine field are represented in a separate small-scale map. This indicates the areal extent of dominant geomorphic processes which operated in the past or have operated. The darker colours signify the areas of depositional landforms and the lighter colours the areas of erosional. The adopted colours are the same ones as those in the French and German systems: glacial-purple; periglacial-lilac; and so on.

6. Actual processes and their geomorphic traces

Types and distribution of actual processes and their geomorphic traces such as patterned ground are illustrated as certain as possible according to the results of the field observations and aerial photography interpretation. They are indicated by symbols in red colour.

IV. Explanation of Legend

1. Hydrography

1.1. Frozen lake and pool

No liquid water exists in the mapping area at present. Therefore, no lakes, pools and streams occur in the subaerial terrain. According to the aerial photograph interpretation, however, one can find that several flat and clear ice masses are situated at the bottoms of the depressions and hollows in ice-cored moraine fields. These ice

masses seem to be formed by refreezing of meltwater, though it is not known at this stage when and in what condition meltwater occurred. Therefore, these ice masses are thought to be frozen lakes and pools, some of them occupying kettle holes. There are many lakes and pools, but only larger ones are indicated on the map.

1.2. Ice sheet and outlet glacier

While the ice sheet surface on the east side of Maku Rock (2121.2 m) and Mount Sentyô (2273.0 m) attains over 1950 m to 2000 m in altitude, that on the west side of the massif is below 1800 m in altitude. From the upper ice sheet to the lower one, outlet glaciers flow down in an ESE-WNW direction in general.

The Gosiki Glacier flowing between Maku Rock and Mount Tyô is a typical outlet glacier, but it does not reach the lower ice sheet; its terminus occupies a basin which is surrounded by Mount Tyô, Mimi Rock, and Tuitate Rock and is lower than the western ice sheet surface (Fig. 2). A part of the glacier stretches southeastward and its terminus intrudes into the large Tyô-no-kubo cirque located on the south of Mount Tyô.

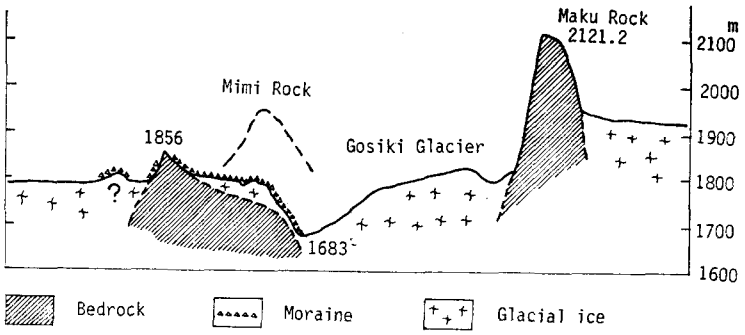

Fig. 2. Schematic section of the central part of Massif C.

A large and gentle outlet glacier is located on the north of the three nunataks of Syôzi Rock, Tuitate Rock, and Maku Rock. A small lobate terminus flows down southward between Tuitate Rock and Maku Rock. There exists a steep outlet glacier on the south of the Mount Tyô massif and it is separated from the lower ice sheet by the slender terminus of the Ôgi Glacier and the lateral moriane, both originating from the Ôgi Moraine Field area.

1.3. Mountain glacier

While outlet glaciers are fed by ice supply from the ice sheet, mountain glaciers have independent glacial regimen controlled by local conditions of the mountain. A small mountain glacier flows down on the south slope of the deep depression formed between Mt. Tyô and Mt. Sentyô (Photo 4). Another local glacier flowing north is located on the north slope of Mt. Sentyô. These two are a kind of cirque glacier fed by drifting snow (YOSHIDA and FUJIWARA, 1963). The glacier between Mt. Tyô and Mt. Sentyô has lowered its surface more than 30 m since the cirque glacier had formed (YOSHIDA and FUJIWARA, 1963).

1.4. Snow hill

Drifting snow driven by southeast winds builds large snow hills around the massif and nunataks. Gentle slopes are formed in windward areas and long streamlined tails in leeward areas. Wind shapes sharp ridges on the snow hills and erodes scoops and moats at the foot of the massif and nunataks. The snow hills and their surface features give variety to the monotonous glacier surface. Snow hills in the Yamato Mountains are very important as a source of the local glaciers and govern the distribution of them. No snow hill exists between Mt. Tyô and Mimi Rock; the Mt. Tyô massif is so high that most of drifting snow cannot be driven to the area behind. We could find no significant change of the hill morphology and distribution on aerial photographs taken in different years.

1.5. Snowpatch in the ice-free area

Small snowpatches are distributed in the ice-free area composed of bedrock and moraines. They have dimensions of several hundreds metres and are situated in the depressions on the windward slopes and at the foot of steep rock walls on the lee side. Distribution of snowpatches which is mostly limited in the same areas where the snow hills are located, implies that the drifting snow sustains the snowpatches. Their locations and shapes on the map indicate the state in December 1975 or January 1982.

1.6. Snow-covered area of glacier

Snow covers considerable parts of the ice sheet and outlet glaciers around the massif even in summer. It seems to be driven by ESE winds, because the main snow-free area where a wide bare-ice field is exposed appears on the west side of the massifs. Snow-covered area on the west of the line between Syôzi Rock and Mt. Tyô was mapped with the aerial photographs taken in January 1982, while the one on the east of the line with those taken in 1969 and 1970.

1.7. Crevasses

A group of crevasses occurs on a middle part of the glacier situated between Mt. Tyô and Mt. Sentyô. It is formed just below an convex break of slope.

1.8. Flow direction of glacier

Although no measurement of glacier movement was carried out, flow directions of glaciers are indicated on the map, judged from their surface configurations in particular from their surface inclinations.

1.9. Ridges on snow hill and glacier

Wind-shaped ridges and some other ridges on snow hills and glaciers are indicated on the map by the same symbols as the ridge form in blue colour.

1.10. Scarp of moat or windscoop

Small trough-shaped or box-shaped valleys are common at the contact between snow hills and rock walls. They are abraded by strong wind action at the bases of rock walls in front and on side of the nunataks and massifs. These features are called moat (YOSHIDA and FUJIWARA, 1963) or windscoop (VAN AUTENBOER, 1964).

Side walls of moats or windscoops are often composed of steep snow or ice cliffs. They are indicated in blue colour.

2. Bedrock lithology and geological structure

2.1. Syenites (Sy)

These rocks comprise three types, porphyritic, coarse, and medium syenite (YANAI *et al.*, 1982), but in this map they are grouped as syenites. They occur in the northeastern part of the mountains, including Syôzi Rock, Tuitate Rock, Maku Rock, Mt. Tyô, and Mt. Sentyô.

2.2. Gneisses (Gn)

Gneisses occupy a southeastern half of the mountains. They show various features such as granitic, augen, banded, and partially migmatite structures (YANAI *et al.*, 1982).

2.3. Amphibolites (Am)

Amphibolites occur as bands and small bodies in gneiss. A considerable body of amphibolites dipping northeast is exposed on a steep cliff in the southern part of Tyô-no-kubo.

2.4. Granite, aplite, and pegmatite (Gr)

Dikes of granite, aplite, and pegmatite are found in syenites, gneisses, and amphibolites. They are less than one metre to several tens of metres in width, and, in most cases, the contact with the host rocks is very sharp.

Basic metamorphosed dikes with a width of several metres occur in syenites, but they are not indicated in the map.

The geological structure of this area is rather simple. The foliation of rocks trends generally in the NW-SE direction and dips 40° to 60°NE. The direction of the foliation coincides with a row of Syôzi Rock, Tuitate Rock, and Maku Rock nunataks. The very linear arrangement of their south-facing walls suggests some fracture or joint structure along the nunataks (YOSHIDA and FUJIWARA, 1963).

Although an anticlinal fold axis and a thrust fault are recognized in gneiss in the south of Mt. Tyô (YANAI *et al.*, 1982), they are not indicated on the map because their structures were not reflected on the landforms.

3. Morphography and morphometry

3.1. Basic relief lines and unit slope

3.1.1. Ridge line and valley axis

Ridges and valleys are classified into the following three types; symmetric, asymmetric, and rounded. The symmetric and asymmetric ones have sharp or more or less clear ridges or axes, while the rounded ones have rounded or nearly flat portions with the width less than 100 m in cross section. If the width of those portions is larger than 100 m, they are to be represnted as independent morphological units.

Main ridge lines and valley axes are illustrated in the main map as well as in the separate overlay sheet.

3.1.2. Boundary of slope

Downslope discontinuities of relief are drawn by symbols of break of slope and smooth change of slope. The former indicates a sharp or angular discontinuity, while the latter a gradual change of inclinations of the ground surface. "V" symbols represent the boundary line point downslope, and are drawn on the steeper side of the line. An inflection line is a boundary line enclosing a single unit slope and separating

it from adjacent slopes. In most cases, it indicates a discontinuity of horizontal curvature or a transitional boundary which is not a clear morphological discontinuity.

3.1.3. Surface features of unit slope

An irregular morphological unit which possesses surface irregularities too uneven to be represented as a slope is distinguished from a unit slope. Topography within the unit cannot be represented in most cases with the symbols for small morphological units (see 3.2.) because of their irregular forms and small size. The irregular morphological units often occur on ice-cored moraines and in moraine fields on glaciers as a chaotic disintegration form of glaciers.

The unit slopes are divided into two types: smooth and rugged. A rugged unit slope possesses surface micro irregularities or unevenness, but its entire form is smooth enough to be considered as a unit slope. The rugged features seem to be related to glacial plucking or recent mass-movement.

3.1.4. Slope form

Shape of the smooth and rugged slope units can be described with the combination of profile and plan form. The forms in profile and plan are classified into convex and concave forms and almost rectilinear one; accordingly, a slope form comprises nine types of unit slopes (e.g. RUHE, 1975, p. 100). An arrow indicates the general trend of the flow line direction, but it is not represented on steep slopes over 40°.

3.1.5. Inclination

A dominant gradient of each slope unit is indicated as four simple classes as follows: 0°–3°, 3°–15°, 15°–40°, and 40°–90°.

3.2. Small morphological unit (less than 100 m in distance)

3.2.1. Ridge form

Ridge topography is classified into six types by its basal width and form in cross section. A boundary of dimension is 25 m in distance. A ridge with its basal width more than 200 m must be separated into two unit slopes bounded by the ridge line. These small ridges often occur in moraine fields, and in particular, many parallel ridges are found on the morainic platform between Mt. Tyô and Mimi Rock. Small ridges composed of drifted snow are distributed on the lee side of the snow hills.

3.2.2. Valley form

Valleys less than 200 m in width between upper edges are classified by transverse valley profiles into four types: i) a symmetric V-shaped valley, ii) an asymmetric V-shaped valley, iii) a trough-shaped valley with concave bottom, and iv) a box-shaped trough valley. Larger valleys are represented by using other symbols in the same case as the ridge form.

The valleys less than 200 m in width are common at the contact between snow hills and rock walls (see 1.10.).

3.2.3. Hillock

Hillocks such as rock towers and domes are found in the mapped area. They are divided into two categories on the basis of the diameter at their margins.

3.2.4. Depressions

A number of round depressions and hollows are developed mainly in the moraine area. Depressions less than 200 m in diameter at their upper edges are divided from larger ones.

3.2.5. Cliff

Cliffs are classified into four categories according to their height and distance in cross section. It sometimes was very difficult to classify their dimensions precisely. Larger cliffs are grouped as the slope units with more than 40° in angle.

4. Morphogenesis

4.1. Tectonic landform

4.1.1. Fault scarp

A low cliff which runs roughly in a NE-SW direction is recognized on the flat surface to the south of the Mt. Tyô. Its straight feature suggests that it is a fault-line scarp formed by structually controlled glacial erosion at an ancient fault contact or a recent fault scarp.

4.2. Glacial landforms

4.2.1. Trough edge

A trough edge refers to an upper end of a trough wall. The trough is perhaps the most spectacular and well known landform, created by glaciers flowing in channels. This is associated with not only a valley glacier but also an ice stream within the ice sheet. Most of them appear to have been eroded beneath the ice sheet (SUGDEN and JOHN, 1976, p. 179).

Most of linear cliffs in this region are considered to be the trough walls which have been cut by outlet and mountain glaciers in association with erosion beneath the ice sheet. The trough edges showso me difference in morphological freshness, but the distinction is not indicated on the map.

4.2.2. Cirque edge

A cirque edge means an upper end of a cirque wall. A cirque is a very popular landform associated with glacial phenomena. Although there are a variety of definitions on cirque morphometry (e.g. EVANS and COX, 1974), most of the authors agree that the morphology of the glacial cirque reflects a combination of glacial and periglacial activities. In ice-sheet landscapes, it is rather difficult to distinguish the true cirque morphology from pre-existing cirques which have subsequently been subjected to ice sheet scouring and from hollows located at the trough head which have been carved by the ice sheet. Accordingly, the cirque in this sheet refers to a cirque-like form related to glacial erosion.

Tyô-no-kubo is a typical cirque in which a local glacier accumulated in the lee by drifting snow and shaped its steep backwall, and subsequently it was occupied by the terminus of the Gosiki Glacier after the local glacier disappeared due to the ice sheet lowering. The possibility, however, that a cirque form had originated in the cirque glaciation before inundation of the ice sheet cannot be excluded. This will be clarified by detailed sounding of bedrock morphology beneath the Gosiki Glacier and Tyô-no-kubo. Two small empty cirques are recognized on Mt. Sentyô and Maku Rock, but it is not sure whether they are true cirques or not. They are too small to be shaped by cirque glaciers and their cirque edges are not clear.

4.2.3. Roches moutonnées

The massifs and nunataks in this area can be regarded as giant roches moutonnées because they are composed of stoss-and-lee topography in various scales. Only

typical roches moutonnées with suitable dimensions (about 100 m) were mapped. They are found on the north-facing slopes of Mt. Sentyô and on the flat surface south of Mt. Tyô.

4.2.4. Striations

Glacial striations and/or crescentic gouges only which were found by field works are indicated on the map. An arrow indicates the direction of the former glacial flow.

4.2.5. Moraine field on glacier

Nearly flat moraines, composed of angular and rounded boulders, pebbles, and sand and silt, cover parts of the ice sheet and glaciers. The thickness of the moraine cover is usually very thin so that it can be described as "one boulder" thick. Accordingly, some of them are not so clear on aerial photographs that only distinct parts are represented on the map. Moraine fields spread to the north of Maku Rock show complex flowline patterns which reflect the ice flow of the outlet glacier. They are derived from basal till as shear moraine composed of relatively small rounded and subrounded stones (YOSHIDA and FUJIWARA, 1963). A long moraine bank situated to the west of the massif is a lateral moraine originated from the Ôgi Moraine Field to the south and stretches northwest for about 7 km from Mimi Rock.

4.2.6. Morainic hill on glacier or ice-cored moraine

Moraine cover with a hilly and sloping form is distinguished from the moraine field. A broad and gently sloping platform between Mimi Rock and Mt. Tyô is an ice-cored moraine as a whole. It is covered almost completely with morainic deposits except small exposures of bedrock in the southwest. According to the observations in the field only thin morainic materials cover the underlying ice. Several small ridges and furrows may show a flow pattern of glaciers on the aerial photographs. Boundaries between the ice-cored part and the moraines in the ice-free area are uncertain, but distribution of some disintegration morphology of the glacier such as pits, furrows, and minor irregular topography may indicate an extent of the ice core. A schematic cross section of the platform is shown in Fig. 2. This platform morphology seems to be associated with both the bedrock swell under the ice and protective effects of debris from the ice-surface lowering by ablation.

Ice-cored moraines are often found at the foot of steep rockwalls, such as south wall of Tyô-no-kubo. Although they represent the same form as talues cones, the ice-cored moraines are preferable rather than talus because some ice-melt hollows and depressions occur on them and all of their adjacent areas are covered with morainic materials.

4.2.7. Moraine on ice-free area

Areal extent of moraines without ice core is very small. Typical but small moraine ridges are found on the western slope of Mimi Rock and a thick morainic sheet covers the gently sloping flat ridge on the south of Tyô-no-kubo. Difficulty of distinction between moraines with ice cores and those without ice core should be emphasized.

4.2.8. Slopes with thin morainic mantle

Bedrock slopes covered with thin morainic materials are distributed in the gentle parts of the mountains and nunataks. Because the materials include erratic boulders, it is easy to distinguish the morainic materials from some frost-riven rock fragments in the field. On the aerial photographs, however, keys of interpretation are only coarse

texture of the surface and geomorphological situation where the area joins the adjacent moraine-covered area.

4.2.9. Glacier karst and pitted moraine

Small-scale irregular landforms were formed on ice-cored moraine by ablation of underlying ice. Their basic features are very similar to those of debris-covered glaciers in mountains of the middle latitude (e.g. IWATA *et al.*, 1980). A conspicuous area of this landform is found on the west of Mimi Rock. The moraine cover is effective for protection against ice wastage, but it is not known what factors caused the differentiation between the areas with and without these landforms.

4.3. Periglacial landforms

4.3.1. Slopes with periglacial debris mantle

Thin frost-riven detritus covering bedrock slopes is recognized on the flat surface of the southeast end of the massif on aerial photographs. Precise distinction between periglacial detritus and morainic materials is impossible without field work. According to the field observation, some erratic boulders were found in the debris mantle at the southeast end of the massif, but most of rock fragments had originated from the bedrock *in situ*. On the contrary, some frost-riven rock fragments were included in morainic materials.

4.3.2. Tor

There exist rock towers and domes on the south slope of Mimi Rock and on the platform between Mimi Rock and Mt. Tyô. Some of them seem to be periglacial tors, though field investigation is insufficient.

4.4. Gravitational landforms

The term of gravitational landforms is employed for the landforms associated with rapid mass-movement.

4.4.1. Landslide scarp

It is likely that a steep landslide scarp was formed on the backwall of the Tyô-no-kubo cirque.

4.4.2. Talus

Two uncertain talus cones are distinguished from the thin morainic debris mantle on the aerial photographs. One is below the landslide scarp in the Tyô-no-kubo cirque and the other is on the southern cliff of the Mt. Tyô massif.

5. Areas of geomorphological processes

5.1. Area of tectonic processes

Uncertain fault scarp to the south of Mt. Tyô is represented by a black colour.

5.2. Area of glacial processes

Glacial landforms such as moraines (including moraine fields and ice-cored moraines), cirque and trough walls, and slopes with thin morainic debris mantle are painted in purple. The darker colour indicates the area of deposition, while the lighter colour the area of denudation.

5.3. Area of periglacial processes

A lilac colour indicates the area of periglacial processes which includes the slope with periglacial debris and periglacial tors.

5.4. Area of gravitational processes

The landslide scarp and talus are represented by a brown colour.

Eolian processes such as wind erosion is somewhat significant in the area, but we could not assess its spatial extent so that it was not represented on the map.

6. Actual geomorphological processes and their geomorphic traces

6.1. Rock fall

It is quite probable that rock falls have often occurred on the steep glaciated walls, as inferred from their freshness, but direct and indirect observations in the field are not enough. Therefore, rock falls are indicated only in the areas where talus is located.

6.2. Patterned ground

Patterned ground comprising sorted circles, polygons, and stripes is best developed in the Aka-kabe Massif (Massif B) and it shows vertical sorting formed by periglacial processes as well as horizontal sorting (YOSHIDA and FUJIWARA, 1963). Almost the same patterned ground as that in the Aka-kabe Massif is found on the gentle slopes around Mt. Tyô (YOSHIDA, 1983).

Surface geometric patterns of debris, such as polygonal, circular, and linear are recognized on the moraine-covered platform between Mt. Tyô and Mimi Rock by aerial photograph interpretation. These patterns consist of indistinct rings and stripes with shallow unevenness. They cover considerable parts of the platform surface, but the symbols on the map are only scatteringly represneted. YOSHIDA (1983) suggests that these patterns are kinds of the underlying ice core rather than the patterned ground due to the real periglacial actions. On the map these patterns are included in the periglacial patterned ground, but intensive field observations and some experimental studies will be needed in order to elucidate their origin.

V. Characteristics of Landform

1. Geomorphological development

The Fukushima Massif (Massif D), the highest of seven ones, has the glacially scoured, rather flat surfaces near the summit. Therefore, the Yamato Mountains must have been covered completely with the ice sheet in the period at its maximum expansion, though the absolute age of that period is unknown. The maximum stage indicated by this glaciation was named tentatively "Yamato Glacial Stage" (YOSHIDA, 1983). The ice sheet had flowed from east to west (to S85°W) at this stage as was indicated by glacial striae and crescentic fractures on glacially polished bedrock beneath the morainic deposits on the lower, 1800–1850 m surface in Massif C (Mt. Tyô area), overriding the mountain peaks.

Then, the ice sheet began to lower its surface at unknown time and the upper part of the mountains emerged from the ice sheet. The retreat of the ice sheet must have taken place a little earlier in the northern part of the mountains than in the southern part, as is indicated by difference in degree of bedrock weathering and of degradation of ice core beneath the morainic deposits. This retreat seems to have been interrupted for a considerable period of time, when the ice surface reached 2100–2200 m above sea

level in the northern part of the mountains (YOSHIDA, 1986). In the southern part, it is difficult to determine the level of the ice sheet. It is inferred, however, that the upper, 2000–2100 m surface might have been covered with the ice sheet during the interruption of ice retreat.

It is also difficult to judge whether this stage indicates the interruption of retreat or the readvance after considerable deglaciation. In the Sør Rondane Mountains 200 km west of the Yamato Mountains, the readvnace of the ice sheet after at least one deglaciation period must have existed between the level of the maximum extent of ice and the present level (VAN AUTENBOER, 1964). Because evidence of readvance has not been found yet, we interpret that at least one interruption of ice retreat would have existed, at the present state of knowledge. This interruption was named tentatively "Fukushima Glacial Stage". Moraines on the 2000–2100 m surface in Massif C might have been deposited at this stage.

Then, the ice surface retreated again to the present level. The ice surface, however, might have stayed for some time at the level some tens of metres above the present ice surface in the near past, when the wide moraines were deposited on the 1800–1850 m surface in Massif C and many of moraines on and near the ice surface in Massif A were formed. This glaciation was named tantatively "Meteorite Glacial Stage". This might be correlated with Insel I in the Alexander-Humboldt Mountains (BARDIN, 1972).

During the retreat of the ice sheet from the area, drifted snow and probably residual continental ice formed cirque glaciers at favorable places in the massifs, and outlet glaciers became distinct, sculpturing precipitous cliffs between massifs or small nunataks. As the retreat proceeded, ice disappeared from some outlet and cirque glaciers, and almost ice-free glacial troughs and cirques emerged.

Because regimen of a glacier is controlled by balance between wastage of ice and nourishment by drifted snow, it is affected mainly by the amount of snow accumulation which depends greatly on the vertical distance from the ice sheet surface and to some extent on aspect and configuration of a glacier. Therefore, variable states of regimen can be seen on cirque glaciers in the mountains (YOSHIDA, 1983). In Massif C, a cirque glacier with highly positive regimen is situated at Mt. Sentyô, one with accumulation and ablation areas in the south-southeast of Mt. Tyô, and one with only ablation surface in the southwest of Mt. Tyô (on the backwall of the Tyô-no-kubo cirque). An empty cirque whose configuration is not of a typical cirque form but is rather shallow and steep can be seen on the western flank of Mt. Sentyô. There is a possibility that the former Tyô-no-kubo cirque glacier originated in a cirque formed before the ice sheet cover, because the cirque configuration is similar to the Nizi-no-kubo cirque in Massif D which is considered to have been formed mainly prior to the ice sheet cover (NAGAO and YOSHIDA, 1984).

2. Morphological difference between Massif C and other Massifs

The Yamato Mountains can be divided into groups by morphology and location (YOSHIDA, 1983). That is, the northern group consists of Massifs D, E, F, and G, the central group Massifs B and C, and the southern group Massif A.

More rugged topography predominates in the northern group. Morainic cover on bedrock shows no conspicuous features such as small-scale undulation but thin

ground moraines. These moraines do not seem to have ice core, though talus deposits including exotic boulders at the foot of steep slopes usually have ice core.

On the other hand, massifs and small nunataks in the southern group are widely covered with moraines which have ice core and are very thin as can be described as "one boulder thick". Precipitous cliffs are found at very limited places.

In the central group, both the gentle slopes or flat surfaces and the precipitous cliffs are developed on the massif and small nunataks. Undulating gentle ridges of the upper parts of the massifs are covered with moraines which have ice core but are 10 to 30 cm thick and rich in finer material. Small-scale undulation due probably to solifluction is found on these moraines.

In Massif C, gentle slopes or flat surfaces can be divided into two levels, namely, 1800–1850 m surface and 2000–2100 m one. The upper surface is widely covered with somewhat thick moraines just mentioned above, but the lower surface is covered almost completely with a thin ice-cored moraine. The latter moraine shows streamlined or pitted features. This indicates that the moraine has still maintained the ice-molded topography, though the degradation of ice core is taking place.

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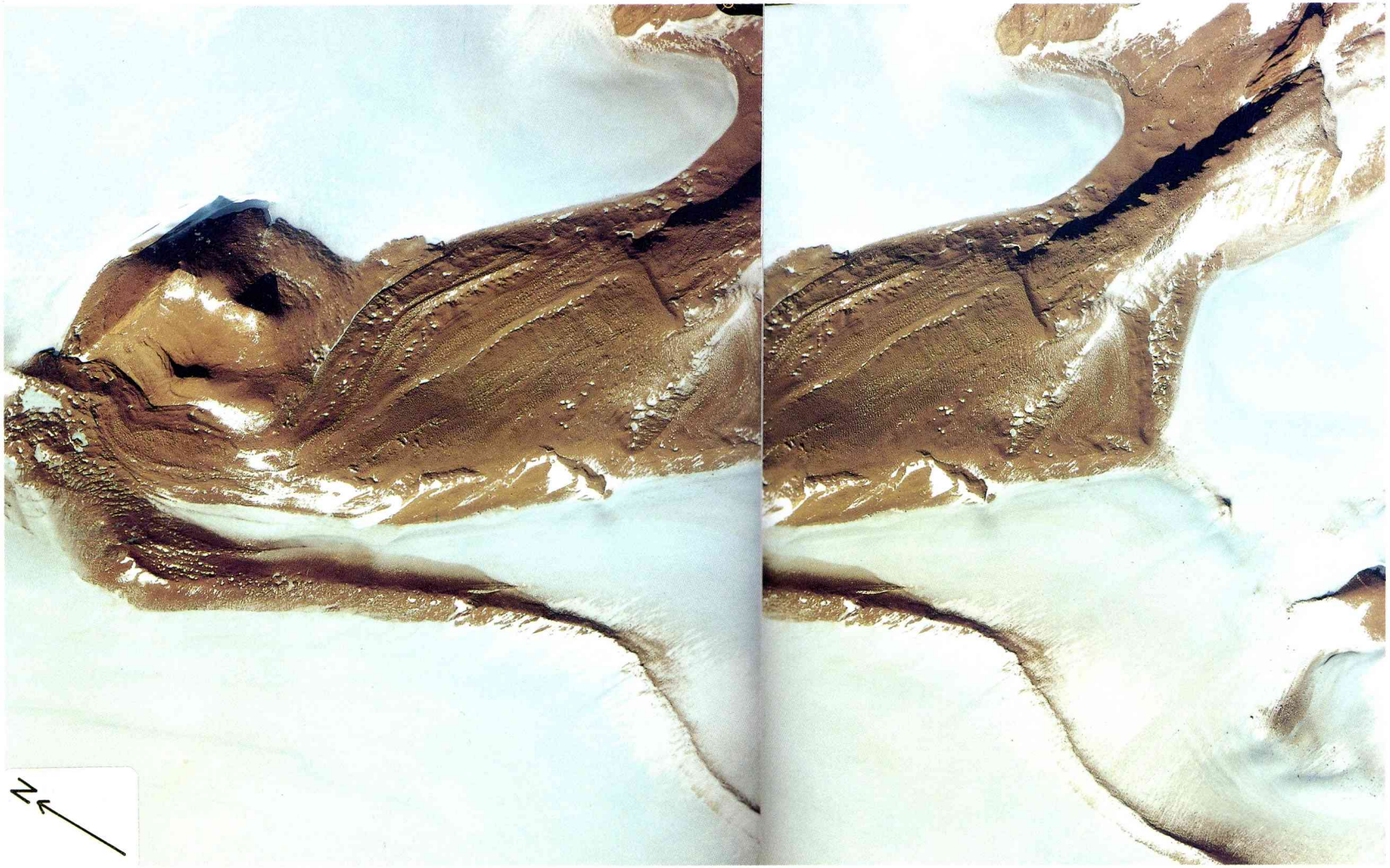

Photo 1. Aerial photographs of the central part of Massif C (Jan. 8, 1982).

Photo 2. Looking the edge of the upper undulating gentle slope from the moraine-covered lower surface (front). The moraine-covered upper surface (right) was cut by the Tyô-no-kubo cirque glacier and a steep cirque wall occurs (left to center).

Photo 3. Looking the moraine-covered lower surface (left), Mt. Tyô (center), and Tuitate Rock and Gosiki Glacier (right) from the summit of Massif C (Mt. Sentyô).

Photo 4. A cirque glacier between Mt. Tyô and Mt. Sentyô. Accumulation (upper) and ablation (lower) areas, and a slightly receding tongue are seen.