Geomorphic Development of the Sôya Coast, East Antarctica

— Chronological Interpretation of Raised Beaches based on Levellings and Radiocarbon Datings —

Kunio OMOTO

1 Introduction

1.1. Previous studies and problems to be solved

There are several ice-free areas along the western margin of the ice sheet that rises gently inland to the east of Lützow-Holm Bay. These areas include Langhovde, Breidvågnipa, Byvåg Asane, Skarvsnes, Kjuka, Telen, Skallen and Skallevikhalsen (from north to south), together with East and West Ongul Island, the Teöya Islands, several small islets and some nunataks (Fig. 1).

The landforms of these ice-free areas have been surveyed earlier by the Japanese Antarctic Research Expedition (JARE), as reported by Yoshikawa *et al.* (1957), Tastumi *et al.* (1959) and Koaze (1963). Raised beaches along Lützow-Holm Bay were investigated by Yoshikawa *et al.* (*ibid.*), Koaze (*ibid.*), Meguro *et al.* (1964), Fujiwara (1973), Yoshida (1970, 1973 and 1977), Moriwaki (1974 and 1976), and by Nogami (1977). The submarine landforms of Lützow-Holm Bay were sounded by Fujiwara (1971), Yoshida (1973), Moriwaki (1975) and Omoto (1976c).

Uchio (1966) voiced some criticism of earlier geomorphic reports on the raised beaches of East Ongul Island; criticism that was based upon his own paleontological studies of Foraminifera. In addition, Omoto (1972) has questioned the validity of some of the radiocarbon dates used in the landform chronology of Antarctica. Such criticisms stem from the fact that our knowledge of geomorphology and paleontology (especially Foraminifera habitation), and our interpretation of radiocarbon datings in Antarctica are still deficient. The radiocarbon dates obtained from East Ongul Island, for example, are not only confusing, but also contradict with the developmental sequences of raised beaches.

In order to clarify the development of coastal landforms and to resolve the confusion over radiocarbon dates in the Sôya Coast, a new geomorphological project entitled "Glacio-geomorphic Study at the Margin of Continental Ice" was organized by Dr. Yoshikawa, Professor at the University of Tokyo. As a part of this project, the present author levelled raised beaches and step landforms in many sections and sampled for radiocarbon dating in the ice-free areas along the Lützow-Holm Bay, during his stay at Syowa Station between 1969–1970 and 1973–1974. He

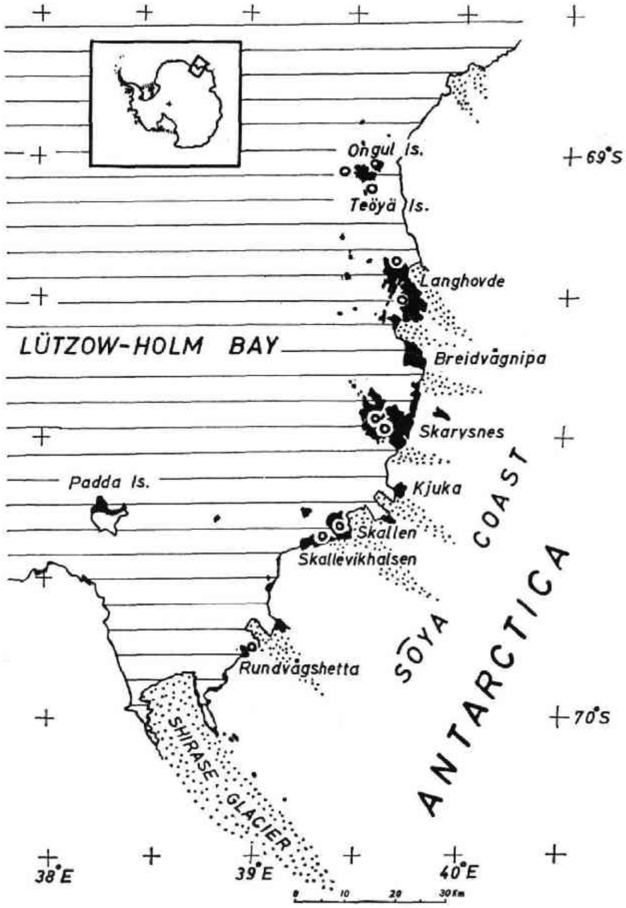


Fig. 1 Index map and locations of levelling sites (circled) on raised beaches and step landforms along the Sôya Coast

subsequently compiled a geomorphic development chronology based not only upon his own measurements of radiocarbon dates (Omoto *et al.*, 1974 and Omoto, 1976b), but also those published in earlier reports.

1.2. Outline of geology and landforms

Geological and petrological studies by Tatsumi *et al.* (1959 and 1961), Saito *et al.* (1961), Kizaki (1962), Tatsumi *et al.* (1964), Sato *et al.* (1965), Yoshida (1970 and 1977), Yoshida *et al.* (1971 and 1976), Ishikawa (1974 and 1977) and Ishikawa *et al.* (1977), and Yanai *et al.* (1974a and b, 1975a and b) are summarized as follows (Fig. 2 and Table 1).

The area is composed mainly of various kinds of gneiss, interbedded with basic bands, granite, thinner marble and quartzite. Most of the metamorphic rocks belong to the granulite facies (Banno *et al.*, 1964a and b). Foliations and boundaries between dark and light coloured bands generally strike north-south and dip 30 to 60 degrees eastward, although local fluctuations and gentle folds are observed in some places. Various radiometric studies have dated the rocks at about 4.7 m.y. (U-Pb method; Saito *et al.*, 1961), about 4.7 m.y. (Rb-Sr method; Nichlayson *et al.*, 1961), and 3.99–5.60 m.y. (K-Ar method; Yanai *et al.*, 1974), which means that the last metamorhic event in the charnockitic gneiss, took place in Early Palaeozoic times.

Table 1 Geological structure of the region around Lützow-Holm Bay (After Tatsumi et al., 1964)

Area	Strike and dip (in general)	Bearing and plunge of fold axes
West part of Prince Olav Coast	SW part; N-S∼N50°W, 50°W NE part; N40°W, 60°W	Variable
Ongul Islands	N-S∼N40°W, 35–50°E∼NE	N→S
Langhovde	N10°–60°E, 30–60° E∼NE	SSW→NNE
Skarvsnes	Variable	WSW→ENE, SE→ NW, SW→NE, etc.
Skallen	N60°E∼EW, 20°–40°NW, or S	WNW→ESE
Inner part of Lützow-Holm Bay	N50°W∼EW, 30°–60°N, or S	

Coastal landforms are characterized by conspicuous glaciation, as evidenced by *roches moutonnée* (Photos 1 and 2), giant *roches moutonnée* (Photos 3 and 4), glacial troughs and grooves (Photos 5 and 6), hanging glaciers (Photo 7), cirques and moraines (Photos 8, 9 and 10), and erratic boulders with glacial striae, each of which is found up to 480 m a.s.l. The striations are not well preserved in the northern part of the area, where mechanical weathering dominates (Photos 11 and 12), but they are well preserved on bedrock in the southern part (photos 13, 14 and 15). The directions of the striations and of glacial valleys are mostly southeast to northwest, or east to west. The coastline of Langhovde is serrated, especially in the middle-west area (Photo 16), but is staircase-like to the northwest (Photo 17). Steep cliffs of bedrock, rising abruptly from sea-level at Langhovde, Breidvågnipa, Byvåg Asane, Skarvsnes, and Skallevikhalsen (Photos 18, 19, 20, 21 and 22), suggest the deep fjords that lie beyond. Groups of low rocky islets found around

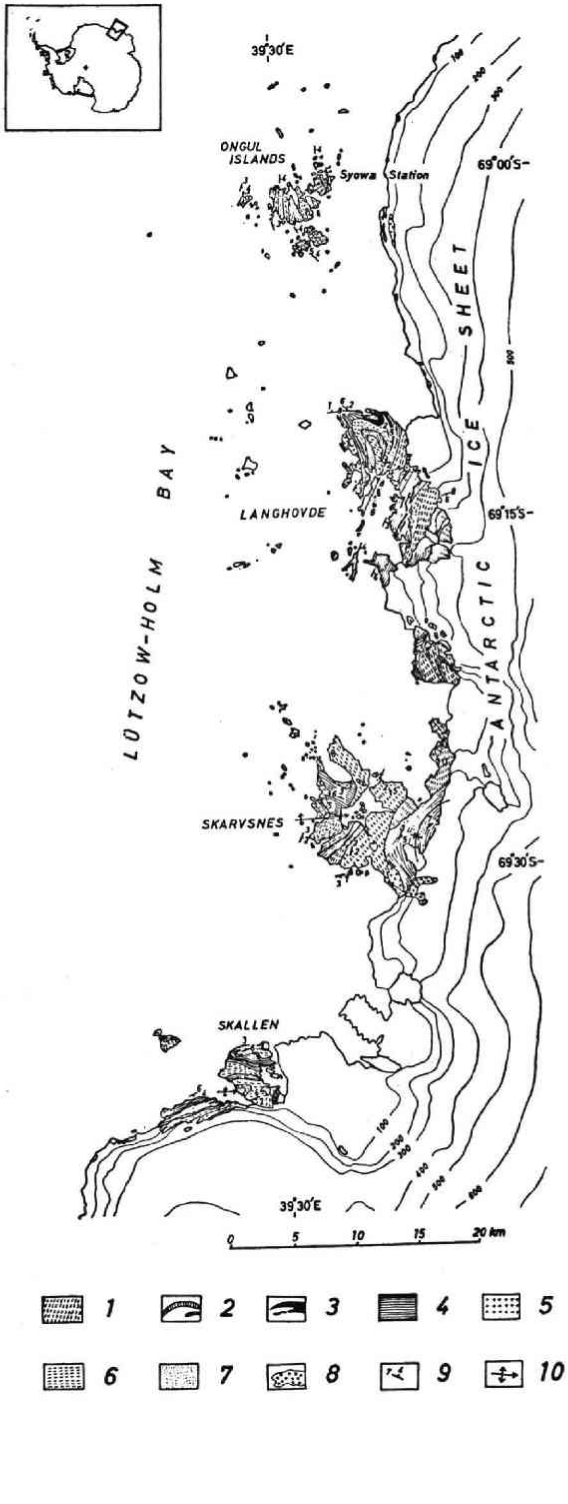


Fig. 2 Geological map of the areas surveyed (Modified from maps in Tatsumi *et al.*, 1964, and Ishikawa *et al.*, 1977)

1: Pyroxene-gneiss with intermediate composition,
2: Marble and Quartzite,
3: Metabasites with ultra-basic and basic composition,
4: Garnet-gneiss with pelitic composition,
5: Granite,
6: Hornblendegneiss,
7: Fossil bearing sand and gravel deposits,
8: Glacial morainic deposits and erratic boulders,
9: Strike and dip at 10 degrees intervals,
10: Anticlinal axis and plunge.

the Ongul Islands, west of Langhovde and Skarvsnes, are of the "Skjaergård landform" type. Raised beaches and step landforms are poorly developed along the sandy inlets of the Ongul Islands, Ongulkalven Island, the Teöya Islands, Langhovde, Skarvsnes, Skallen, Skallevikhalsen, Rundvågshetta, and other ice-free areas (Photos 23, 24, 25, 26, 27, 28, 29a and b, 30, 31, 32, 33, 34 and 35). They have fossil shells in their sediments at several places (Photos 36, 37 and 38). Periglacial phenomena such as patterned ground, cryoturbation steps, rock shattering and gentle slopes remain at several places within the ice-free areas (Photos 39, 40, 41, 42, 43 and 44).

2 Geomorphological Description

2.1. Ice sheet

The surface altitude of the Antarctic ice sheet increases rapidly near the coast and more slowly further inland, reaching 1,500 m a.s.l. 120 km east of Syowa Station (Fig. 3). The ice surface has a steep gradient near the coast, and experiences a catabatic wind all the year round; *i.e.* it is a "marginal slope" (Fujiwara, 1964 and 1971, Fujiwara *et al.*, 1971), consisting of blue ice and/or bare-ice rich in cracks and crevasses up to ca. 500 m a.s.l. The cross or longitudinal profile closely resembles both the hypsographic curve of Antarctic ice (Meinardus, 1926) and the parabolic curve (Bardin *et al.*, 1967).

Subglacial landforms east of Syowa Station were sounded by the present author (Omoto, 1976a). There are two deep subglacial valleys and a deep sumbarine valley, the depths of each exceeding 500 m below mean sea level to the east of Syowa Station. In the eastern part of the Lützow-Holm Bay there are some deep submarine valleys oblique to the coast line (Omoto, 1976c). These subglacial and submarine landforms are of course glacial in origin and are arranged at intervals of ca. 15 km to the east of Syowa Station, which suggests that they may have been controlled originally by the local geological structure of the bedrock.

In some places the ice sheet reaches as far as the salt waters of Lützow-Holm Bay, but elsewhere it ends at ice-free areas and nunataks, or changes into glaciers, such as Langhovde, Hamna (Photo 45), Honnör, Tenpyo, Telen, Skallen, Skallevikhalsen, Rundvågshetta and Shirase.

2.2. Ice-free areas

The field investigations, including levellings of raised beaches and step landforms, were carried out in the austral summer seasons of 1970 and 1974 on the northwest coast of East Ongul Island, the west coast of the Teöya Islands, the north and west coasts of Langhovde, Kizahashihama and its environs at Skarvsnes, the

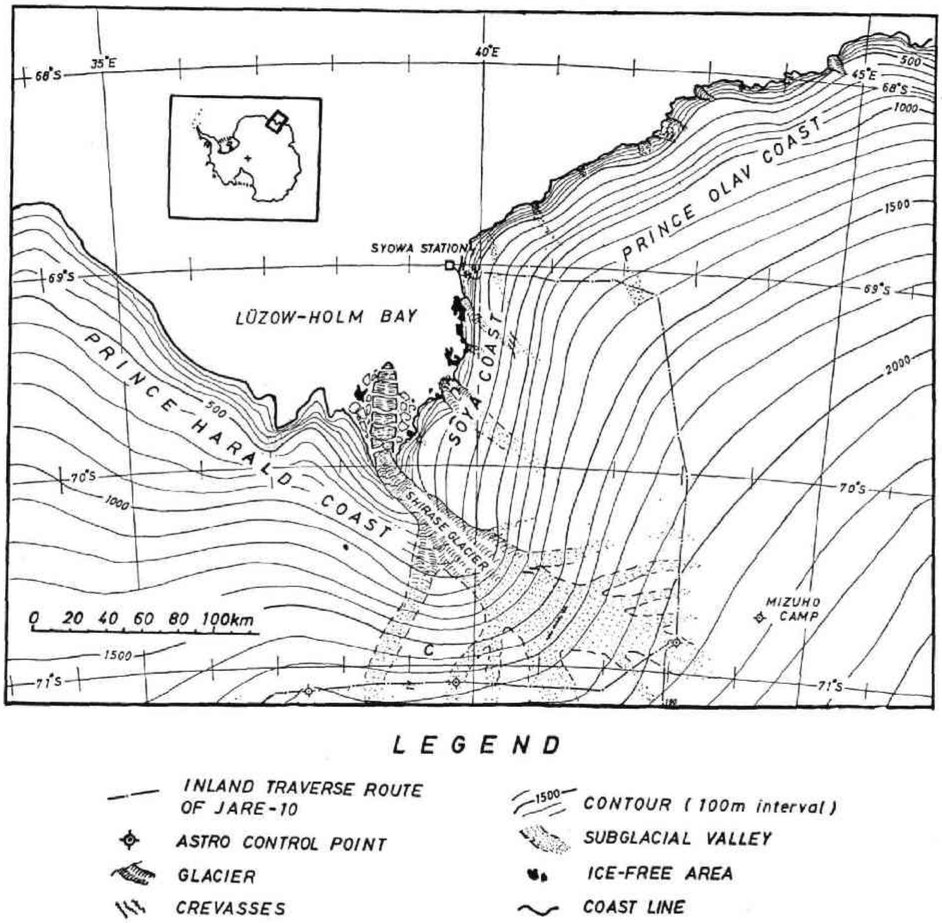


Fig. 3 Ice surface landforms of the Sôya Coast (Contour interval 100 m)

east coast of Skallen and Skallevikhalsen, and on the north coast of Rundvågshetta (Fig. 1). The raised beaches and step landforms together with their hinterlands will now be described in detail.

2.2.1. Ongul Islands

The Ongul Islands consist of East and West Ongul and many small scattered islands. The surface of the islands is undulating in nature, and reaches 20 to 30 m in height. The highest point in the center of West Ongul is 47.7 m a.s.l. The rises, 10 to 20 m in relief, are *roches moutonnée*, and the hollows are mostly filled by sand and gravel, sometimes by erratic boulders with glacial striae, and by melt water in summer. The undulation is very complicated, generally trending nearly east to west, *i.e.* oblique to the direction of the gneiss structure, which is nearly north to south in East Ongul and NNW to SSE in West Ongul, although minor hollows are adapted to lithologic structure. There are few glacial striae on the bedrock surface, since the latter is generally subjected to severe mechanical weathering and especially to exfoliation (Photo 11). Periglacial phenomena are poorly developed on both islands (Photo 39).

Raised beaches and step landforms at several levels up to 20 m in height, found along small inlets on both islands, are nearly flat or slope gently seaward, and sometimes terminate as low cliffs at the seaward end.

The sediments are mostly gravely sand beds, including erratic boulders and decomposed sand and sub-angular gravel produced by exfoliation and fluvial erosion. Molluscan shell fragments, fossil Foraminifera, Ostracoda and echinoid spines are embedded in the sediments. They are contained in a layer of silty sand 0.3 m to 0.6 m thick at Kitamihama. *Adamussium colbecki* and *Laternula elliptica* are relatively well preserved near the surface, but are absent in the lower layers of the sediments. Many fossil *Adamussium colbecki* are scattered at 3 to 4 m a.s.l. at Kainohama. This sediment, which is apparently of marine origin, has yet to be found in small filled hollows on the surface above 20 m a.s.l.

Fujiwara (1973) investigated and summarized the raised beaches at Mizukumizawa near Syowa Station as follows: They are referred to as surface I (14.0–11.5 m a.s.l., the oldest), II (10.0–9.5 m a.s.l.), III (7.0–6.0 m a.s.l.), IV (4.5–3.0 m a.s.l.) and V (below 2m a.s.l.). The author's levelling distinguished the levels of raised beaches and step landforms on the Ongul Islands as shown in Table 2 and Fig. 4.

The author observed flat surfaces on Ongulkalven Island at levels of 18 to 20 m, 24 to 25 m, 27 to 29 m, and 33 to 35 m a.s.l. (Photo 24). Each flat surface is bounded by steep slopes. The thin deposits consist of sand, rounded gravel, and erratic boulders. Flat surfaces lower than 18m a.s.l. resemble the raised beaches or step landforms in the Ongul Islands. The radiocarbon dates for the Ongul Islands are listed in Table 3[1].

2.2.2. Teöya Islands

The Teöya Islands are separated from West Ongul Island to the south by the Minamino-seto Strait, and consist of three main islands. They are characterized by the low relief undulations of *roches moutonnée*, and the gneiss generally strikes N30° to 40°W and dips to the east monoclinally. Raised beaches and step landforms are particularly well developed on the various "pocket beaches" as summarized in Table 2 and Fig. 5. Flat surfaces between 6.9 and 10.0 m a.s.l.

1) Radiocarbon dates with asterisks are based on a personal communication from Dr. Nogami.

Table 2 Raised beaches and steps in the eastern part of Lützow-Holm Bay, East Antarctica (height in meters above sea-level)

Ongul Is.	Teöya Is.	Langhovde	Skarvsnes	Skallen	Skallevikhalsen	Rundvågshetta
—	—	—	36.0-39.0	—	—	—
33.0-35.0*	—	—	33.4-34.0	—	—	—
—	—	—	30.0-30.5	30.9-32.3	—	—
—	—	—	—	29.7-30.2	—	—
—	—	—	28.4-29.0	—	—	—
27.0-29.0*	—	—	—	27.1-28.1	—	—
—	—	26.6-27.4	—	—	—	—
24.0-25.0*	—	—	24.8-25.2	24.3-25.7	23.9	23.0
22.1	—	—	22.0-22.5	22.5-23.4	22.1	—
—	—	21.7-23.5	21.3	—	—	21.3
20.3-21.1	—	—	20.3	20.3-21.1	20.0-21.9	—
18.4-19.4	19.4	18.3-20.7	18.6-19.0	19.1-19.7	—	19.7
17.7	—	—	—	—	—	—
16.3	—	—	16.8	—	—	—
15.5-15.8	15.4	—	15.8	15.5-16.2	15.9-17.6	—
14.5-15.0	—	—	—	—	—	—
14.1	—	—	—	—	—	—
13.6-13.8	—	—	—	13.9-14.7	13.7	—
12.7-13.1	—	—	—	—	—	13.0
12.3-12.4	12.2	12.0-15.2	12.4-14.0	—	—	—
11.8-12.0	—	—	11.1-12.0	11.1-11.7	—	11.3
10.0-11.3	10.7-10.9	10.2-10.8	10.6-10.7	—	10.6-11.1	—
—	10.0	—	—	—	—	—
9.4-9.6	—	—	9.6-10.1	—	9.7-10.0	—
9.1	9.3	—	—	—	—	—
—	8.7	8.6-9.2	8.3-8.8	—	8.1-8.4	—
7.8-8.2	7.8	—	—	7.8-8.8	—	—
7.4-7.5	—	—	—	—	—	—
6.3-6.8	6.9	6.2-7.2	6.1-6.6	6.1-7.3	—	6.5
5.4-5.9	—	—	—	5.5-5.7	5.9	—
—	4.6-4.8	4.6-5.4	—	—	5.3	—
4.3-4.6	4.0-4.3	—	3.9-4.4	4.3-4.8	4.0	4.3
3.4	—	—	—	—	—	—
2.1-2.6	2.0-3.5	2.0-3.6	2.0-2.5	2.0-3.4	2.0	2.0

* Raised beach levelled at Ongulkalven Island.

are subdivided into several small and narrow steps. The raised beaches at 2.0 to 3.5 m, 10.7 to 10.9 m a.s.l. and the highest one are erosional, and others have deposits less than 2 m in thickness, consisting of sand and gravel.

2.2.3. Langhovde

The Langhovde area, located 20 km south of Syowa Station, is bounded to the east by the Langhovde Glacier and ice sheet and to the west by the shoreline, and is 14 km north-south and 8 km east-west in extent. The area is composed mainly of various kinds of gneiss. The geological structure is clearly indicated by the structure of the gneiss. The most characteristic feature of the southern part is a

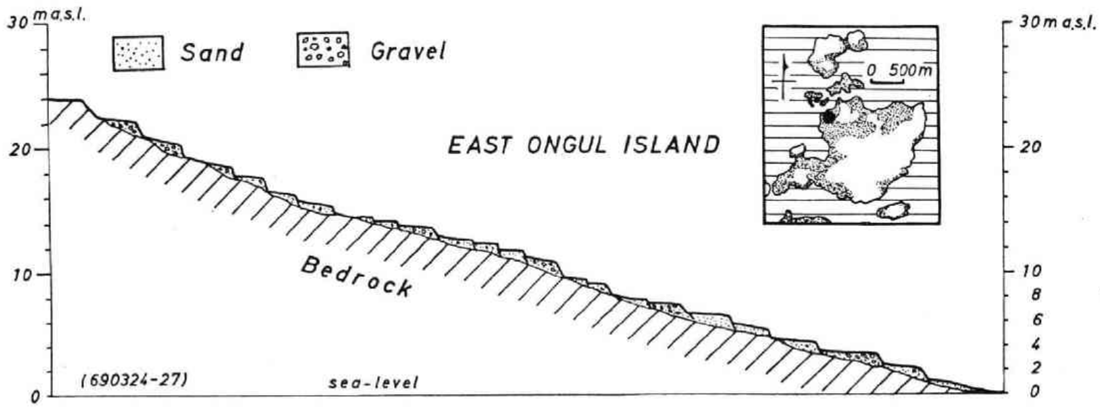


Fig. 4 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in East Ongul Island

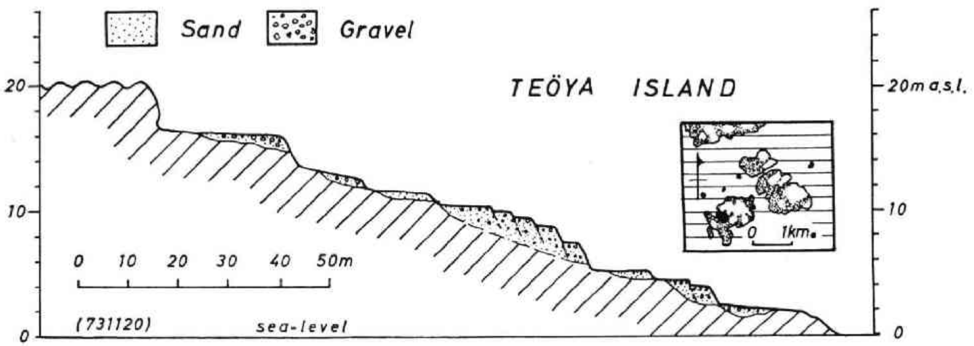


Fig. 5 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Teöya Islands

Table 3 Radiocarbon dates at East Ongul Island and West Ongul Island

Elevation (m a.s.l.)	^{14}C Age (yr BP)	Sample
16	5,850±100	Fragments of Mollusca
12	$34,000^{+3,000}_{-2,000}$	*ibid.*
12	30,700±2,000	*ibid.*
9–10	22,800±1,000	*ibid.*
7–8	$31,200^{+2,500}_{-1,900}$	Tests of Foraminifera
5–6	older than 30,000	*ibid.*
3–4	$29,500^{+2,400}_{-1,900}$	*ibid.*
3.5	25,840±2,450*	*Adamussium colbecki*
3–4	3,840±110	*ibid.*
2.5	older than 31,510*	*Laternula elliptica*
2	2,510±110	*Adamussium colbecki*
2	1,450±110	*ibid.*

Note: Radiocarbon dates with asterisks were sampled from West Orgul Island by Dr. Nogami.

monoclinal structure striking N10°E and dipping to the east. The strike changes to N60°E, however, east of Nakanotani Valley, east of Yukidori Valley and at Mt. Heito.

The landforms of Langhovde are characterized by conspicuous glacial features, and are rich in relief, including giant *roches moutonnée* (Photo 3), troughs (Photo 5), and steep cliffs (Photo 18). A number of troughs, both large and small, have formed along lines of weakness such as joints and faults, suggesting selective erosion by former glaciers. The deep depressions of the glacial troughs are often filled with moraines and by melt water in summer season. A conspicuous glacial trough named Nakanotani Valley, located in the middle of the area, divides the area into two parts. The arrangement of glacial troughs and depressions (subaerial and submarine), which has been discussed by Fujiwara (1971) and by the author (1976c), corresponds to the strike of foliation of the gneisses in the area. The slopes of mountains in the area have been carved into steep-walls by glacial abrasion and plucking. They are steeper on the western side (down-stream or lee-side) and gentler on the eastern side (upstream of ice), and are undoubtedly stoss and lee features. Moraines overlying the area are observed from the lowland up to nearly 500 m a.s.l.

The raised beaches and step landforms that have developed near the present shoreline and in the lowlands around Kominato Inlet, Yatsude Valley, Yukidori Valley, and Lake Oyayubi were investigated by Yoshikawa *et al.* (1957), Tatsumi *et al.* (1959), Moriwaki (1974), and Ishikawa (1976).

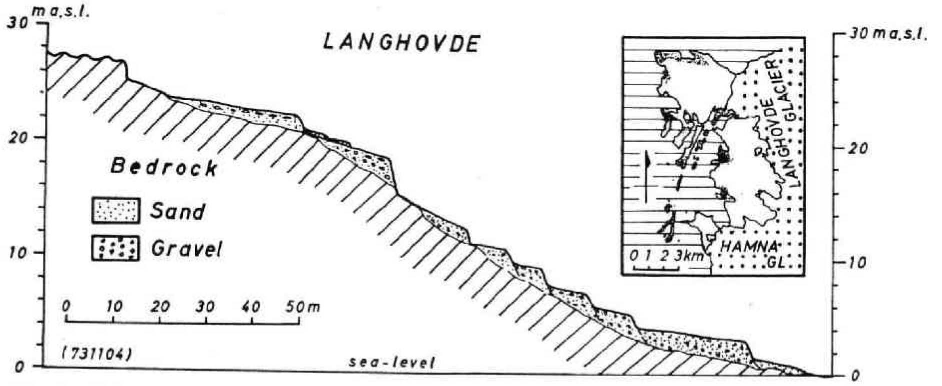


Fig. 6 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Langhovde

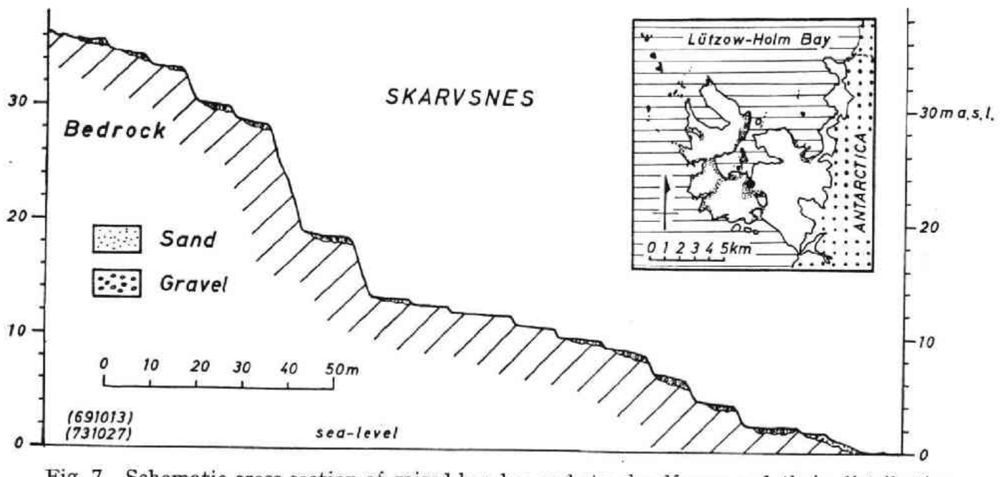


Fig. 7 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Skarvsnes

The author investigated and levelled the raised beaches and step landforms of Kominato Inlet and at the mouth of Yukidori-zawa, as shown in Fig. 6 and Table 2. He distinguished nine flat surfaces of raised beaches composed mainly of morainic sand and gravel. The lowest surface at the mouth of Yukidori-zawa is deltaic in composition, whilst the highest resembles an elevated wave-cut platform, and is almost devoid of deposits.

Fossil shells contained in raised beach deposits, such as *Laternula elliptica* and *Adamussium colbecki*, were sampled and dated (Moriwaki, 1974, Ishikawa, 1976, Omoto, 1976b, and Nogami 1977) as shown in Table 4.

Table 4 Radiocarbon dates at Langhovde

Elevation (m a.s.l.)	^{14}C Age (yr BP)	Sample
6	older than 33,400	*Laternula elliptica*
6	10,250±210	*Adamussium colbecki*
5-6	23,830±910	*Laternula elliptica*
5.5	3,730±220*	*ibid.*
5.1	4,570±120*	*ibid.*
2	2,000±220	unknown
1.5	4,290±90	*Adamussium colbecki*
1.5	3,840±90	*Laternula elliptica*
1.5	3,305±130	*Adamussium colbecki*
1.4	1,030±100*	*Laternula elliptica*
−3.4*	older than 31,700*	*ibid.*
−4.6*	older than 33,200*	*Adamussium colbecki*

Note: Radiocarbon dates with asterisks are based on personal communication from Dr. Nogami. Two samples at -3.4 m and -4.6 m were collected from Zakuro-ike whose present water level is m below present sea-level.

2.2.4. Skarvsnes

The largest ice-free area, Skarvsnes is located 50 km to the south of Syowa Station. It is bounded to the east by the ice sheet and to the west by a shoreline with many indentations. The land surface has a complicated structure, and the shoreline is serrated, with some embayments.

The area is composed of various kinds of gneiss covered with thin morainic deposits. The landforms are characterized by glaciated features, such as the undulating low relief of *roches moutonnée*, giant *roches moutonnée* with rich relief as seen at Skjegget peak (400 m a.s.l.), Mts. Suribachi (258.0 m a.s.l.) and Tenpyo (254 m a.s.l.), and troughs and steep cliffs (Photos 4, 20, 21, 30a and b). Needless to say, the whole area has been glaciated under the control of the local geological structure of the gneiss. Conspicuous depressions containing two saline lakes, Lake Hunazoko (23 m below mean sea-level) and Lake Suribachi (32 m below the mean sea-level), are located in the northwestern and southern parts of Skarvsnes respectively (Photos 46 and 47). Other lakes whose present water levels are below sea-level are found in the Langhovde area. There are other lakes in the hollows of glacial troughs in Skarvsnes, the largest lake touching the ice sheet to the southeast of Sakrvsnes. The shoreline landforms consist of slopes which in many places are steeper than those found in the Ongul Islands, and which are especially steep along the southern face of Skjegget peak (north of Langpollen, Photo 20), east of Osen (Bay), and south of Mt. Tenpyo (Photo 21). These steep slopes once formed U-shaped valleys, but the southern halves of the valleys have been lost completely as a result of subsequent glaciation. As a result there are deep drowned fjords parallel to (and in front of) the steep slopes, as described elsewhere by the author (Omoto, 1976c).

Raised beaches and step landforms are well developed along some of the inlets in Skarvsnes. At Kizahashihama (Photos 29, 30a and b), the author distinguished more than ten steps at 2, 2.5, 4.4, 6.6, 8.8, 10.1, 12.0, 14.0 and 19.0 m a.s.l. as shown in Table 2 and Fig. 7, showing continuous uplift of the area. They consist mainly of thin layers of sand and gravel derived from morainic deposits. Marine silt or clay beds were deposited in some places, however, and in these beds fossil shells *in situ*, *Adamussium colbecki* and *Laternula elliptica* (Photos 36, 37 and 38), were sampled up to 10 m a.s.l. and dated (Table 5). Ice-wedged polygons and stone circles were found at several levels on the raised beaches and in the coastal inter-tidal zone.

Table 5 Radiocarbon dates at Skarvsnes

Elevation (m a.s.l.)	^{14}C Age (yr BP)	Sample
15.5	5,860±170*	*Laternula elliptica*
14	7,450±135	*ibid.*
14	6,020±175	*ibid.*
13.0*	6,630±230*	Serpuloid tubes
12.0	6,700±180*	*Laternula elliptica*
11.7	5,370±160*	*ibid.*
8	$31,600^{+2,800}_{-2,100}$	Fragments of Mollusca
8.0	7,680±250*	Serpuloid tubes
4.7	8,130±200*	*Laternula elliptica*
4.5*	6,180±260*	Serpuloid tubes
2.0*	5,870±210*	*ibid.*
1.8	3,600±100	*Adamussium colbecki*
0.5	3,180±250	*Laternula elliptica*
− 1**	4,830±150	*ibid.*
− 1.4**	3,530±130*	*ibid.*
− 3.8**	3,120±110*	*ibid.*
− 6.0**	2,510±110*	*ibid.*
−10.4**	2,000±120*	*ibid.*
−19.6**	4,540±210*	*ibid.*
−22.8**	3,200±130*	*ibid.*
−23**	4,190±100	*ibid.*
−23**	3,200±130	Fragments of Mollusca
−30*	5,640±130	Serpuloid tubes
−32*	5,230±155	Mummy seal

Note: Radiocarbon dates with asterisks are based on a personal communication from Dr. Nogami. Elevation with an asterisk was collected from Suribachi-ike and elevation with two asterisks was collected at Hunazoko-ike 23 m below from present sea-level.

2.2.5. Skallen

Skallen, about 15 km to the southwest of Skarvsnes, projects 5 km north-south and 3 km east-west into the sea from the ice sheet, has an area of ca. 10 km², and attains a maximum height of 186 m a.s.l. in the southern part. The landforms are characterized by the gently undulating erosional surfaces of *roches moutonnée* (Photo 1). The trend of undulation, with broad ridges and depressions, (the largest depression, located near the middle of Skallen, is occupied by Lake Skallen Ooike), is ENE-WSW to E-W, and has been carved conformably to the general trend of the geological structure, as indicated by folding and by the alternation structures of the gneissic bedrock.

The surface was apparently subjected to glacial scouring, as is shown by well-preserved striations, grooves, and quarried surface with stoss and lee topography (Photos 1, 6 and 14). On the other hand, morainic deposits are distributed only as thin ground moraines, upon which stone stripes and stone circles have developed in some places (Photo 43). Mechanical weathering such as congelifraction can be seen in some places, but the process may not be intense, as is indicated by the degree of preservation of the striated surfaces.

The direction of the former ice flow, as inferred from the directions of glacial striae and grooves, is generally SE-NW, intersecting the general trend of major relief. Two different directions of striation are often seen, however, suggesting a change in the direction of ice flow during the shrinking of the ice sheet.

The western shoreline is rather monotonous in plan, but the eastern shoreline is full of indentations facing the floating ice tongue of Skallen Glacier. Raised beaches and step landforms are well developed along the east coast, but are rarely seen along the west coast. The author investigated them and has summarized them in Fig. 8 and Table 2.

The surfaces at 4.3–4.8, 5.5–5.7, 6.1–7.3, 7.8–8.8, 16.7–18.8, 19.1–19.9 and 20.3–21.1 m a.s.l. are erosional in origin. The surfaces at 2.0–3.4, 3.6, 6.5–7.8 and 14.2 m a.s.l. look very flat. Most of the raised beaches and step landforms consist of thin morainic sand and gravel, including marine silt or clay in some places, *i.e.* to the southeast of Skallen, where dark-green to brown coloured marine silt ca. 5 m thick was observed. There is a small moss community on the 16.7–18.8 m surface, and stone circles on the surfaces above 27.1 m a.s.l.

2.2.6. Skallevikhalsen

Skallevikhalsen is separated from Skallen to the east by the narrow but deep Skallevika, the depth of which exceeds 300 m below mean sea-level (Omoto, 1976c), and ends at the snout of a small receded outlet glacier. The area, 7 km east-west and 2 km north-south, with a maximum height of nearly 300 m a.s.l., is bounded to the south by the ice sheet (Photo 22).

Staircase landforms predominate with precipitous slopes and flat surfaces conformable with geological structure. Cirque landforms have developed on the northwest coast, in the middle part, and on the east coast of Skallevikhalsen.

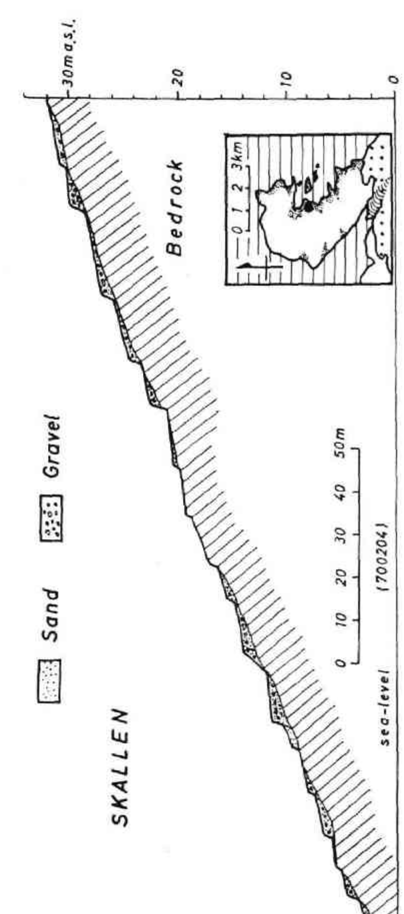


Fig. 8 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Skallen

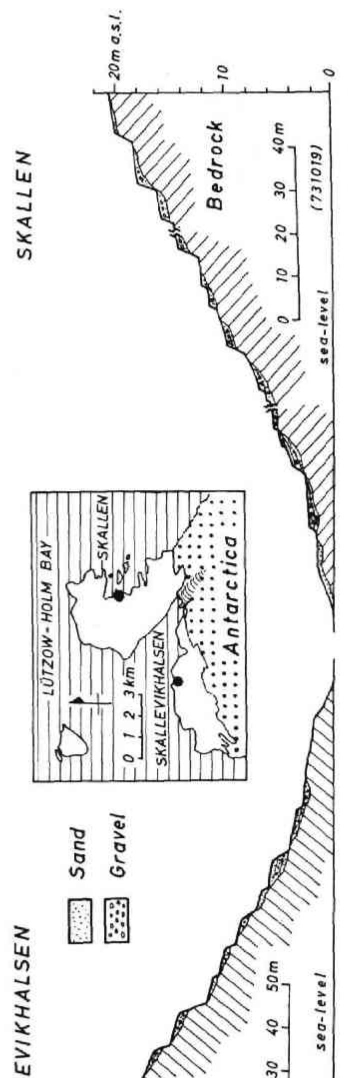


Fig. 9 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Skallevikhalsen

The directions of glacial striae are the same as those in Skallen, and intersect the general trend of the landforms. The glacial deposits consist of thin ground moraines, resting in shallow depressions or on the leesides of hillocks.

Raised beaches and step landforms have developed on the northern and western coasts of the area, where marine sediments containing fragments of molluscan shells are distributed. They have not yet been dated. The results of levelling by the present author are shown in Fig. 9 and Table 2.

2.2.7. Rundvågshetta

Rundvågshetta located to the west of Havsbotn, the innermost part of Lützow-Holm Bay and about 25 km to the southwest of Skallevikhalsen, is bounded on the east by Rundvåghsetta Glacier, on the south by the ice sheet, and on the west by a shoreline with many indentations. Its landforms are characterized by the gently undulating erosional surface of *roches moutonnée* (Photo 2). The trend of the broad undulating ridges and depressions is ESE-WNW, and is conformable to the general trend of the geological structure, as indicated by folding and the alternation structures of the gneiss.

The surfaces have apparently been subjected to glacial scouring, as is shown by well-preserved striations, grooves, and quarried surfaces with toss and lee topography (Photos 2, 15 and 35). On the other hand, morainic deposits are distributed only as thin ground moraines, on which stone stripes, stone circles, and rock shatterings have developed in some shallow glacial troughs (Photos 15 and 44). Another shear moraine is observed on the recessional ice sheet (Photo 10).

The northern shoreline is rather monotonous in plan, but the western shoreline is full of indentations. Raised beaches and step landforms are poorly developed in this area, though there are wide flat erosional surfaces consisting of elevated wave-cut platforms in the northern part. The author levelled the raised beaches on the northeast coast, as shown in Fig. 10 and Table 2. The lower surfaces at 2.0–

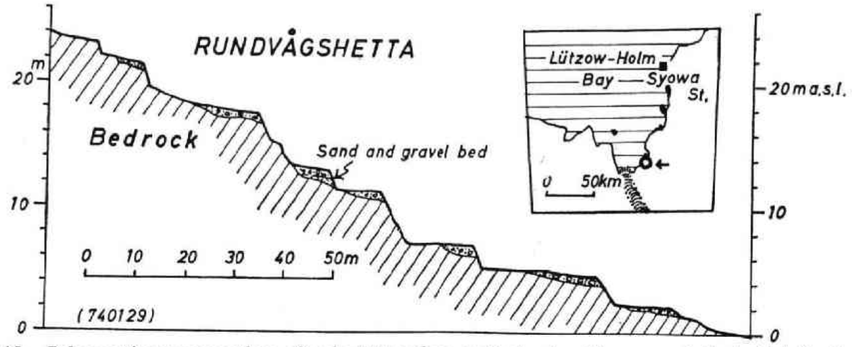


Fig. 10 Schematic cross section of raised beaches and step landforms and their distribution (dots on inset map) in Rundvågshetta

2.5 and 4.3–5.0 m a.s.l. consist of sand and gravel, and marine silt beds, and a beach ridge runs parallel to the present shoreline. The raised beaches between 13 m to 22 m a.s.l. resemble elevated marine-boulder pavement. Three raised beaches at 6.5–7, 11.3–12 and 23–24 m a.s.l. are erosional in origin.

2.2.8. Other areas

Yoshida (1970) described raised beaches or elevated marine boulder pavements at 8, 20–23, 26 and 30–34 m a.s.l. on Hinode Point, and marine boulder pavements or pitted beaches with subround to sub-angular gravel at 10, 15 and 29–31 m a.s.l. on Shinnaniwa.

2.3. Submarine landforms

Murauchi (1960) noticed a deep channel on the continental shelf between Ongul Island and the continent. Fujiwara (1971), who sounded the depth of the channel, found that it exceeds 600 m below mean sea-level, and its northern extension was traced by Moriwaki (1975). Other deep troughs were detected from poor sounding data in front of Shirase Glacier (Murauchi, 1960 and Yoshida *et al.*, 1964), and Honnör Glacier (Fujiwara, 1971). The outline of the submarine landforms in inner Lützow-Holm Bay had remained obscure, however.

An echo-sounding traverse east of Lützow-Holm Bay undertaken in 1973 revealed three deep submarine valleys; Telen, Skjegget and Honnör (Omoto, 1976c). They cut deeply into the metamorphic rock, and have undulating long-profiles, steep U-shaped cross-profiles and the deepest points

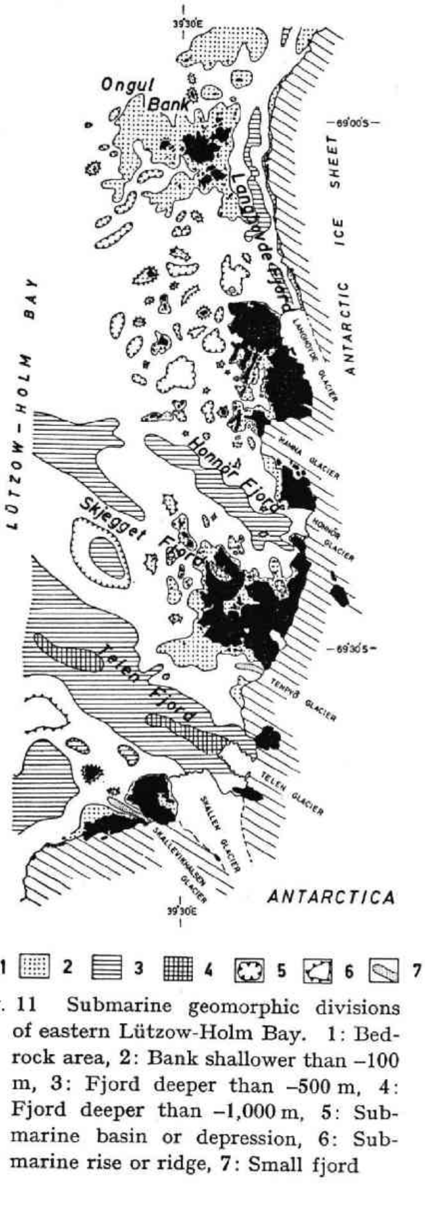


Fig. 11 Submarine geomorphic divisions of eastern Lützow-Holm Bay. 1: Bedrock area, 2: Bank shallower than –100 m, 3: Fjord deeper than –500 m, 4: Fjord deeper than –1,000 m, 5: Submarine basin or depression, 6: Submarine rise or ridge, 7: Small fjord

midway. They extends eaward from the floating ice tongues of marginal glaciers. Steep cliffs to the south have been lost due to severe glaciation. All of this morphological evidence indicates that the deep submarine valleys are drowned fjords. The submarine landforms are summarized as shown in Fig. 11.

3 Discussion

3.1. The ice sheet

3.1.1. Expansion and maximum thickness of the ice sheet

Glacial deposits and striations traced up to 180 m a.s.l. or more in Skallen, 350 m in Skarvsnes, and 500 m in south Langhovde, prove that the ice sheet or glaciers covered the present ice-free areas at least once. The ice-free landforms have been severely modified by the oscillating ice sheet. Koaze (1964) thought that the ice sheet had expanded 20 km westward near Syowa Station, and that its thickness was at least 400 m, and Fujiwara (1971) concluded that the ice sheet had expanded at least 20 km off the coast.

Deep submarine valleys and basins (drowned fjords and cirques) sounded by the author (1976c) also prove that the advancing ice scooped deeply into the sea bottom. The maximum extension of the ice sheet was calculated based on its maximum thickness. Assuming the same depth of submarine fjords and long and cross-profile of the ice sheet similar to the present one, the ice sheet must have extended 75 km westward, filling the whole of Lützow-Holm Bay (Fig. 12). This range is somewhat shorter than those suggested by Hollin (1962)[2] and Cameron (1964 and 1965)[3].

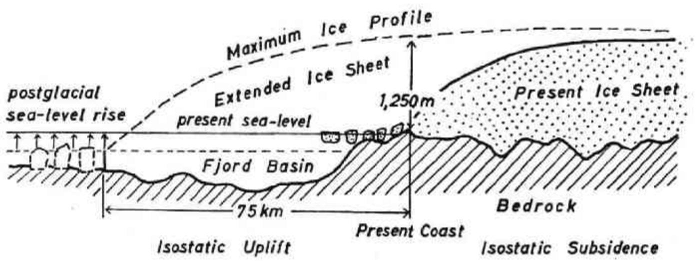


Fig. 12 Estimated extension and thickness of the ice sheet at the time of maximum glaciation in the survey area

2) Hollin considered that the "grounding line" (the line where the ice shelf begins to float) shifted 90 km seaward on a sea-floor of about 0.1 degrees declivity as a result of a drop in sea-level of 150 m during the last glaciation in the Northern Hemisphere, and that the ice thickness at the original grounding line increased by 1,230 m.

3) Cameron estimated that the ice terminus was about 85 km north of the present ice terminus of Vanderford Glacier during the maximum glaciation of the Antarctic continent and ice attained a thickness of 3,194 m over Vanderford valley.

The maximum thickness of glacier ice is calculated to have been about 1,050 m at submarine Telen Fjord judging from its depth and assuming a drop of 100 m in sea-level. Judging from the subaerial and submarine landforms, the maximum ice thickness reached at least 1,250 m at the location of the present coast line, including the part above sea-level.

3.1.2. Date of retreat of the ice sheet

The continental ice retreated from the Ongul Islands before the formation of the 20 m high raised beach, because it has not undergone glaciation by continental ice (Yoshikawa *et al.*, 1957). Meguro *et al.* (1964) have reported a discordance between landforms and radiocarbon dates of molluscan shells and Foraminifera.

Since sediments and raised beach features have not been subjected to glaciation by inland ice, it follows that the retreat of continental ice from the Ongul Islands occurred 23,000 yr BP at the latest, but not earlier than 50,000 yr BP. The radiocarbon dates should be corrected as discussed later, but judging from the evidence presented above the retreat might have taken place 30,000 yr BP at the latest.

3.2. Glaciation

The glaciers deeply eroded such weak zones as fractures, joints and soft rocks, resulting in the formation of fjords such as Langhovde, Honnör, Skjegget and Telen Fjords, as well as many submerged cirques and/or basins, while the resistant areas of hard rock remained as the *roches moutonnée* landforms that form Langhovde and Skarvsnes, and as ridges. Pre-glacial fluvial valleys or depressions may have facilitated the ice advance at first.

Glacial valleys, grooves, and striae in bare rock areas indicate that the main direction of flow of past glaciers was SE to NW. Such submarine relief features as fjords, troughs, cirques and ridges are arranged mainly SE to NW, SSE to NNW or E to W in direction (Fig. 11). The NE-SW arrangement of submarine valleys and submerged cirques and/or basins is perhaps due to individual movements of isolated ice masses. In many cases, subaerial glacial valleys continue into submarine glacial valleys, which means that both were scooped out by a glacier almost at the same time.

Though Honnör, Skjegget and Telen Fjords are oblique to the margin of the ice sheet, Langhovee Fjord runs nearly parallel to the margin of the ice sheet, and changes its direction from. NNW to N and NNE. Another submarine valley extending northward near Tottuki Point (Moriwaki, 1975) may be the extension of the subglacial valley detected by the author (Omoto, 1976a). Other deep fjords have their origins inland, but their origins are uncertain because subglacial landforms remain unclarified.

The surface velocities of the ice sheet and of glaciers have been measured either by triangulation or by air photo interpretaton in several places (Tatsumi *et al.*, 1959, Nakano *et al.*, 1962, Ageta *et al.*, 1971, Fujiwara *et al.*, 1972 and Moriwaki, 1977), as shown in Table 6. The values are very small except for Shirase Glacier in comparison with the speed of ice flow presented by Mellor (1959).

Table 6 Surface velocities of ice sheet (*) and glaciers on the Sôya Coast

Area or Glacier	Velocity (m/yr)	Measured by
Near Mukai-iwa*	10.0–3.2	Fujiwara and Yoshida
Langhovde Glacier	ca. 172	*ibid.*
Hamna Glacier	5.4–2.6	*ibid.*
Shirase Glacier	ca. 1,800	*ibid.*
Skallen*	ca. 4	Ageta and Naruse
Hinode Point*	4.5–2.0	Moriwaki and Omoto

3.3. A comment on the validity of radiocarbon dates

Many geomorphologists may believe radiocarbon dates to be absolute ones, but we must approach both the actual values and the meaning of radiocarbon dates with care. In most laboratories the error of measurement is expressed as $\pm 1\sigma$ of statistical error based on the counting rate of the sample. The probability of the counting rate included in $\pm 1\sigma$ is 68.75%. The author selected some radiocarbon dates from earlier reports, and calculated the error included in $\pm 3\sigma$ (Most of these earlier measurements were taken from Gakushuin University reports). The results are shown in Table 7. All samples show an infinite age at the upper limit, whilst the lower limits have been shortened. It is impossible, therefore, to

Table 7 Some radiocarbon dates in the survey areas. Calculations based on a statistical error of the sample

^{14}C Age (1)	$34,000^{+3,000}_{-2,000}$	$31,600^{+2,800}_{-2,100}$	$31,200^{+2,500}_{-1,900}$	30,700±2,000	$29,500^{+2,400}_{-1,800}$
^{14}C Age (2)	$34,000^{+2,960}_{-2,160}$	$31,600^{+2,110}_{-1,670}$	$31,200^{+1,990}_{-1,600}$	$30,700^{+1,860}_{-1,510}$	$29,500^{+1,590}_{-1,330}$
^{14}C Age (3)	28,736 ~ 54,852	27,374 ~ 41,060	27,132 ~ 39,854	26,820 ~ 38,488	26,043 ~ 35,694

^{14}C Age (1) Original data, (2) author's calculation ($\pm 1\sigma$), (3) author's calculation ($\pm 3\sigma$)

Note: Basic data quoted here are based on the values reported by Kigoshi (1973). The present author first calculated the counting rate to one standard deviation, indicating the original radiocarbon date (2), and then calculated the range of error include in $\pm 3\sigma$(3).

discuss the sequence of development of old raised beaches with precision, because radiocarbon dates are only reliable back to 30,000 yr BP.

The following fact should be noted as regards the correction of radiocarbon dates in Antarctica. Living organisms in Antarctica always yield older dates, not modern ones, and the counting rate of modern Antarctic samples[4)] differs from that of 95% NBS oxalic acid which is the modern standard value (Broecker *et al.*, 1961, and Omoto, 1972 and 1976b). This deviation is considered to be a consequence of low ^{14}C concentrations caused by the melting of ancient ice on the margin of the ice sheet (Omoto, 1972). Hence it is necessary to take into account accurate modern values when calculating and correcting radiocarbon dates. It is impossible as yet to determine the modern standard value for the whole of Anatrictica, but it is possible to determine the local modern standard value. The correction of earlier measurements of radiocarbon dates may be achieved simply by reducing the value of the local modern standard. The deviation in radiocarbon dates measured earlier is small in older samples but it cannot be ignored in younger samples. In the former case, some older samples may be overscaled upon recalculation. The maximum deviation pertaining to the Sôya Coast would not be over 3,000 years, judging from the samples newly dated by the author (Omoto, 1972 and 1976b).

It is difficult to remove the error in radiocarbon dating, especially in dating fossil shells, because the density of ^{14}C is variable between places or between sea water and atmosphere, contrary to the principal hypothesis of radiocarbon measurement. Of course one of the largest errors in radiocarbon measurement is attributed to the annual variations of ^{14}C in the atmosphere that occurred during the last glacitation. The present sea water in the survey area is not of modern age (as represented by the 95% NBS oxalic acid standard), and the ancient sea water in which the sampled shells lived also would indicate older values than the appropriate value. Measurements of radiocarbon age, therefore, and especially those for fossil shells, will yield values older than the true age.

It seems to the present author that this error is the result of an incorrect supposition in the principal hypothesis of radiocarbon measurements, *i.e.* the supposition

4) A sample of modern sea water in McMurdo Sound yielded a date of 600 to 1,300 yr BP (Broecker et al., 1961 and Marini et al., 1967). As mentioned above, Antarctic sea water has significantly lower ^{14}C activity than that accepted as the world standard. Radiocarbon dating of marine organisms therefore yields apparent ages older than true ages, e.g. the mummified seals in southern Victoria Land have yielded ages ranging from 615 to 4,600 yr BP, a Lake Bonney Seal dead a few weeks was determined to be 815±100 yr BP, and a seal freshly killed at McMurdo Sound had an apparent age of 1,300 yr BP. Dort (1971) believed that the slightly desiccated seals he studied had been dead only a few years, that the mummified remains with pelts intact or nearly so came from seals that had died 20–30 years earlier, and that no bare skeletal remnants were more than 200 years old. Thus the author expects radiocarbon dates in Antarctica should be interpreted with caution.

of constant radiocarbon activity over time. Judging from the contradiction between radiocarbon dates and the sequence of landform development in Antarctica, it may be best to conclude that radiocarbon activity earlier than 20,000 yr BP actually varied, contrary to the hypothesis of radiocarbon measurements, and thus radiocarbon dates should be corrected to take this into account.

3.4. Glacial isostacy and isostatic upheaval

After studying the rasied beaches on East Ongul Island, Yoshikawa *et al.* (1957), Yoshida (1970 and 1973), and Fujiwara (1973) estimated that the upheaval since the retreat of continental ice has been 20 meters. This estimate is in good agreement with the altitude of the upper limit of marine sediments and terrace-like landforms.

Yoshida (1973) considered that isostatic upheaval did not occur, even if the eustatic sea-level drop brought active movement of ice, because the sea-level drop did not bring about an increase of ice thickness but rather selective ice movement onto the lower bedrock area. Meguro *et al.* (1964) and Uchio (1966) studied Foraminifera samples at 3 m to 12 m a.s.l. on East Ongul Island and concluded that they were originally deposited at a depths exceeding 100 m, and were subsequently uplifted isostatically into a shallow water environment.

Based upon a study of deep drowned fjords, the present author has proposed that the ice once extended 75 km westward from the present coastline of inner Lützow-Holm Bay at the time of maximum glaciation, its maximum thickness being ca. 1,250 m, such that most of the present ice-free areas would have been submerged below the present sea-level, and that isostatic upheaval of 200 m to 250 m (calculated after Fairbridge, 1961) took place after the ice retreat from the area (Omoto, 1976a). If this proposition is accepted then Foraminifera habitation on a sea bottom ca. 100 m deep and isostatic upheaval of 120 m are both easy to believe. Harada (1960) detected positive gravity anomaly off the coast of Lützow-Holm Bay, and a negative anomaly near the coast. This means that isostatic upheaval since the retreat of ice from the Ongul Islands has yet to reach full compensation.

Though the data are insufficient for a discussion of the sea-level at ca. 30,000 yr BP, if it was as high as the present sea-level, then according to Oka (1970) and Flint (1971) the rate of isostatic upheaval at East Ongul Island must have averaged 0.4 mm/yr since the retreat of ice, a rate of isostatic upheaval that seems to be much too slow.

Figs. 13 and 14 show the relationship between altitudes and radiocarbon dates for samples collected from raised beach deposits in the survey area. They suggests that raised beaches and step landforms below 16 m a.s.l. in Skarvanes and East Ongul Island were formed during the last 6,000 years. The fossil shells at 16 m

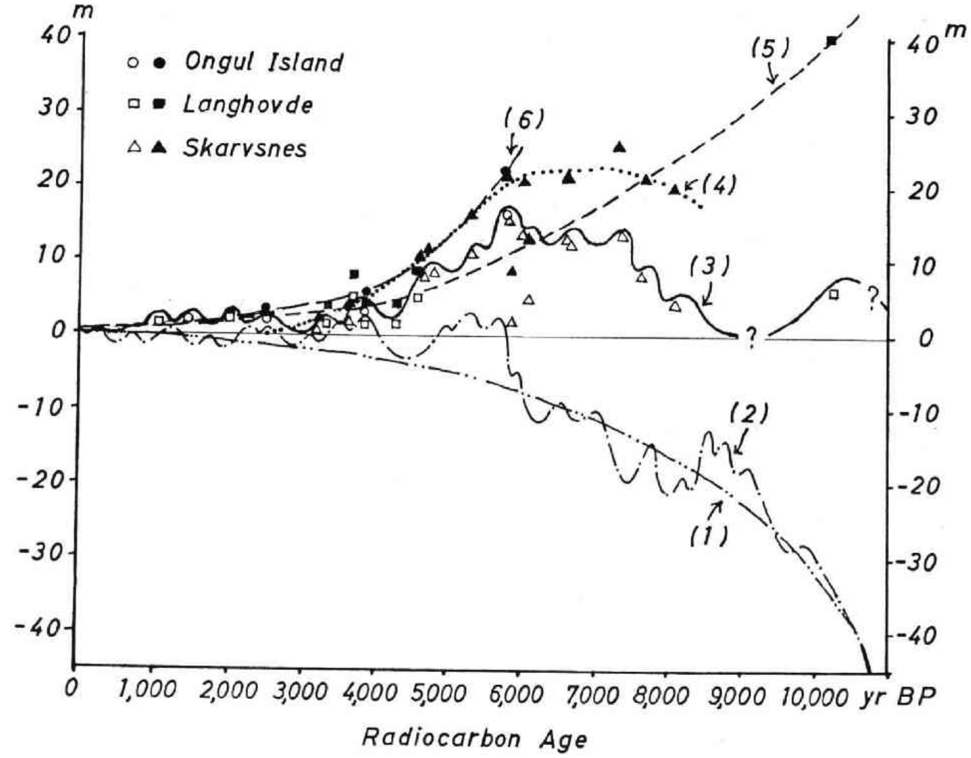


Fig. 13 Interrelation of land and sea-level, and total upheaval since a given point in time in the Lützow-Holm Bay Area. Radiocarbon dates of shells relative to altitude are shown by white symbols, and altitude corrections for eustatic rise of sea-level of Shepard (1963) are shown by black symbols. Curves are as follows:

(1) Eustatic sea-level changes, Shepard (1963),
(2) Eustatic sea-level changes, Fairbridge (1961),
(3) Eustatic sea-level changes relative to present sea-level in the Lützow-Holm Bay area,
(4) Total upheaval since a given point in time in Skarvsnes,
(5) Total upheaval since a given point in time in Langhovde,
(6) Total upheaval since a given point in time in the Ongul Islands.

Note: Curves (4), (5) and (6) are based on curve (1). i.e. Altitude corrections were made by accumulating a value that was calculated by decreasing the height between the Shepard curve and present sea-level to the altitude of the sampling site. Radiocarbon dates for Hunazoko-ike and Zakuro-ike are excluded.

a.s.l. were uplifted isostatically following the retreat of the ice sheet, and their ages coincide with the date of the high sea-levels around the Japanese Islands (Iseki, 1957 and Fujii *et al.* 1967). As the sea-level at that time did not exceed 16 m above present sea-level even in Japan, where tectonic uplift has been recorded, it is very likely that upheaval occurred in the survey areas.

There are two theories concerning eustatic sea-level changes in the postglacial

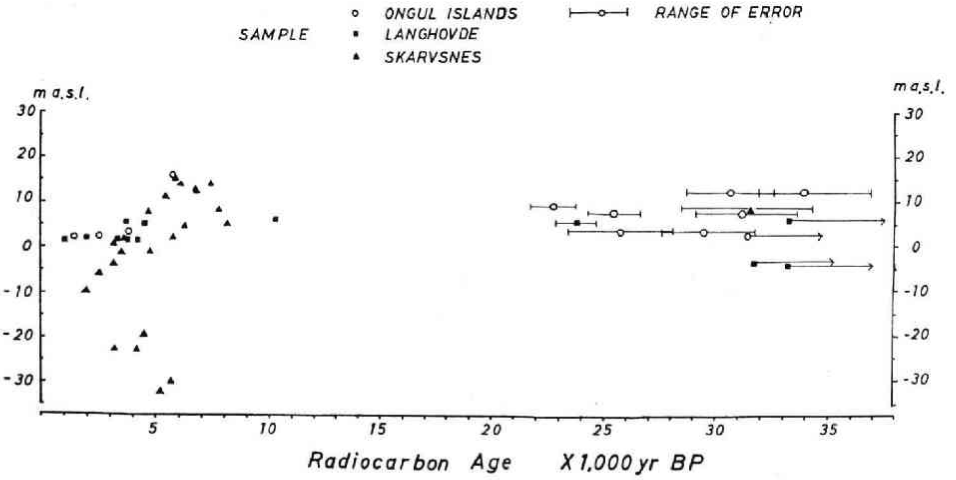


Fig. 14 Relationship between altitudes and radiocarbon dates for samples collected in the survey areas

period, especially in the Holocene; the smooth curve suggested by Shepard (1963), and the fluctuating curve suggested by Fairbridge (1961). Fig. 13 shows that the amounts of relative upheaval above sea-level since 6,000 yr BP predicted on the basis of the two curves are 24 m and 22 m in Skarvsnes, as indicated by curve (4). The altitudes of the samples shown by white symbols in Fig. 13 indicate the lower limit of eustatic sea-level changes in the survey area, disregarding any upheaval, whilst curves (4), (5) and (6) indicate the relative upheaval that has taken place since 8,000 yr BP in Skarvsnes, 10,250 yr BP in Langhovde and 6,000 yr BP in the Ongul Islands respectively. It is obvious from the figure that isostatic upheaval was represed or occurred at the the same speed as sea-level rises in Skarvsnes up to 5,500 yr BP or 6,000 yr BP, and that upheaval subsequently exceeded rises in sea-level. Isostatic upheaval in East Ongul Island and Langhovde ceased between 1,000 yr BP and the present, whilst in Skarvsnes it ceased ca. 2,000 yr BP. The author has calculated the rate of isostatic upheaval in the survey areas, as shown in Table 8.

The estimated rate of upheaval in the survey areas based on the present sea-level, varies between 0.2 mm/yr and 2.7 mm/yr but calculations based on the Shepard cruve yield a rate of relative upheaval nearly 4 mm/yr. The rates of upheaval in Langhovde range between 0.2 mm/yr and 4.0 mm/yr, which exceeds the speed of postglacial sea-level rise since 10,000 yr BP. In Skarvsnes, upheaval seems to have been surpressed since the time of the lowest sea-level during the last glaciation in the Northern Hemisphere, but the area began to emerge after 8,000 yr BP. During the first 2,000 years, however, the rate of upheaval was nearly

Table 8 Estimated rates of isostatic upheaval of ice-free areas, East Lützow-Holm Bay

Ice-free Area	Rate of Upheaval (mm/yr)			Radiocarbon date
	(1)	(2)	(3)	
Ongul Islands	2.7 0.4	3.8	2.7	5,850 yr BP 30,700 yr BP
Langhovde	0.6 0.2	4.0	4.0	10,250 yr BP 33,400 yr BP
Skarvsnes	2.6 0.3	3.8	3.7	5,860 yr BP 31,600 yr BP

Note: (1) Relative isostatic upheaval for present sea-level
(2) Relative isostatic upheaval for Shepard curve (1963)
(3) Relative isostatic upheaval for Fairbridge curve (1961)

the same as that of the postglacial sea-level rise, but it soon exceeded the speed of the latter after 6,000 yr BP, and formed the 16 m high raised beach. In the Ongul Islands, the rate of upheaval before 6,000 yr BP is still not well known, but it resembles those calculated for Skarvsnes between 6,000 yr BP and 4,000 yr BP, and in Langhovde after 4,000 yr BP. We may conclud that the rate of upheaval in Langhovde was either equal to or slightly greater rate of sea-level rise. In the author's opinion the differneces in the rates of upheaval between places are due to the differences both in the time of ice sheet retreat and in the crustal response.

Radiocarbon dates for the samples from Zakuro-ike suggest that it was separated from sea 31,700 yr BP at the latest as a result of isostatic upheaval in the area. Hunazoko-ike was also separated from the sea 2,510 yr BP, at which time it is assumed that the sea-level was less than 2.2 m above present sea-level *i.e.* the height of a col between the lake and sea. It is estimated that the water level in Hunazoko-ike fell at a rate of 0.7 mm/yr, based on the present lake level (–27 m), four radiocarbon dates (GaK–6379, 6380, 6383 and 6384 in Table 5) and the altitudes of sampling sites.

According to Yoshida (1970 and 1973), the large scale retreat of the ice sheet occurred 30,000 yr BP at the latest, and the ice-free areas were submerged once at least. It is uncertain whether the sea-level then was at about the present sea-level or not. Yoshida had no data between 20,000 yr BP and 6,000 yr BP. He considered that the areas had been submerged again during the postglacial sea-level rise and that the ice-free areas were uplifted iostatically accompanying a eustatic drop in sea-level.

Moriwaki (1974) confirmed the existence of high sea-levels at about 4,000, 10,000, 24,000 and 30,000 yr BP or earlier, corresponding roughly to the warmer substages suggested by ice core analysis at Bryd Station (Epstein *et al.*, 1971). The levels of 30,000 yr BP and 4,000 yr BP seem to support the argument for eustatic changes of sea-level. The high stand of sea-level at 10,000 yr BP, however, appears somewhat early in comparison with the worldwide postglacial rise of sea-level.

Two groups of fossil shells found at the same altitude in Skarvsnes and East Ongul Island are of different ages (Fig. 14). This suggests that the sea-level dropped after the deposition of the older shells, and that the younger sheells were deposited after the sea subsequently rose to approximately its former level. It is also possible that the older shells were re-deposited from somewhere else in the sea in which the younger shells lived. Fujiwara (1973) pointed out the latter possibility Mizukumi-zawa in East Ongul Island. In many places both older and younger fossil shells coexist *in situ* (Fig. 14), *i.e.* they lived at different times in seas that were at a similar sea-level, and no crustal movements occurred between the life time of the older fossil shells and that of the younger. Not all samples with similar radiocarbon dates are located at similar altitudes, *e.g.* the samples at Skarvsnes, where *Laternula elliptica* and serpuloid tubes have similar radiocarbon ages at different altitudes, due perhaps to differences in the depth of their habitats.

The lack of marine sediments measured between 24,000 yr BP and 10,000 yr BP (Fig. 14) is an interesting fact, for which several possible explanations exist, as follows: (1) The sea-level was below the present sea-level between 24,000 yr BP and 10,000 yr BP, and hence marine sediments cannot be found above the present sea-level. (2) Marine molluscan shells that lived between 24,000 yr BP and 10,000 yr BP have subsequently been eroded away completely by marine agents. (3) The local environment was too bad for molluscan shells to live between 24,000 yr BP and 10,000 yr BP. The most reasonable and practical explanation is (1), because the sea-level drop of 110 m to 140 m below the present sea-level is believed to have occurred during the last glaciation in the Northern Hemisphere. Explanation (2) is only tenable if we assume supposition that during the postglacial sea-level rise marine sediments, including marine molluscan shells, were eroded away. Explanation (3) can be deduced from explanation (1).

Six phases of sea-level changes, both transgressions and regressions, are distinguished by radiocarbon dates at 29,500–34,000 yr BP, 22,800–25,400 yr BP, ca. 10,250 yr BP, ca. 5,850 yr BP, 4,290–4,700 yr BP and 3,180–3,840 yr BP. The altitudes of step landforms and raised beaches along the east coast of Lützow-Holm Bay are accordant with the heights calculated from the mean rate of upheaval (2.1 mm/yr) at East Ongul Island and the dates of sea-level oscillations given by Fairbridge (1961), as shown in Fig. 15. The step landforms and raised beaches undoubtedly indicate the periodicity of land upheaval and/or of sea-level oscillation.

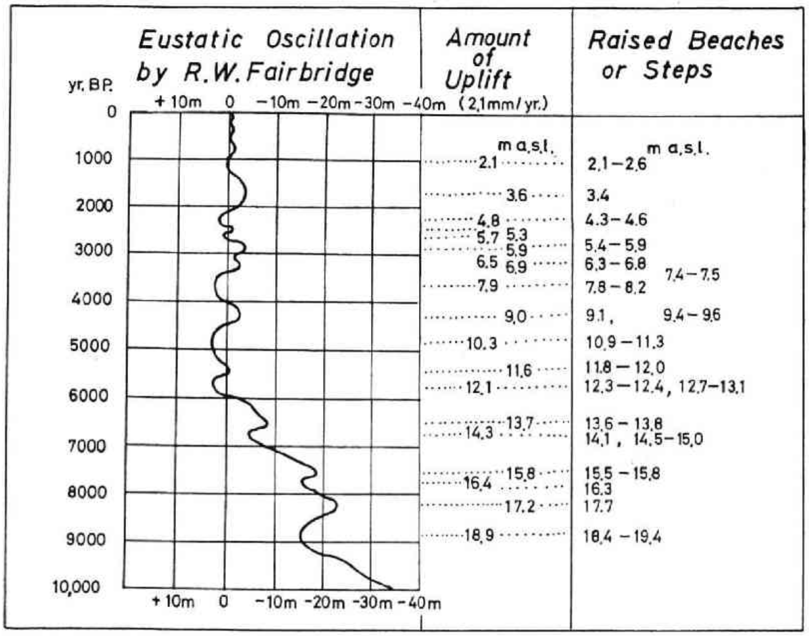


Fig. 15 Correlation of raised beaches with eustatic oscillations

3.5. Geomorphic development

3.5.1. Emergence of the Ongul Islands

The survey areas were overlain by continental ice about 1,000 m thick which extended 75 km beyond the present coastline. Dominant ice streams scooped deep into fjords and glaciated valleys, or eroded low relief landforms such as *roches moutonnée*. Ice streams flowed mainly southeast to northwest or south to north.

The raised beaches did not suffer inland ice erosion, *i.e.* the inland ice retreated before the formation of raised beaches 30,000 yr BP at the latest. Following the retreat of ice sheet, isostatic upheaval started along the margin, but it was retarded for a while by thick ice in such regions as deep drowned fjords and their environs.

The Foraminifera assemblages sampled on East Ongul Island (Uchio *et al.*, 1964) lived on a sea-floor ca. 100 m in depth at least 30,000 yr BP.

West Ongul Island emerged at little earlier than East Ongul Island. Both islands were emerged as a result of intermittent upheavals caused by isostacy and sea-level lowering during the last glaciation in the Northern Hemisphere. At that time these islands and many small adjacent islands formed one large landmass with low relief.

3.5.2. Formation of raised beaches

Many raised beaches and step landforms with low relative heights (below 1 m) developed along inlet coasts and sandy beaches. Most of them consist of fine to coarse morainic materials, and it is impossible to distinguish the developmental sequences from their facies (Fig. 16).

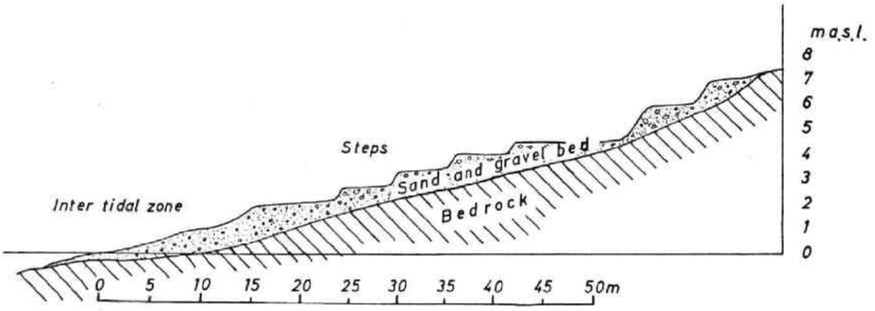


Fig. 16 Geologic cross section of step landforms

The raised beaches in the survey areas have been characterized by Yoshida (1970) as follows; (1) Pitted beach, often observed in Antarctica, is not found except at Shinnaniwa. (2) Raised beaches are protected against erosion by drift snow covering and by icefoot. (3) Wave cut platforms and sea cliffs are rare or indistinct. (4) Marine sediments are morainic in origin and consist of unsorted silt, sand and gravel. (5) Ice-pushed ridges are found at Shinnaniwa. (6) The height of raised beaches is below 20 m a.s.l. along Lützow-Holm Bay and 30 m a.s.l. to the east of Prince Olav Coast. Yoshida (1973) also pointed out that the relative height between raised beaches is too small as compared with eustatic sea-level changes.

Fujiwara investigated the raised beaches of Mizukumi-zawa, near Syowa Station, and concluded that surfaces I (14.0–11.5 m) and V (below 2 m) are of transgressional origin and were formed during the interstadial preceeding the Late Würm and during the postglacial respectively, and that surface II (10.0–9.5 m) is of regressional origin and was formed immediately after the above interstadial. It is impossible to give a definite date for surfaces III (7.0–6.0) and IV (4.5–3.0 m), which are composed of coarse materials, because radiocarbon dates of fossil shells on these surfaces range from 20,000 yr BP to 30,000 yr BP.

Nogami (1977) considered that these step landforms were formed not by wave actions, but by the freeze-thaw cycle of sea water or ground water.

Step landforms are so fresh that they suggest intermittent upheaval or continuous upheaval under oscillating sea-level conditions. A transgression led to the deposition of fossil shells on the flat terrace surface formed by the earlier

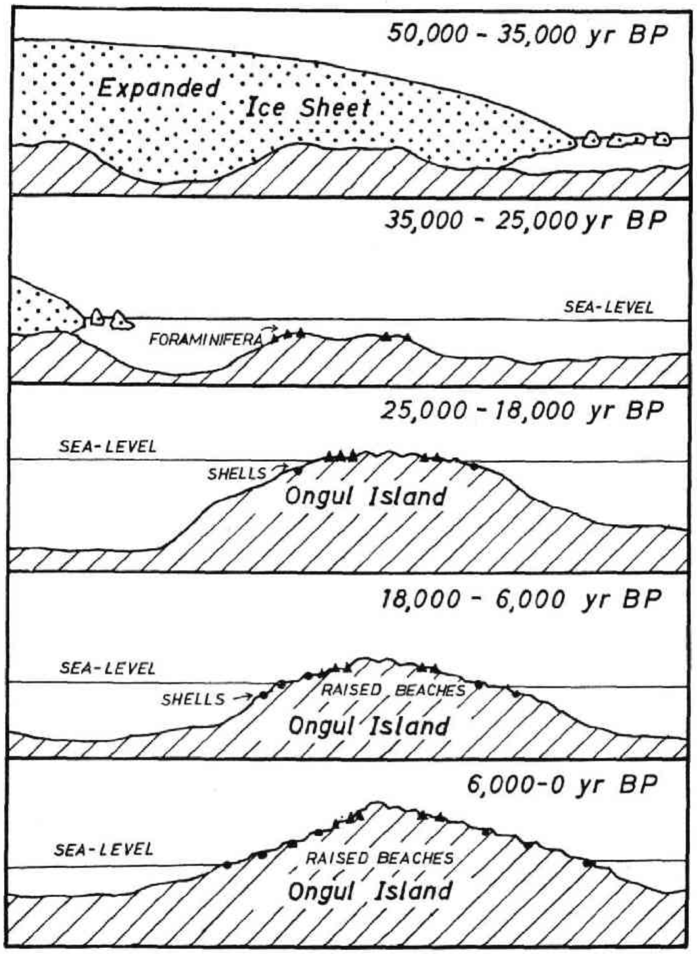


Fig. 17 Schematic development of raised beaches and step landforms in Lützow-Holm Bay

regression, and intermittent regressions (or intermittent upheavals through sea-level fluctuations) formed the steps. In the present author's opinion, the rate of isostatic upheaval along the Sôya Coast either exceeded or blanced the rate of eustatic sealevel rise. The raised beaches and step landforms lower than 16 m a.s.l. were formed 6,000 yr BP in East Ongul Island and Skarvsnes and were uplifted isostatically up to 16 m a.s.l.

Fortunately, the beaches in narrow inlets were protected from wave action and preserved by a covering of snow and ice. The development of landforms in Ongul Island is schematized in Fig. 17.

3.6. Correlation

It is open to question whether or not the surge of the Antarctic ice sheet commenced everywhere at the same time, but fortunately some radiocarbon dates are available for the retreat and/or recession of Antarctic ice. It is difficult to construct correlations of Pleistocene and Holocene landforms and stratigraphy between the various ice-free areas in Antarctica, however, because the details of isostatic subisdence and upheaval and the basic data required for radiocarbon dating, in particular the value of modern carbon standard, have yet to be established. Raised beaches and other landforms have been correlated, therefore, by assuming the reliability of radiocarbon dates reported and the consistency of altitudes or relative heights of the raised beaches.

Péwé (1960) and Bull *et al.* (1962) identified several retreats and expansions of the Antarctic ice sheet correlated with the Interglacials and Glacials in the Northern Hemisphere. The glacier ice retreated 50,000 yr BP from Dry Valley in McMurdo Sound, and no conspicuous ice expansion at a later date has yet recognized (Wilson, 1964). In their discussion of the late Cenozoic glaciation in McMurdo Sound, Denton *et al.* (1970) detected four recessions of the Ross Ice Shelf at 9,490, 6,100, 5,900 and 4,450 yr BP respectively since the Ross Ice Shelf I Glaciation (38,400 yr BP). Calkin *et al.* (1970) reported an advance of Meserve Glacier, an alpine type glacier in Wright Valley, at 12,200 yr BP (Black *et al.*, 1968). These dates, especially those for the last 10,000 yr BP, seem to accord well with the eustatic curve of Fairbridge (1961).

The older dates are full of contradictions, but it is obvious that the ice sheet retreated from the Ongul Islands 30,000 yr BP at the latest. It is possible to correlate the date of the ice sheet retreat from Lützow-Holm Bay with the date of the ice retreat from Dry Valley at McMurdo Sound (Wilson, 1964), although no convincing evidence exist to substantiate it.

The author has correlated and grouped the raised beaches of ice free areas along the Sôya Coast, based on field investigations in their altitudes, sediments and structures (Table 9 and Fig. 18).

Curl *et al.* (1974) measured the raised beaches and residual surfaces (marine or subaerial) on King George Island with considerable precision (Table 10). They are at 2.4–2.6, 3.5–3.8, 4.7, 6.1–6.8, 7.8, 8.6, 11.0, 13.8, 14.7, 16.0, 18.0, 19.7, 24.2 and 32.0–32.7 m a.s.l. and may be correlated with those in Lützow-Holm Bay simply on the basis of their altitudes, since there has been a similar amount of isostatic upheaval (Adie, 1964). Further radiometric datings may enable us to correlate these raised beaches more exactly with those in other regions.

Raised beaches have been recognized at 2, 15, 20, 30 and 45 m a.s.l. on Peterson Island, south of the Grearson Hills on the Budd Coast, and a seal elephant carcass

Table 9 Raised beaches and step lanforms in Lützow-Holm Bay (Grouped).

Group	Altitude (m a.s.l.)
I	2.0—2.7
II	3.4—3.7, 4.0—4.8
III	5.2—6.0, 6.3—6.9, 7.4—7.8, 8.2—8.8
IV	9.1—9.8
V	10.0—10.7
VI	11.1—12.0, 12.2—14.1, 14.4—15.0
VII	15.5—16.5, 17.0—17.7
VIII	18.4—19.7
IX	20.3—21.3
X	22.1—23.7
XI	24.1—26.0
XII	27.2—28.4
XIII	30.0—30.5
XIV	31.2—32.5
XV	33.0—35.0
XVI	Higher than 35

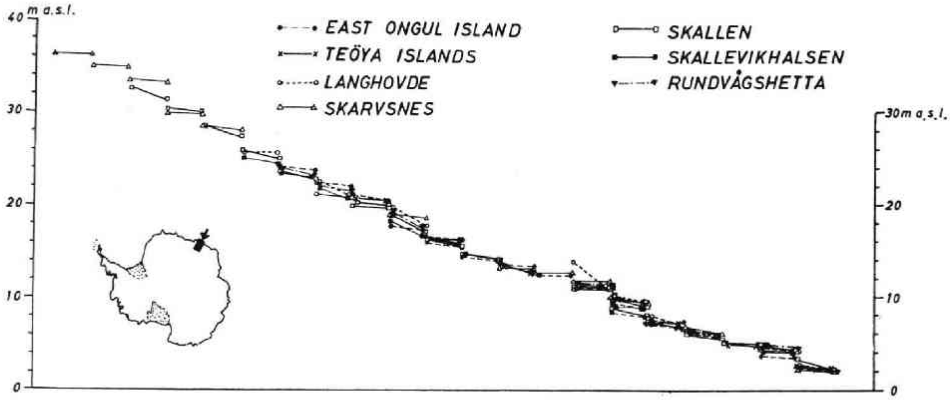


Fig. 18 Schematic projections and correlation of raised beaches and step landforms along the Sôya Coast. *Note*: This figure is drawn by overlapping Figs. 4–10, but horizontal distance of each raised beach and step landform is ignored.

Table 10 Raised beach and residual surfaces at King George Island (After Curl, J.E., 1974)

Location	Raised beach and residual surface (m a.s.l.)
Ardley Island	3.8, 7.8, 16.0 and 32.0
Suffield Point	3.5, 4.7, 8.4, 11.0, 13.8, 14.7 and 16.0
North spit	2.4, 6.8 and 11.0
Barton Peninsula	2.5, 6.1, 11.0, 19.7, 36.0*, 44.9* and 55.0*
Potter core	2.4, 6.7, 8.6, 18.0, 24.2, 46.4*, 55.5* and 98.6*
Plaza Point	2.6, 6.4, 32.7, 41.1*, 51.5*, 72.9* and 150.0*

Note: Asterisk indicates a residual surface.

embedded in the 30 m level deposits was dated 1,800±130 yr BP (Voronov *et al.*, 1962). The 2 m level can easily be correlated with the corresponding beach in Lützow-Holm Bay, but others are difficult to correlate. The accuracy of dates determined for sea elephants and seals in Antarctica is doubtful, as mentioned above.

Raised beaches at 13.5 m a.s.l. at Marble Point in Victoria Land originated 4,600±200 yr BP, and those at 20.4 m a.s.l. 7,000 yr BP (Nichols, 1964). Another date of 5,850 yr BP at 16 m a.s.l. in the northern part of East Ongul Island (Yoshida, 1970) is intermediate in comparison with the dates mentioned above. The organic samples that were dated had lived those after the sea-level drop following the postglacial sea-level rise between 5,000 and 6,000 yr BP.

Prominent terraces and beach ridges have been found at 2, 7, 15, 20, 30, 45, 60, 90 and 120m a.s.l. in various parts of the Grearson Hills (Korotkevich, 1971). The marine origin of levels below 30 m is unquestionable, even though no morphological difference is observed between the levels below and above 30 m, except for the latter's poor roundness of boudlers and pebbles, which can be explained by their having suffering period of weathering, as well as by the galcial removing of unconsolidated marine sediments. Korotkevich concluded that marine levels substantiated by fauna are found at 45 and between 275 m and 305 m on the Antarctic Peninsula, at 5–7, 13.3, 50–100 and 185 m in Victoria Land, at 3–4 and 7–30 m in Lützow-Holm Bay, up to 35–40 m a.sl. in the Vestfold Hills, and up to 30 m in the Grearson Hills.

It has been calculated from radiocarbon dates, that the period required for an upheaval of 13.5 m was calculated 4,600 years in Victoria Land (3 mm/yr), that a 3– 4m upheaval took 3,840 years in Lützow-Holm Bay (1 mm/yr), and that a 30 m upheaval took 1,800 years in the Grearson Hills (17 mm/yr). It is assumed that terraces at several different elevations developed contemporaneously. According to Denton *et al.* (1970), shells from the marine deposits at 59–63 m a.s.l. near McMurdo Sound gave an age of 49,000 yr BP, and shells from the other deposits at 28.5–31.7 m a.s.l. gave contradicting ages: 34,800 yr BP and 47,000 yr BP. It is estimated therefore, that the rate of upheaval was less than 1.3–0.7 mm/yr or 0.9 mm/yr. The postglacial upheaval amounted to over 30 m, and it is possible that the higher coastal benches at 100 m or more are of marine origin. The upheaval totalled 200 m in the survey areas, which agrees with the upheaval in Victoria Land (Dort, 1969).

4 Summary

(1) The recession of ice from the ice-free areas probably started 30,000 yr BP at the latest, considering isostatic recovery and radiocarbon dates, but not earlier

than 50,000 yr BP. An investigation of the deep Telen Fjord suggests that the ice sheet has retreated 75 km inland since the time of maximum glaciation in these areas (Omoto, 1976c).

(2) The ice-free areas are characterized by conspicuously glaciated landforms such as giant *roches moutonnée*, deep U-shaped valleys, troughs and cirques at Langhovde, Breidvågnipa and Skarvsnes, and undulating hilly lands with relatively low relief, consisting of *roches moutonnée* with striae, crescentic gouges, grooves and erratic boulders in other areas.

(3) The coastline is rather simple except in Langhovde, Skarvsnes and in some other ice-free areas, and in ice tongue and glacier areas, such as Shirase, Skallen, Honnör and Langhovde Glaciers. The coastal landforms are "Skjaergård" on the northwest coast of Skarvsnes and around the Ongul Islands, and "Fjärd" on the west coast of Langhovde and Osen (Bay) in Skarvsnes. Nearly vertical cliffs stand abruptly above sea-level and deep drowned fjords are hidden in front to the south of Breidvågnipa, at Skjegget peak, along the eastern inlet of Osen (Bay), on the south of Mt. Tenpyo and to the east of Skallevikhalsen.

(4) Some deep drowned fjords among the ice-free areas exceed 500 m in depth below mean sea-level. Many submarine basins north and west of Langhovde may be interpreted as submerged glaciated cirques. Banks less than 100 m deep were undoubtedly eroded by the advance and retreat of the ice sheet (Omoto, 1976c).

(5) Isostatic upheaval reached at least 120 m in the Ongul Islands after the ice sheet retreat. This is less than is indicated by other data (Omoto, 1976c), but is enough to support earlier studies of Foraminifera (Meguro *et al.*, 1964 and Uchio, 1966). The rates of isostatic upheaval in some ice-free areas have been estimated (Table 8).

(6) Some radiocarbon dates from the Sôya Coast obviously contradict the developmental sequence of raised beaches, due probably to an error associated with radiocarbon dates. It is necessary to reduce the radiocarbon dates by the local modern carbon standard value, but the correction would be less than 3,000 years. The radiocarbon content was uncertain prior to 20,000 yr BP, contrary to the principal assumption of radiocarbon consistency.

(7) The raised beaches and step landforms lower than 20 m a.s.l. were formed by postglacial sea-level fluctuations, if all the radiocarbon dates earlier than 20,000 yr BP are true. Fossil shells were deposited by a transgression on flat terrace surfaces produced by an earlier regression or on bedrock covered with thin morainic deposits, whilst interposed regressions intermittently formed steps in front of beaches. The raised beaches are not easy to correlate with radiocarbon dates, even if the samples are taken from flat terrace surfaces, because of the

possibility of re-deposition, re-exposure, or of contamination.

(8) Geomorphic development (Fig. 17); 50,000–30,000 yr BP: The survey areas were overlain by thick continental ice, especially at East Ongul Island. The continental ice was about 1,000 m in thickness and it extended 75 km beyond the present coastline. The ice sheet retreated from East Ongul Island 30,000 yr BP at the latest.

30,000–18,000 yr BP: Isostatic upheaval occurred soon after the recession of the ice sheet. Foraminifera assemblages that lived on the sea-bottom more than 100 m below sea-level emerged with the isostatic upheaval near East Ongul Island.

18,000–6,000 yr BP: At the time of the lowest sea-level of the last glaciation in the Northern Hemisphere, East and West Ongul Islands had already emerged and did not suffer glacial erosion by the ice sheet. Isostatic upheaval was perhaps repressed, ice strems flowed over the lower bedrock surface, and the ice decreased in thickness at the margin of the ice sheet.

6,000–0 yr BP: The recession of the ice sheet brought isostatic upheaval. The raised beaches formed about 6,000 yr BP were uplifted isostatically up to 16 m a.s.l. in East Ongul Island and Skarvsnes. Continuous isostatic upheaval and several sea-level flucutations after 6,000 yr BP created raised beaches and step landforms. This proves that the rate of isostatic upheaval in the survey areas exceeded the rate of postglacial sea-level rise, especially over the last 6,000 years.

Acknowledgements

I would like to express my deep appreciation to Professor Kasuke Nishimura of Tohoku University, who kindly discussed my work and encouraged me to write this paper. Professor Nishimura also read this manuscript critically, gave many useful suggestions, and kindly corrected my sentences.

I am deeply indebted to the personnel of the 10th and 14th wintering teams of the Japanese Antarctic Research Expeditions of 1969–1970 and 1973–1974, especially Professors Kusunoki and Hirasawa of the Polar Research Institute, the leaders of the 10th and 14th parties, and Dr. M. Kikkawa, Messrs M. Masuda, M. Yagi, M. Yoshida, S. Ota, H. Yabuuma, M. Kajikawa, K. Nakamura and H. Jobashi, who kindly gave me assistance and helped me undertake levellings.

I also wish to express my thanks to Professor Yoshikawa of the University of Tokyo, Professor Yoshida of the Polar Research Institute, and Professor Fujiwara of Hiroshima University, for their useful suggestions on this study and for their encouragement.

Thanks are also extended to Dr. Nogami, a member of the 17th JARE, who kindly gave useful radiocarbon information to me, and to Richard Wiltshire, Lecturer at Tohoku University, who read this manuscript and corrected my sentences.

References (*in Japanese)

Adie, R.J. (1964): *Sea-level changes in the Scotia Arc and Graham Land,* (*in Antarctic Geology*, ed. by R.J. Adie), North-Holland Pub. Co., Amsterdam, 27–32

Ageta, Y. and R. Naruse (1971): Measurements of Ice Flow around Skallen Rock, South of Syowa Station, Antarctica, *Ant. Rec.*, **42** 61–64

Banno, S., T. Tatsumi, H. Kuno, and T. Katsura (1964a): *Mineralogy of granulite facies in the area around Lützow-Holm Bay, Antarctica.* JARE Sci. Rep., Ser. C, **1** 1–12

——, ——, **Y. Ogura and T. Katsura** (1964b): *Petrographic studies on the rocks from the area around Lützow-Holmbukta.* (in *Antarctic Geology*, ed. by R.J. Adie), North-Holland Pub. Co., 405–414

Bardin, V.I. and I.A. Suyetova (1967): *Basic Morphometric Characteristics for Antarctica and Budget of the Antarctic Ice Cover.* JARE Sci. Rep., Special Issue, **1** 92–100

Black, R.F. and C.J. Bowser (1968): Salts and associated phenomena of the termini of the Hobbs and Taylor Glaciers, Victoria Land, Antarctica. Intl. *Union Geod. Geoph., Commit. Snow and Ice. Pub.*, **79** 226–238

Broecker, W.S. and E.A. Olson (1961): Lamont radiocarbon measurements VIII. *Amer. Jour. Sci., Radiocarbon,* **3** 190–200

Bull, C. (1962): Quaternary glaciations in southern Victoria Land, Antarctica. *Jour. Glac.* **4** (32) 240–241

——, **B.C. McKelvey, and P.N. Webb** (1962): Quaternary glaciations in Victoria Land, Antarctica. *Jour. Glac.*, **4** (31) 63–78

Calkin, P.E., R.E. Behling and C. Bull (1970): Glacial History of Wright Valley, Southern Victoria Land, Antarctica. *Ant., Jour. U.S.*, **5** 22–27

Cameron, R.L. (1964): Glaciological Studies at Wilkes Station, Budd Coast, Antarctica. *Ant. Res. Ser.*, **2** 1–36

—— (1965): *The Vanderford Submarine Valley, Vincennes Bay, Antarctica.* (in *Geology and Paleontology of Antarctica* ed. by J.B. Hadley), Amer. Geoph. Union, Washington, D.C., 211–216

Curl, J.E. and N.W. Tenbrink (1974): Glaciology and glacial chronology in the South Shetland Islands. *Ant. Jour. U.S.*, **9** (4) 168–171

Denton, G.H., R.L. Armstrong and M. Stuiver (1970): Late Cenozoic Glaciation in Antarctica: The Record in the McMurdo Sound Region. *Ant. Jour. U.S.*, **5** 15–21

Dort, Jr. W. (1971): Mummified seals of southern Victoria Land. *Ant. Jour. U.S.*, **6** 210–211

—— **and D.S. Dort** (1971): Sodium sulfate deposits in Antarctica. *Modern Geology*, **1** 97–117

Epstein, S., R.P. Sharp and A.J. Gow (1971): Climatological implications of stable isotope variations in deep ice cores, Byrd Station, Antarctica. *Ant. Jour.*, **6** 18–20

Fairbridge, R.W. (1961): Eustatic Changes in Sea-level. (*in Physics and Chemistry of the Earth,* ed. by L.H. Ahrens *et al.*), **4** 99–185

Flint, R.F. (1971): *Glacial and Quaternary Geology.* John Wiley & Sons Inc., New York, 329

Fujii, S. and Fuji, N. (1967): Postglacial sea-level in the Japanese Island. *Jour. Geosci. Osaka City Univ.*, **10** 43–50

Fujiwara, K. (1964): Preliminary Report on the Morphology of the Inland Ice Sheet of the Mizuho Plateau, East Antarctica *Ant. Rec.* **23** 1835–1845

—— (1971): *Outline of Scientific Program and Its Results* (in *Rep. Jap. Trav. Syowa-South Pole.*, ed. by T. Nagata), JARE. Sci. Rep. Special Issue, **2** 23–29

——, **S. Kakinuma, and Y. Yoshida** (1971): *Survey and Some Considerations on the Antarctic Ice Sheet. ibid.*, 30–48

—— (1971): Soundings and Submarine Topography of the Glaciated Continental

Shelf in Lützow-Holm Bay, East Antarctica*. *Ant. Rec.*, **41** 81–103

Fujiwara, K. and Y. Yoshida (1972): Ice Flow Measurements on the East Coast of Lützow-Holm Bay, Antarctica.* *Ant. Rec.* **44** 79–92

——— (1973): The Landforms of Mizukumi Zawa near Syowa Station, East Antarctica*. *Ant. Rec.*, **46** 44–66

Harada, Y. (1960): Japanese geodetic surveys in Antarctica. *Jap. Sci. Mon.*, **13** (4) 4–5

Hollin, J.T. (1962): On the Glacial History of Antarctica. *Jour. Glac.*, **4** 173–195

Iseki, H. (1957): Relative Changes of Sea-level and Late Quaternary Formations in Japan.* *Quat. Res.*, **1** 39–44

Ishikawa, T. (1974): Geology of Langhovde, Lützow-Holm Bay, East Antarctica*. *Ant. Rec.*, **51** 1–17

———, **T. Tatsumi, K. Kizaki, K. Yanai, H. Ando, T. Kikuchi, Y. Yoshida, and Y. Matsumoto** (1976): *Explanatory Text of Geological Map of Langhovde, Antarctica* (Ant. Geol. Map. Ser. Sheet 5, Langhovde). *Natl. Inst. Polar Res.* 12

——— (1977): *Explanatory Text of Geological Map of Padda Island, Antarctica* (Ant. Geol. Map. Ser. Sheet 10, Padda Island). *Natl. Inst. Polar Res.* 4

———, **K. Yanai, Y. Matsumoto, K. Kizaki, S. Kojima, T. Tatsumi, T. Kikuchi and M. Yoshida** (1977): *Explanatory Text of Geological Map of Skarvsnes, Antarctica* (Ant. Geol. Map Ser. Sheet 6 and 7 Skarvsnes). *Natl. Inst. Polar Res.* 12

Kigoshi, K. (1973): *Gakushuin University Radiocarbon Datings.* (in Appendices of The Palaeolithic Site at Douara Cave in Syria, 1973), *Univ. Mus., Univ. Tokyo, Bull,* **5.** 143–144

Kizaki, K. (1962): Structural Geology and Petrology of East Ongul Islands, East Antarctica. *Ant. Rec.*, **14** 1147–1155

Koaze, H. (1964): Geomorphology of the Bare Rock Area in the Neighbourhood of Syowa Station, Antarctica*. *ibid.*, **20** 61–71

Korotkevich, YE. S. (1971): Quaternary Marine Deposits and Terraces. *Sov. Ant. Exp.*, **82** (4) 185–189

Marini, M.A., M.F. Orr, and E.L. Coe (1967): Surviving macromolecules in Antarctic seal mummies. *Ant. Jour. U.S.*, **II** (5) 190–191

Meguro, H., Y. Yoshida, T. Uchio, K. Kigoshi, and K. Sugawara (1964): *Quaternary Marine Sediments and Their Geological Dates with Reference to the Geomorphology of Kronprince Olav Kyst.* (in *Antarctic Geology., ibid.*), 73–80

Meinardus, W. (1929): Die hybpsographischen Kurven Grönlands und der Antarktis und die Normalform der Inlandeisoberfläche. *Petermanns Geogr. Mitt.* 72

Mellor, M. (1959): Ice Flow in Antarctica. *Jour. Glac.*, **3** 377–384

Moriwaki, K. (1974): Radiocarbon Datings of Fossil Shells on Raised Beaches on the East Coast of Lützow-Holm Bay, East Antarctica*. *Ant. Rec.*, **48** 82–90

——— (1975): Submarine Topography near Syowa Station, Antarctica*. *ibid.*, **54** 101–115

——— (1976): Glacio-Geomorphological Observations in and around Ice-Free Areas in the Vicinity of Syowa Station, Antarctica*. *Ant. Rec.* **57** 24–55

Murauchi, S. (1960): *Reports of the Earth Science Division* (The Report of the Third Japanese Antarctic Research Expedition Wintering Team)*. *Ministry of Education,* 42–52

Nakano, T., T. Kaji, and Y. Harada (1960): Some Information on the Glacier and Geology in the vicinity of Ongul Island. *Ant. Rec.*, **10** 32–36

Nichlayson, L.O., A.J. Burger, T. Tatsumi, and L.H. Ahrens (1961): Age Measurements on Pegmatites and a Basic Charnockite Lense Occurring near Lützow-Holm Bay, Antarctica. *Geoph. et Cosmoch. Acta.*, **22** 94–98

Nichols, R.L. (1964): *Present status of Antarctic glaciology* (*in Antarctic Geology, ibid.*), 123–137

Nogami, M. (1977): On the raised beaches along the Prince Olav Coast, East Antarctica*. *Resume of Quat. Res.*, **6** 10

Oka, Y. (1970): Some Considerations on the Sea-level Changes in the Late Pleistocene*. *Geographical Science (Chirikagaku)**, **14** 11–21

Omoto, K. (1972): A Preliminary Report on Modern Carbon Datings at Syowa Station and it's Neighbourhood, East Antarctica. *Ant. Rec.*, **43** 20–24

———, **H. Makita, and Y. Koseki** (1974): Tohoku University Radiocarbon Measurements II. *Sci. Repts. Tohoku Univ. 7th Ser.* (*Geogr.*), **24** 205–209

——— (1976a): Subglacial Geomorphology of Mizuho Plateau and around Yamato Mountains, East Antarctica. *ibid.*, **26** 45–94

——— (1976b): Tohoku University Radiocarbon Measurements III. *ibid.*, **26** 126–150

——— (1976c): Glacio-geomorphic Study on Submarine Morphology East of Lützow-Holm Bay, East Antarctica. *ibid.*, **26** 241–297

———, **T. Nakata, and M. Koba** (1976): Tohoku University Radiocarbon Measurements IV. *ibid.*, **26** 299–310

Péwé, T.L. (1960): Multiple Glaciation in the McMurdo Sound region Antarctica: A progress report. *Jour. Glac.*, **68** 498–514

Saito, N., T. Tatsumi, and K. Sato (1961): Absolute Ages of Euxenite from Antarctica. *Ant. Rec.*, **12** 1,057–1,062

Sato, T. (1964): Submarine Topography and Several Bottom Sediments around Prince Olav and Prince Harald Coast, Antarctica. *ibid.*, **21** 1,777–1,787

———, **Y. Iwabuchi, A. Iijima, K. Oinuma, and K. Kobayashi** (1965): *Geological Research on Bottom Sediments Sampled by the 5th Japanese Antarctic Research Expeditioh. JARE. Sci. Rep., Ser. C.* **4** 42

Shepard, F.P. (1963): *Thirty-five thousand years of sea-level* (in *Essays in marine geology*, in honor of K.O. Emery, ed. by Clements, T.). Los. Univ. South. Cal. Press., 1–10

Tatsumi, T., and T. Kikuchi (1959): Report of Geomorphological and Geological Studies of the Wintering Team (1957–1958) of the First Japanese Antarctic Research Expedition. *Ant. Rec.*, **7** 373–388, and **8** 443–463

——— (1961): Geology of the Region around Syowa Sattion, Ongul Island, Lützow-Holm Bay, Antarctica. *ibid.*, **11** 762

———, **and K. Kizaki** (1964): *Geology of the Region Around Lützow-Holmbukta and the "Yamato Mountains (Dronning Fabiolafjella)"*. (in *Antarctic Geology, ibid.*), 293–303

Uchio, T. (1966): Critical Review of the Marine Geological Results Around the Syowa Station Obtained During the First Series of the Japanese Antarctic Research Expeditions (1956–1962). *Ant. Rec.*, **27** 78–87

Voronov, P.S. (1952): The rate of Most Recent Uplift of Budd Coast, East Antarctica. *Sov. Ant. Exp.*, **35** 133–136

Wilson, A.T. (1964): Origin of Ice ages: an ice shelf theory for Pleistocene glaciation. *Nature*, **201** 147–149

Yanai, K., and Y. Ueda (1974): Absolute ages and Geological Investigations on the rocks in the area of Around Syowa Station, East Antarctica. *Ant. Rec.*, **48** 70–81

———, **K. Kizaki, T. Tatsumi, and T. Kikuchi** (1974): *Explanatory Text of Geological Map of East Ongul Island, Antarctica* (Ant. Geol. Map Ser. Sheet 1). *Natl. Inst. Polar Res.*, 13

———, **T. Tatsumi, and T. Kikuchi** (1974): *Explanatory Text of Geological Map of West Ongul Island, Antarctica* (*ibid.* Sheet 2). *Ibid.*, **5**

———, ———, ———, **and T. Ishikawa** (1975): *Explanataory Text of Geological Map of Teöya, Antarctica* (*ibid.* Sheet 3). *ibid.*, 3

———, ———, **and T. Kikuchi** (1974): *Explanatory Text of Geological Map of Ongulkalven Island, Antarctica* (*ibid.* Sheet 4), *ibid.*, 3

Yoshida, M., and H. Ando (1970): Geological Survey in the vicinity of Lützow-Holm Bay and the Yamato Mountains, East Antarctica. *Ant. Rec.*, **39** 46–54

———, ———, **T. Ishikawa, and T. Tatsumi** (1976): *Explanatory Text of Geological Map of Skallen, Antarctica* (*ibid.* Sheet 9). *ibid.*, 18

Yoshida, M. (1977): *Geology of the Skallen Region, Lützow-Holmbukta, East Antarctica. Mem. Natl. Inst. Polar Res., Ser. C*, **11** 58

Yoshida, Y. (1962): *Report on the Geographical Devision of the* **4***th Japanese Antarctic Research Expedition*, 1961–1962*. *Ministry of Education*

———, **S. Murauchi, and K. Fujiwara** (1964): *Submarine Topography Off the Kronprince Olav Kyst, Antarctica.* (in *Antarctic Geology. ibid.*). *ibid.*, 710–714

——— (1969): Echo-sounding of Ice-covered Waters from Surface of Ice*. *Ant. Rec.*, **34** 14–22

——— (1970): *Raised Beaches and Saline Lakes along the Prince Olav Coast, Antarctica**. (in *Gendaino-chirigaku*), Asakura-shoten, Tokyo, 93–118

——— (1973): *Geomorphology of the Ice-free Areas and the Changes of the Ice Sheet**. (in *Nankyoku*, ed. by K. Kusunoki, *et al.*), Kyoritsu-shuppan Co., Tokyo, 237–281

——— (1977): Fluctuation of the Antarctic Ice Sheet and the Quaternary*. *Quat. Res.*, **15** 168–175

Yoshikawa, T., and H. Toya (1957): Report on Geomorphological Results of the Japanese Antarctic Research Expedition, 1956–1957. *Ant. Rec.*, **1** 1–13

Photo 1 *Roches moutonnée* landforms seen in central Skallen

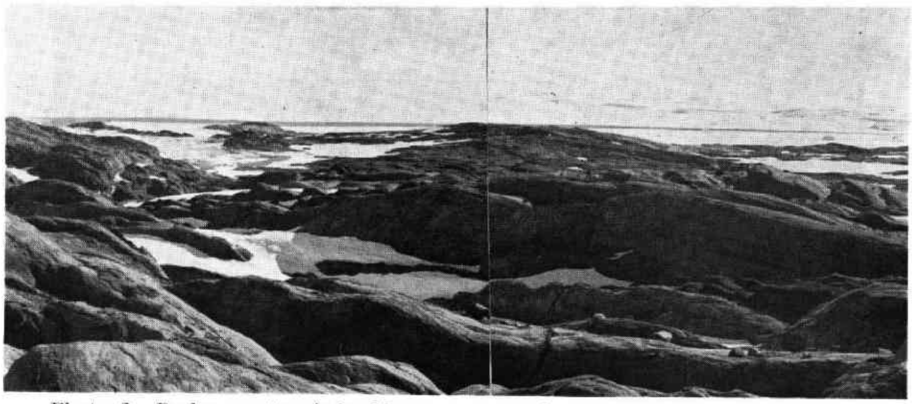


Photo 2 *Roches moutonnée* landforms seen on the east coast of Rundvågshetta

Photo 3 Giant *roches moutonnée* landforms seen in the northern part of Langhovde (Oblique air view)

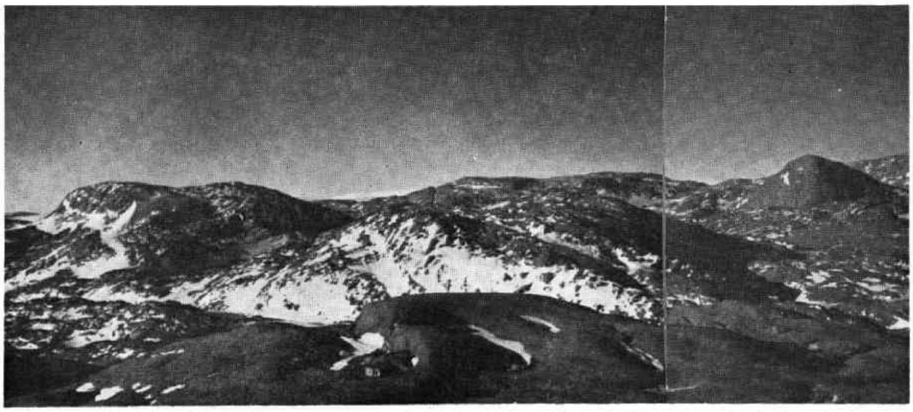


Photo 4 Giant *roches moutonnée* landforms seen in the southern part of Skarvsnes

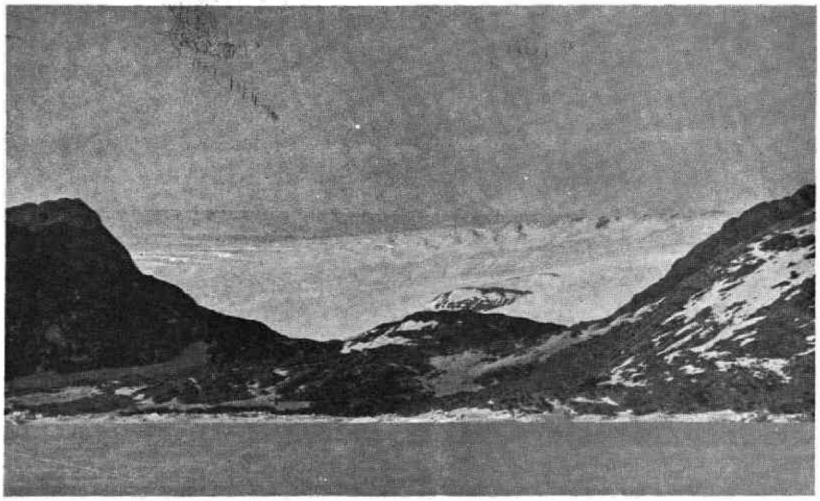


Photo 5 A glacial trough seen in central Langhovde

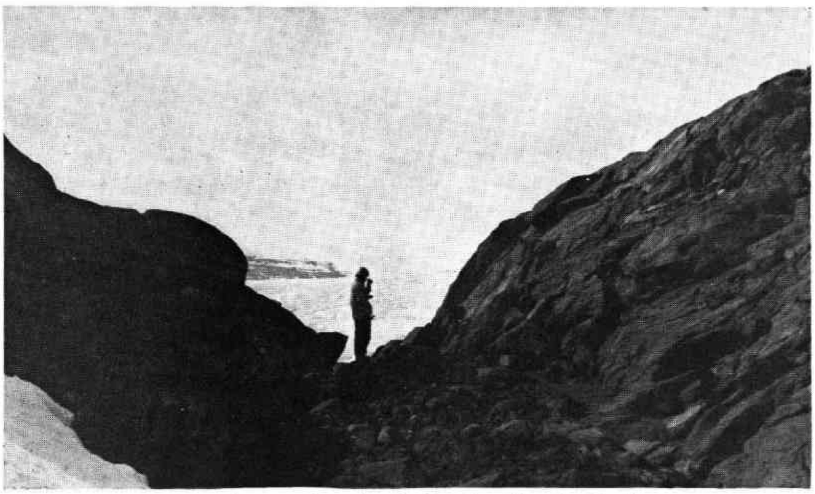


Photo 6 Small scale glaciated valley in Skallen

Photo 7 A hanging glacier and a cirque seen in central Langhovde

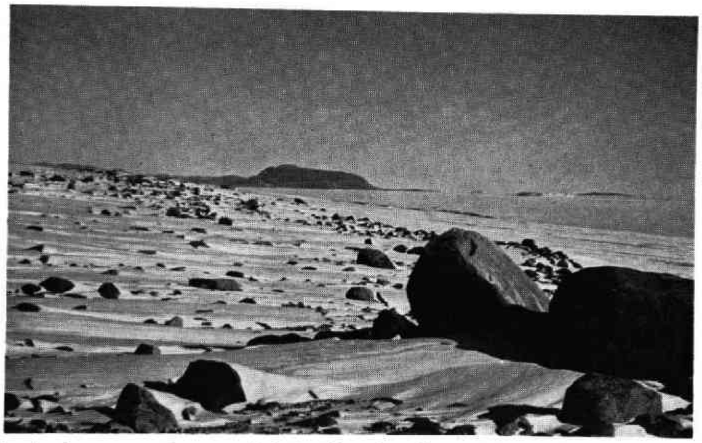


Photo 8 A shear moraine parallel to the shoreline at Mukai-iwa, opposite Syowa Station

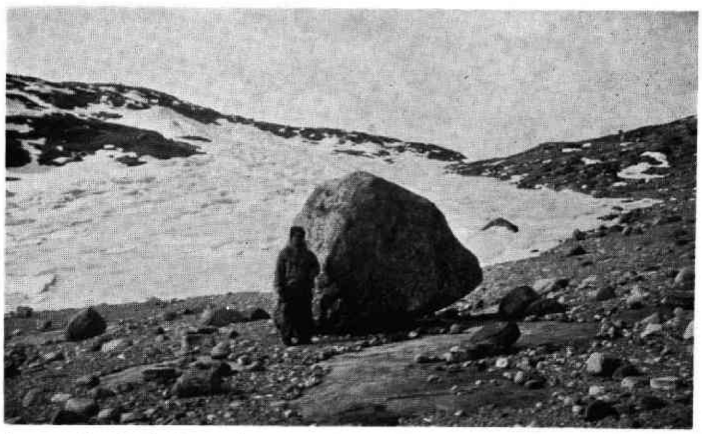


Photo 9 A recessional glacier and a ground moraine in the eastern part of Breidvågnipa

Photo 10 A shear moraine in the southern part of Rundvågshetta

Photo 11 Cellular deflations found on bedrock in East Ongul Island

Photo 12 A rock-cave landform with cellular deflations in the southern part of Skarvsnes

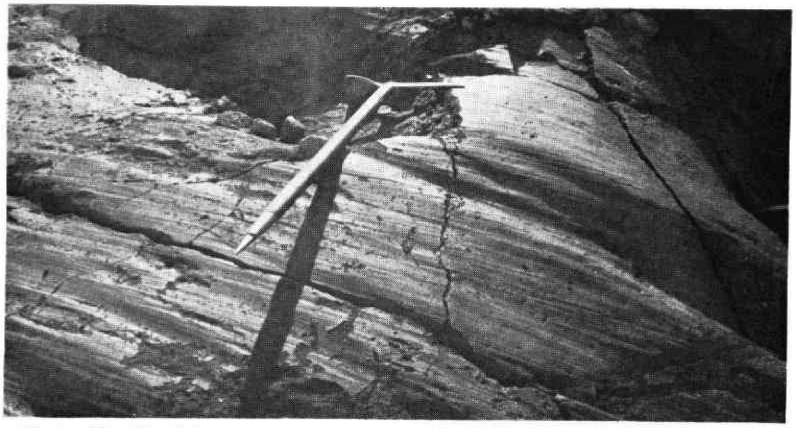


Photo 13 Glacial striae on bedrock in the southern part of Breidvågnipa

Photo 14 Glacial grooves and crescentic gouges on *roches moutonnée* landforms in Skallen

Photo 15 Glacial striae on bedrock in the eastern part of Rundvågshetta

Photo 16 Serrated shorelines in the western part of Langhovde

Photo 17 Strandflats in central Langhovde

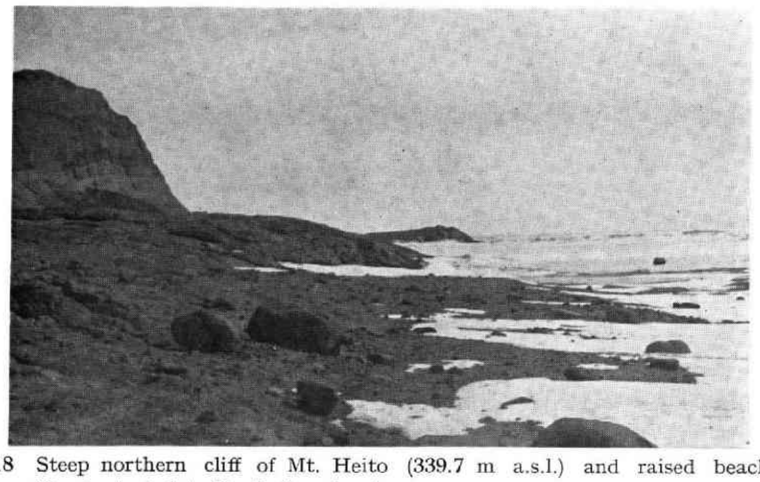


Photo 18 Steep northern cliff of Mt. Heito (339.7 m a.s.l.) and raised beaches at Kominato Inlet, North Langhovde

Photo 19 Steep cliffs stand nearly vertical ca. 300 m, at the southern end of Breidvågnipa

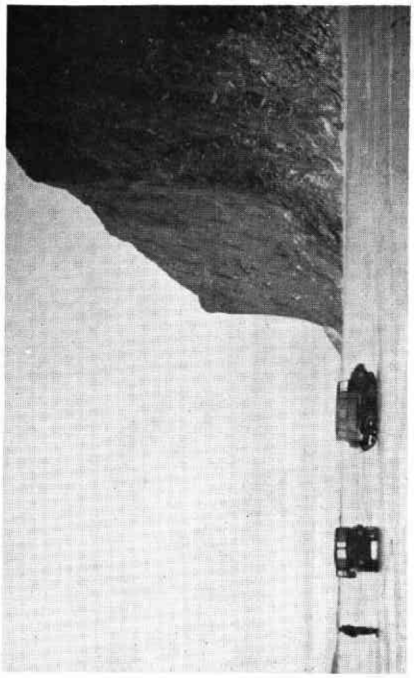


Photo 20 Steep southern slope of Skjegget peak (400 m a.s.l.) and Langpollen (Inlet), northwest of Skarvsnes

Photo 21 Steep southern slope of Mt. Tenpyo (254 m a.s.l.), in the southeast part of Skarvsnes

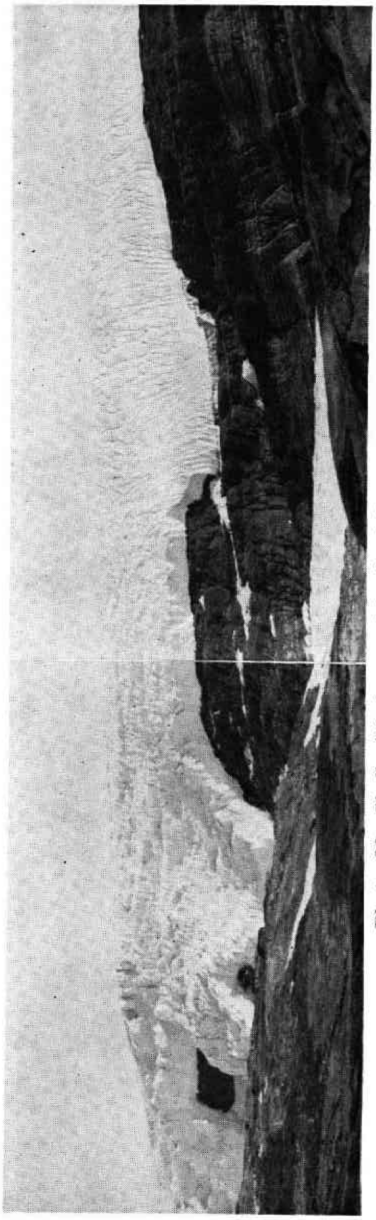


Photo 22 Skallevikhalsen and its ice-fall viewed from Skallen

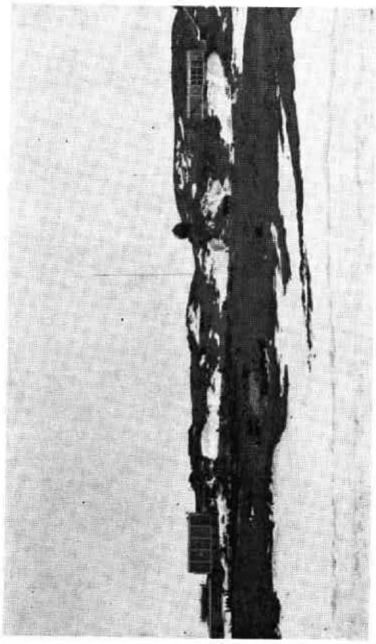


Photo 23 Raised beaches at Syowa Station, East Ongul Island

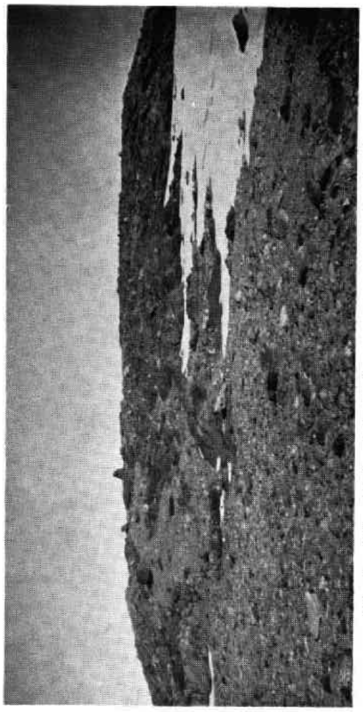


Photo 24 Raised beaches and wave-cut platforms in Ongulkalven Island

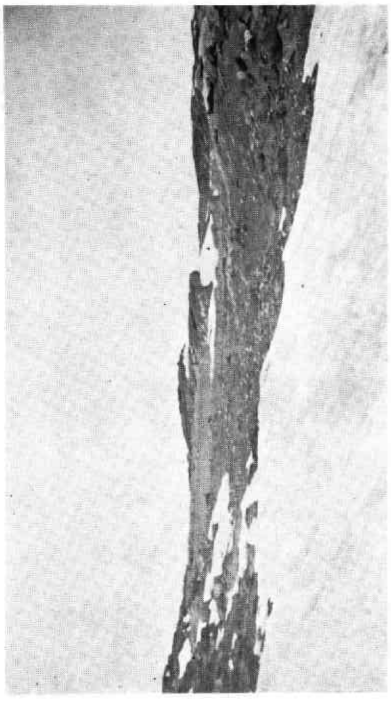


Photo 25 Raised beachhes in the middle western part of the Teöya Islands

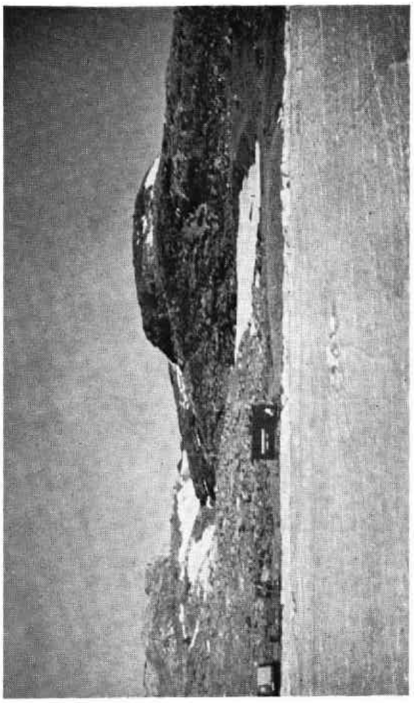


Photo 26 Raised beaches on middle west coast of Langhovde

Photo 27 Raised beaches at the mouth of the Yukidori-zawa, in central Skarvsnes

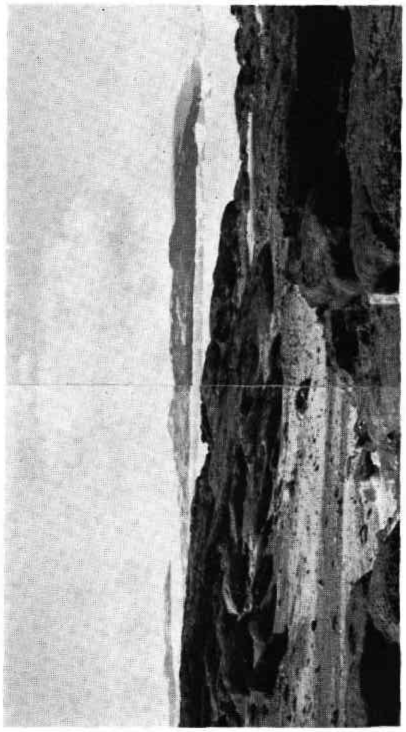


Photo 28 Wave-cut benches and raised beaches in the northern part of Skarvsnes

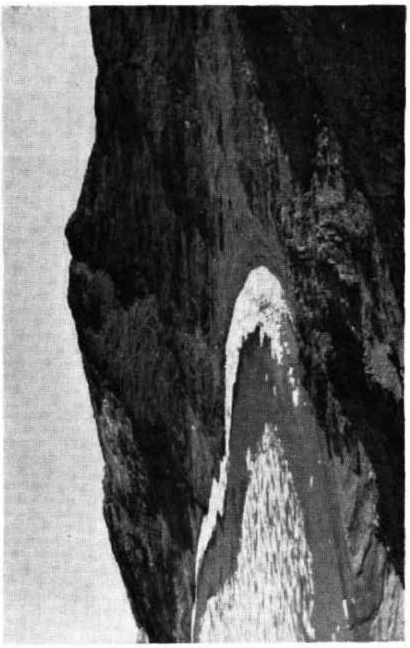
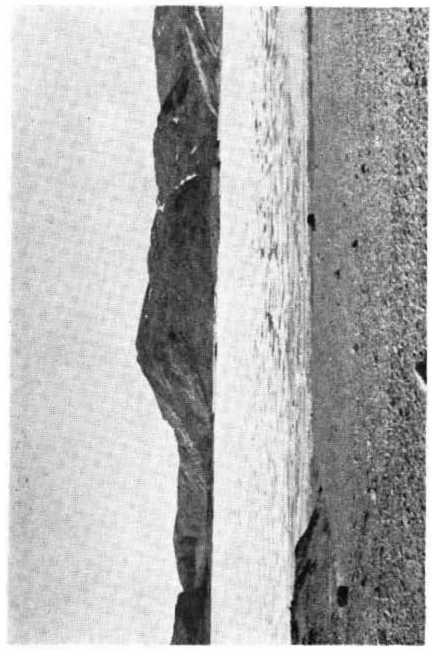
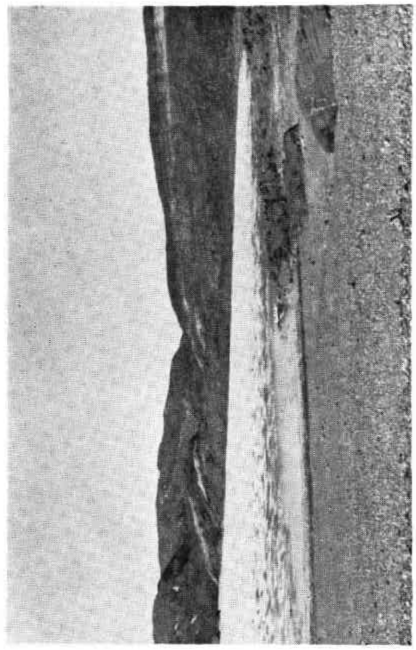


Photo 29 Raised beaches and step landforms in Kizahashihama (Beach), Osen (Bay), Skarvsnes





Photos 30a (left) and b (right). Stereographic view of "step landforms" at Kizahashihama (Beach), Skarvsnes

Photo 31 The lowest raised beach on the east coast of Skallen

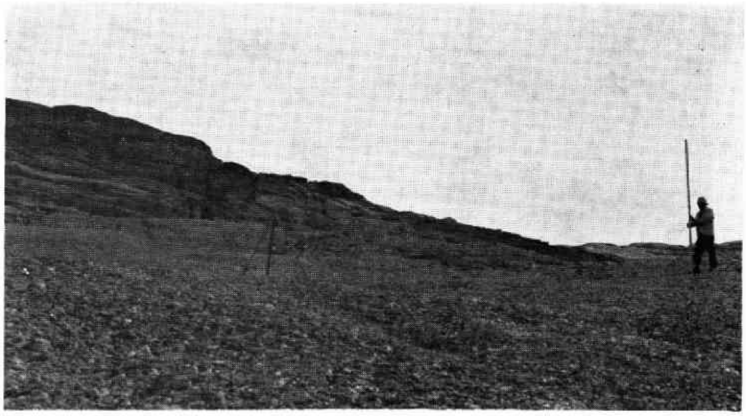


Photo 32 Raised beaches and step landforms on the east coast of Skallen

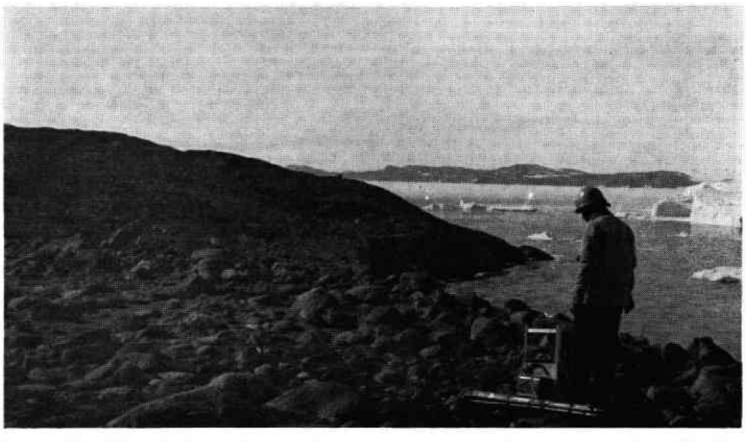


Photo 33 Elevated marine-boulder pavement on the east coast of Skallen

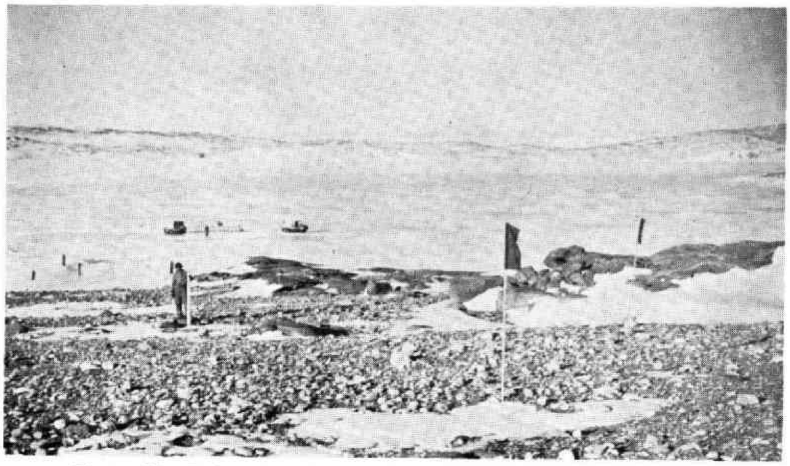


Photo 34 Raised beaches on the east coast of Skallevikhalsen

Photo 35 Raised beaches in the northern part of Rundvågshetta

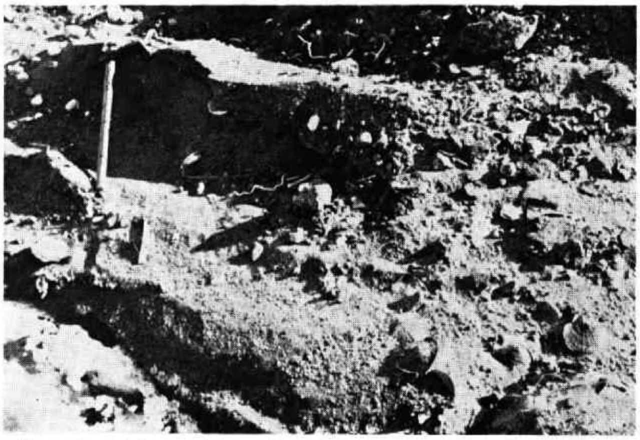


Photo 36 Fossil shells (*Adamussium colbecki*), seen on Kitamihama Beach, near Syowa Station, East Ongul Island

Photo 37 Fossil shells "*in situ*" (*Laternula elliptica*), seen at Kominato Inlet

Photo 38 Fossil shells "*in situ*" (serpuloid tubes), seen north of Mt. Suribachi, southern Skarvsnes

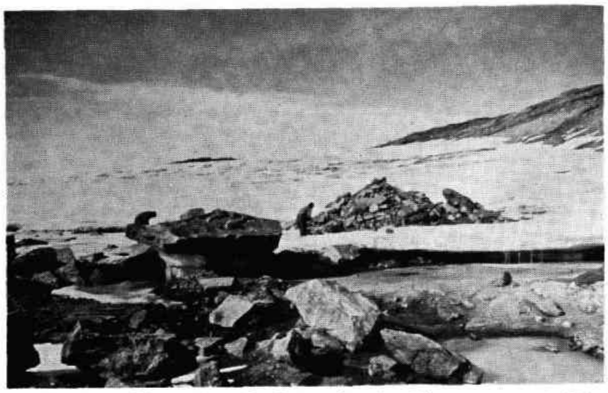


Photo 39 Champ de pierraille and rock shattering landforms seen at West Ongul Island

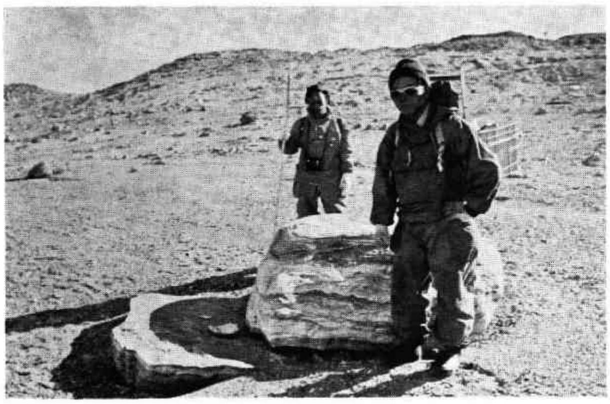


Photo 40 Moraine stone that has slid down as a result of freeze-thaw action, seen at West Ongul Island.

Photo 41 Thin ground moraine and stone circles seen in the central part of Breidvågnipa

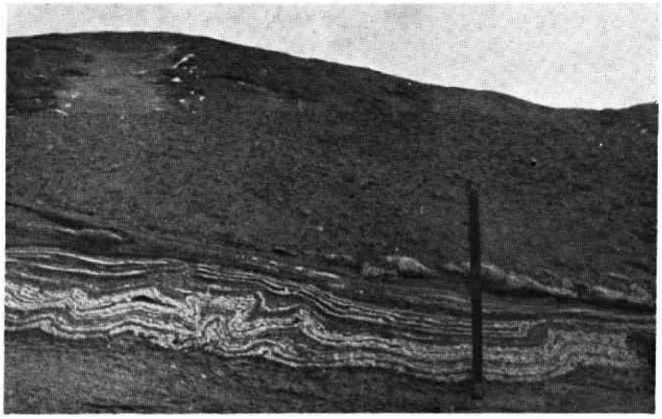


Photo 42 Involution phenomena found in lacustrine deposits in the east part of Lake Hunazoko, Skarvsnes

Photo 43 Sorted polygons seen in Skallen

Photo 44 Rock shattering and ice-wedged polygon seen at Rundvågshetta

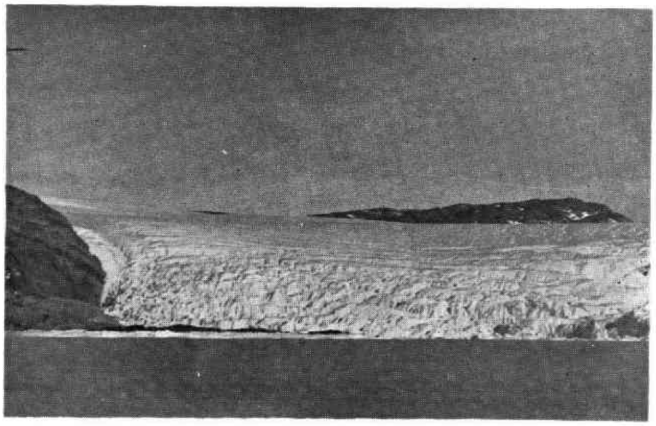


Photo 45 View of Hamna ice-fall

Photo 46 View of Lake Hunazoko (23 m below mean sea-level) northwest part of Skarvsnes

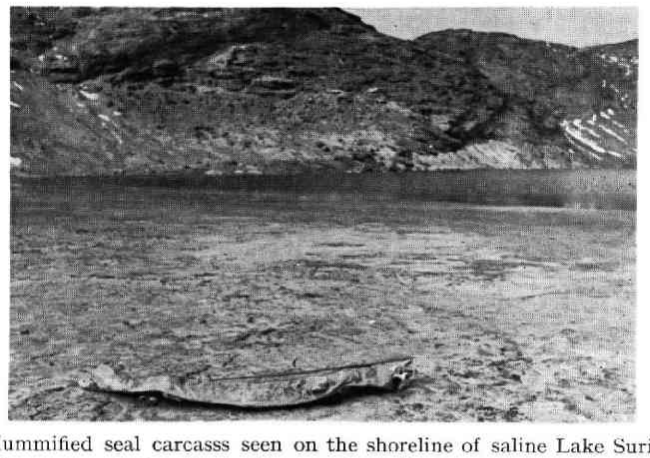


Photo 47 Mummified seal carcasss seen on the shoreline of saline Lake Suribachi, (32 m below mean sea-level), southern part of Skarvesnes