SUBMARINE TOPOGRAPHY OF LÜTZOW-HOLM BAY, ANTARCTICA

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Abstract: The huge depression of the central part of Lützow-Holm Bay is the drowned glacial trough extending from the Shirase Glacier. This trough and another off the Telen Glacier were formed probably by glaciation along faults. The sea floor of Lützow-Holm Bay is divided into the eastern and the western parts by the central trough. The greater part of the western sea floor is 300 m deeper than the northeastern sea floor. This difference in depth was caused probably by faulting. Many drowned glacial troughs exist in the eastern part. They were eroded selectively by ice streams conformably with the strike of gneissic foliation of bedrock. Rows of circular depressions seem to have been formed also along the strike of foliation by the plucking of the ice sheet. Cross profiles of troughs indicate the possibility of occurrence of multiple glaciations. Directions of troughs are different from those of glacial striae in coastal ice-free areas, and this seems to indicate that part of lower ice in troughs flowed in the different direction from the upper part of the ice sheet.

1. Introduction

The survey of the submarine topography of Lützow-Holm Bay started from the 9th Japanese Antarctic Research Expedition (JARE-9, 1968) in the vicinity of the Ongul Islands situated in the eastern part of Lützow-Holm Bay. Results of surveys from JARE-9 to JARE-18 clarified and suggested the following characters (FUJIWARA, 1971; MORIWAKI, 1975, 1979; OMOTO, 1976). 1) The depth of the continental shelf of the eastern part of Lützow-Holm Bay is shallower than 300 m. 2) Several conspicuous drowned glacial troughs exist immediately off the present ice streams in the Sôya Coast. 3) The huge drowned glacial trough exists in the central part of Lützow-Holm Bay and it seems to join the Shirase Glacier. 4) The rather deep continental shelf, 500 m to 600 m in depth, seems to extend in the western part of Lützow-Holm Bay.

The present authors carried out systematic sounding in the southern and the western parts of Lützow-Holm Bay in JARE-22 (1981) for the purpose of clarifying the characteristics of submarine topography of Lützow-Holm Bay.

2. Echo Sounding and Positioning

The survey was carried out at intervals of 1 or 2 km on each survey line by two parties which used GS-3 (28.5 kHz) and NSL-1300 (20 kHz) echo sounders (YOSHIDA, 1969; MORIWAKI, 1979), respectively. Table 1 shows the comparison of values obtained by the sounders at the same position. Sounded values were corrected after they were classified into three ranks of depth (shallower than 500 m, 500–1350 m, deeper than 1350 m) in order to simplify the calculation (Fig. 1). Figure 1 was drawn accord-

Table 1. Comparison of sounded values by GS-3 and NSL-1300 (corrected value).

1981 Date	Sep. 21	Aug. 24	Aug. 27	Aug. 29	Sep. 11	Sep. 23	Oct. 10	Nov. 20	Sep. 25	Oct. 14
GS-3	48 m (46)	534 m (518)	528 m (512)	536 m (520)	532 m (516)	526 m (510)	540 m (524)	537 m (521)		540 m (524)
NSL-1300	48 m (46)					538 m (522)			558 m (541)	
GS/NSL	1					0.98			0.97	
Wire	46 m				589 m	571 m		621 m		
Location	Nisi-no-ura Cove	Ongul Strait CM point							E0	

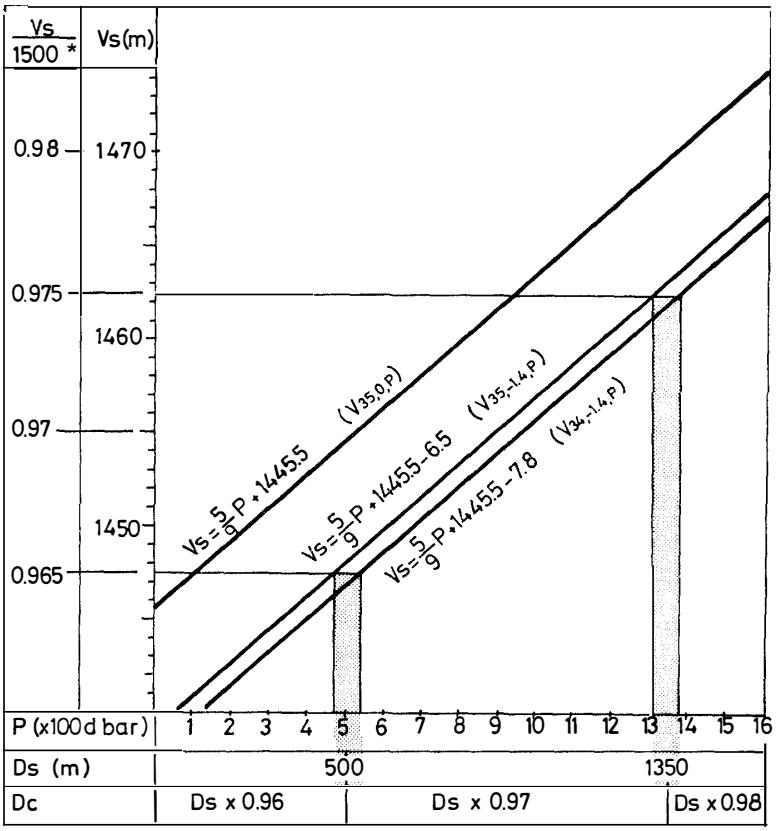

Fig. 1. Classification of correction factors. Vs: velocity of sound in sea water, P: hydraulic pressure, Ds: read depth, Dc: corrected depth, 1500: velocity of sound set in the echo sounder.*

ing to Manual for Oceanographic Observations (The Japan Meteorological Agency, 1978). Values of water temperature and salinity were assumed to be −1.4°C and 34–35‰, respectively without regard to depth. These values were based on measurements of the water temperature and salinity in the Ongul Strait (10 m to 600 m in depth) and other places by the authors and by WAKATSUCHI (1982).

The base line for the survey was set from Benten Island (39°15′E, 69°02′S) to Hjartöy (island) (39°18′E, 69°38′S) in the north-south direction, and base points AO . . . GO were fixed at intervals of 10 km on the base line. Survey lines from the base points were extended toward west and they were kept on the extension of the line connecting

two or more flags of 1-km intervals. Distance was measured with the distancemeter of the snow vehicle, which was examined by the electro-tachyometer on the distance of 1 km. Many positions of sounding points were checked up by triangulation, method of side intersection, and method of resection pointing to some exposed rocks. Survey lines were compelled to bend in the vicinity of 38°E by the hummocked ice zone 10 km wide stretching in the north-south direction. Positions of ice-free rocks and coastlines shown on the topographic map of Lützow-Holm Bay (1:250,000) edited by the Geographical Survey Institute, Japan (1963) were corrected on the basis of geodetic data obtained since 1966 (JARE Geodetic Survey Data) and satellite images of ERTS (1974). The error in location of sounding stations seems to be less than 1 km in the greater part of the survey area, but it may be greater than 1 km near the west end of that area.

3. Submarine Topography

3.1. Situation of Lützow-Holm Bay

The continental shelf off the Prince Olav Coast extends to Lützow-Holm Bay with the shelf edge 300–400 m deep, in the ENE-WSW direction parallel with the coastline (YOSHIDA *et al.*, 1964). Off the eastern coast of Lützow-Holm Bay, a broad ridge extends in the direction of NNW from the vicinity of the Ongul Islands, and the shelf edge is about 100 m shallower than that off the Prince Olav Coast (FUJIWARA, 1971). Such features of the continental shelf disappear in the vicinity of 38°E, 68°30′S, from where the shelf break seems to be deepened and to be embayed toward south. The huge glacial trough of the central Lützow-Holm Bay (MORIWAKI, 1979) is located SSE of the embayment of shelf break (Fig. 2).

The shelf edge 500 m deep off the western part of Lützow-Holm Bay is located near 37°E, 68°20′S (Fig. 3). The water deepens toward west of that shelf edge. Off the Riiser-Larsen Peninsula, the shelf edge about 300 m deep has been known near 35°E, 68°10′S. The greater part of shelf break off the western coast of Lützow-Holm Bay is not obvious, but it extends in the quite different direction from that off the Prince Olav Coast. Its direction seems to be NW-SE (Fig. 2). Such NW-SE trending topographic features are predominant in the vicinity of Lützow-Holm Bay.

Lützow-Holm Bay is occupied wholly by the continental shelf as mentioned above. The sea floor of that is divided into the eastern and the western parts by the depression of the central part of Lützow-Holm Bay.

3.2. The eastern part of Lützow-Holm Bay

The greater part of the eastern Lützow-Holm Bay is shallower than 300 m in depth and its sea floor is a hillocky topography eroded by the ice sheet. It has been known that conspicuous drowned glacial troughs exist off the present ice streams in the Sôya Coast north of Skallevikhalsen (FUJIWARA, 1971; MORIWAKI, 1975; OMOTO, 1976). Those troughs extend toward northwest and join the huge trough of the central part of Lützow-Holm Bay except the trough in the Ongul Strait off the Langhovde Glacier (MORIWAKI, 1979). The sounding in JARE-22 clarified some features south and west of Skallevikhalsen (Figs. 4, 5).

The topography of the eastern part of Lützow-Holm Bay can be divided into three sections, *i.e.* the northeastern section (En), the middle east section (Em) and the south-

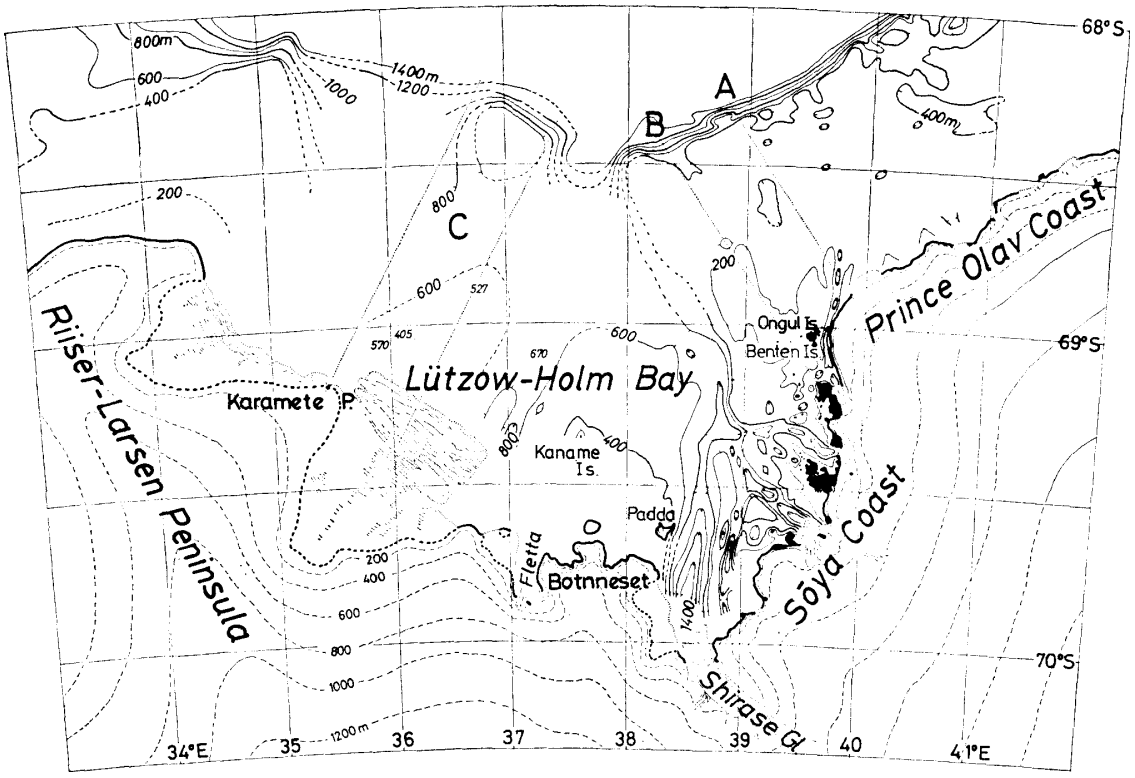

Fig. 2. Topography around Lützow-Holm Bay. Contour interval: 200 m. A, B, C: positions of profiles shown in Fig. 3.

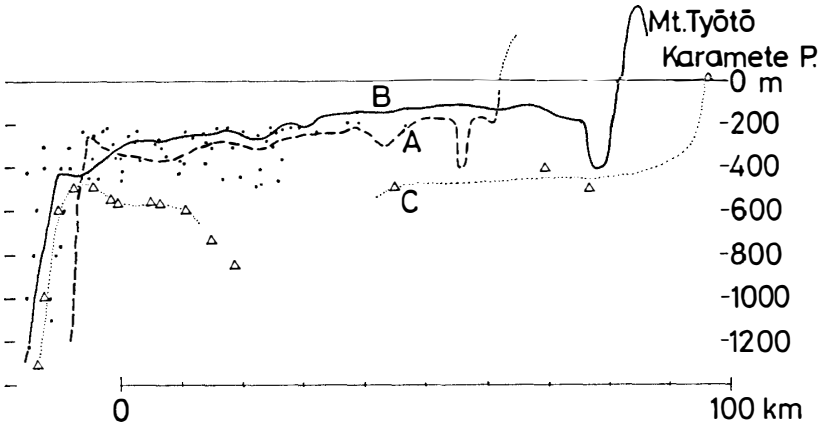

Fig. 3. Profiles of the continental shelf off the western Prince Olav Coast and off the western coast of Lützow-Holm Bay. A: off the Prince Olav Coast, B: off the east coast of Lützow-Holm Bay, C: off the west coast of Lützow-Holm Bay (shown in Fig. 2).

eastern section (Es) by drowned glacial troughs off the Honnör Glacier and off the Telen Glacier (Fig. 6).

3.2.1. Northeastern section (En)

The En section occupies north of the trough off the Honnör Glacier. The sea floor deepens generally from 100 m to 300 m as from near the coast to the continental

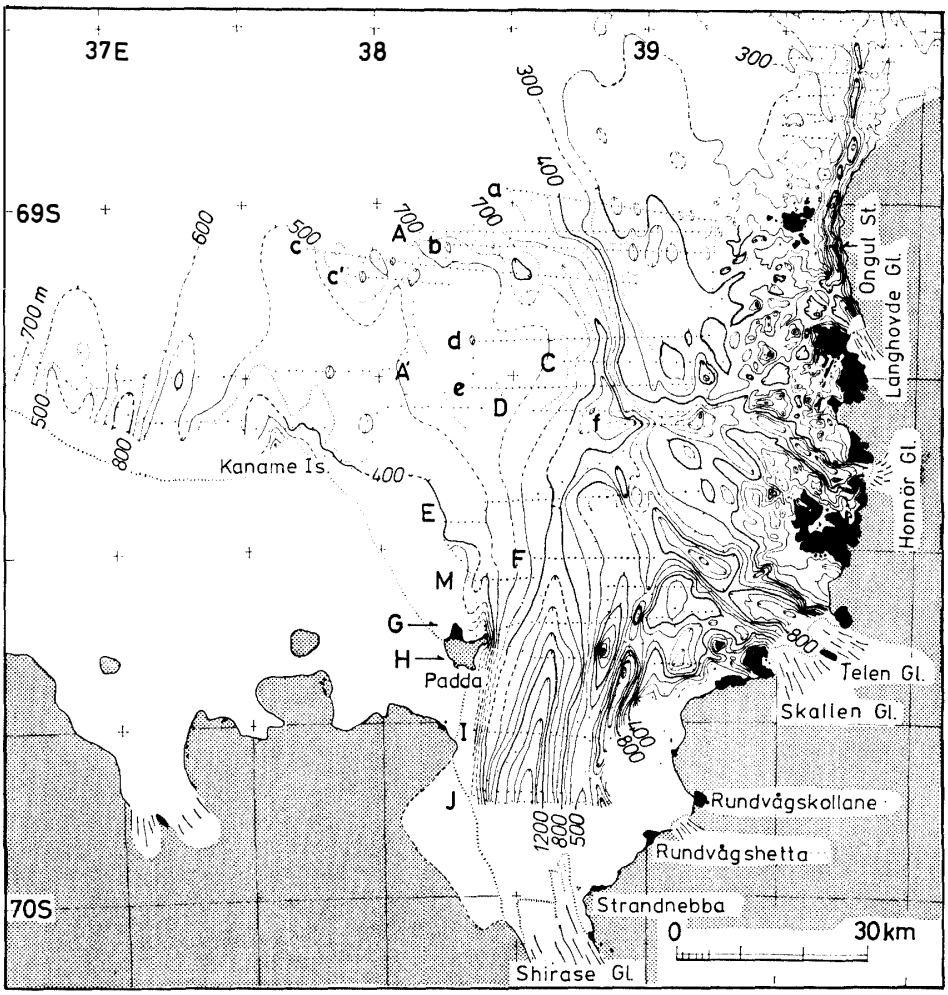

Fig. 4. Bathymetric chart of the main part of Lützow-Holm Bay compiled by MORIWAKI, *who made use of data of* FUJIWARA *(1971),* MORIWAKI *(1975, 1979),* OMOTO *(1976) and the authors. Contour interval: 100 m; dots: position of sounding (JARE-15, -18, -22); alphabet letters: survey line and position of profile (shown in Fig. 5), a-f: JARE-18, A-J and M: JARE-22.*

shelf edge, and it presents a hillocky topography with the relative height of about 100 m. Drowned troughs have silty and clayey deposits in their deeper parts, but the undulating submarine geomorphic surface in this section is overlain with little deposits the same as most part of ice-free areas around Lützow-Holm Bay (MORIWAKI, 1975). These facts may indicate that this surface is a remnant of a former peneplain glaciated by the ice sheet (FUJIWARA, 1971; YOSHIDA, 1983).

The drowned glacial trough off the Langhovde Glacier branches away into three troughs, *i.e.* one extending toward north through the Ongul Strait, one extending toward north-northwest then toward north through the Nisi-no-ura Strait, and one extending westwards (FUJIWARA, 1971). Directions of those troughs are concordant with the strike of gneissic foliation of the adjacent exposed basement rocks (Fig. 6). The submarine topography around the Ongul Islands suggests that there had been change in direction of ice flow (MORIWAKI, 1975). Glacial striae of the Ongul Islands and the Mukai Rocks indicate that the ice flowed westwards (YOSHIKAWA and TOYA, 1957;

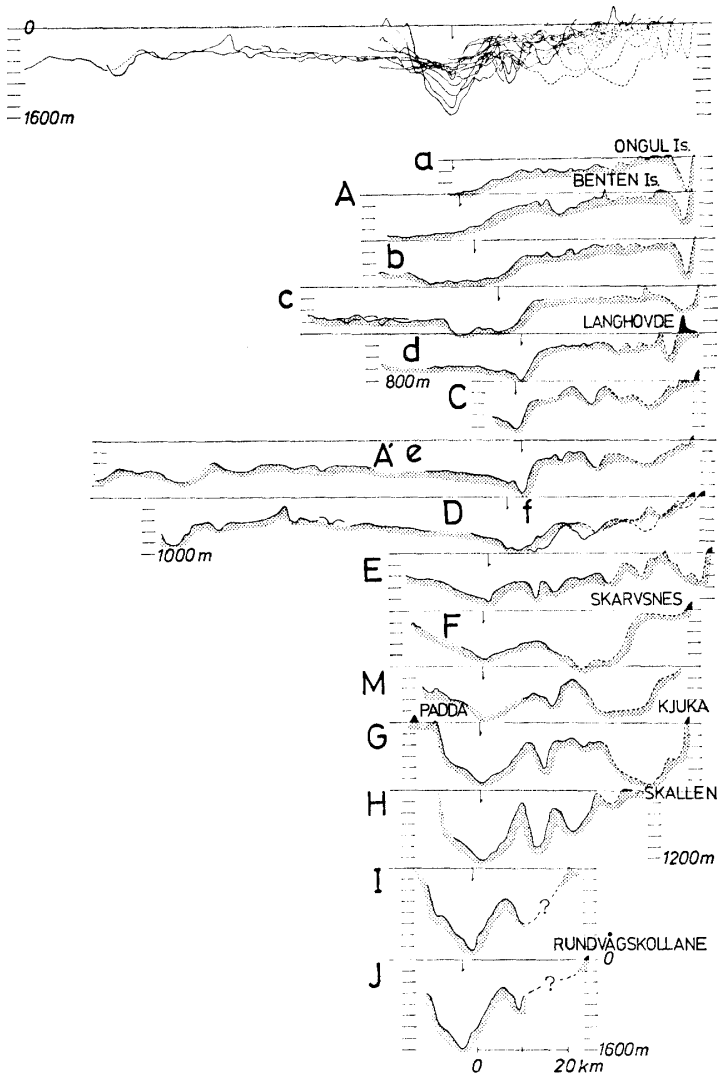

Fig. 5. Profiles of submarine topography of Lützow-Holm Bay, shown in Fig. 4. Top figure is superimposed profiles of all at the position of arrow of each one.

YOSHIDA, 1973; MORIWAKI, 1976) as well as northwards (YOSHIDA, unpublished). Therefore, in the vicinity of the Ongul Islands, the direction of ice flow changed certainly during the expansion or shrinkage of the past ice sheet on land and on the shallow sea floor. But the direction of ice flow in the deep trough of the Ongul Strait is regarded to be different from that of the upper part of ice even in the same expansion time (Fig. 6). It is known by measurement of ice core of Byrd Station that the direction of ice movement varies as the depth of ice increases (GARFIELD and UEDA, 1976), and it is also known that the direction of glacial groove is different from that of glacial striae on the edge of the groove in the case of small scale (YOSHIDA, 1973).

Terrace-like gentle slopes in the cross profile of the trough in the Ongul Strait suggest multiple glaciations (FUJIWARA, 1971).

Circular depressions west of Langhovde are arranged in two directions of NE-SW and NNE-SSW. They are considered to have been formed by plucking of the ice

sheet which moved as sheet flow from the east, because the directions of rows of them coincide with the strike of foliation of the adjacent basement rocks of Langhovde and neighboring "skjaergard" (FUJIWARA, 1971; Fig. 6).

3.2.2. Middle east section (Em)

The Em section is the sea floor between troughs off the Honnör Glacier and off the Telen Glacier. These troughs cut across the strike of foliation of basement gneissic rocks at least near the present coast (Fig. 6). Another drowned glacial trough extends from Skarvsnes in the direction of NW (OMOTO, 1976). This direction coincides with the strike of foliation of rocks in the eastern part of Skarvsnes and neighboring skjaergard. The sea floor deepens gradually from 100 m around Skarvsnes to 500 m near the confluence of glacial troughs off the Honnör Glacier and off the Telen Glacier. A part of sea floor in the vicinity of the confluence of troughs is shallower than 300 m. In general the depth of sea floor of the Em section is deeper than that of the neighboring En section near the central part of Lützow-Holm Bay. This may be ascribed to areal glacial scouring by concentrated ice around the troughs.

3.2.3. Southeastern section (Es)

The Es section is the south of the trough off the Telen Glacier. The greater part of this section was clarified by sounding in JARE-22. Rows of circular depressions north and south of Hjartöy are arranged in the direction coinciding with the strike of foliation of the neighboring exposed rocks (Fig. 6). The depression southwest of Hjartöy is huge and deeper than 700 m (Fig. 4). These circular depressions seem to have been caused by plucking of the ice sheet moving from the southeast same as the rows of depressions west of Langhovde. The conspicuous trough extending straight in the direction of north-south is developed between the above-mentioned depressions and Einstödingen (island) (Fig. 4). This trough is parallel with a huge trough off the Shirase Glacier and it joins the glacial trough off the Telen Glacier in the north. In the south, this trough is considered not to join the Shirase Glacier but to extend toward the coast between Rundvågshetta and Strandnebba. An obvious ice stream exists not in that place but between Rundvågshetta and Rundvågskollane (Fig. 4). The relation between this ice stream and the trough is unknown. The trough differs in its situation from the usual relation between an ice stream and a drowned trough, but it shows also a glacial trough feature with basin and sill topography. Einstödingen is located on a ridge extending northwards and separating this trough from the trough off the Shirase Glacier.

The general depth of the Es section increases towards offing of the coast. It seems also to have been caused by glacial erosion as in the case of the Em section (Fig. 4).

3.2.4. The relationship between geological structure and glacial topography

The glaciated submarine topography of the eastern part of Lützow-Holm Bay trends conformably with the foliation of gneissic bedrock (Fig. 6). Rather narrow glacial troughs were formed in zones where the direction of ice movement coincides with that of the strike of foliation of bedrock. But glacial troughs off the Honnör Glacier and off the Telen Glacier do not seem to indicate such relationship at least near the present coast. The direction of the former trough seems to coincide with the strike of foliation of bedrock in Systerflesene (island) rather than with that on the coast. On the other hand, the latter trough appears to be controlled by fault, because of its broader and

deeper features. The direction of the drowned glacial trough east of Einstödingen is discordant with the strike of gneissic foliation of rocks on the Sôya Coast. Such situation suggests that the trough originated in the glaciated fault line.

Rows of circular depressions in parallel with the coast are formed by plucking of the ice sheet in places where ice moved across the foliation structure of bedrock.

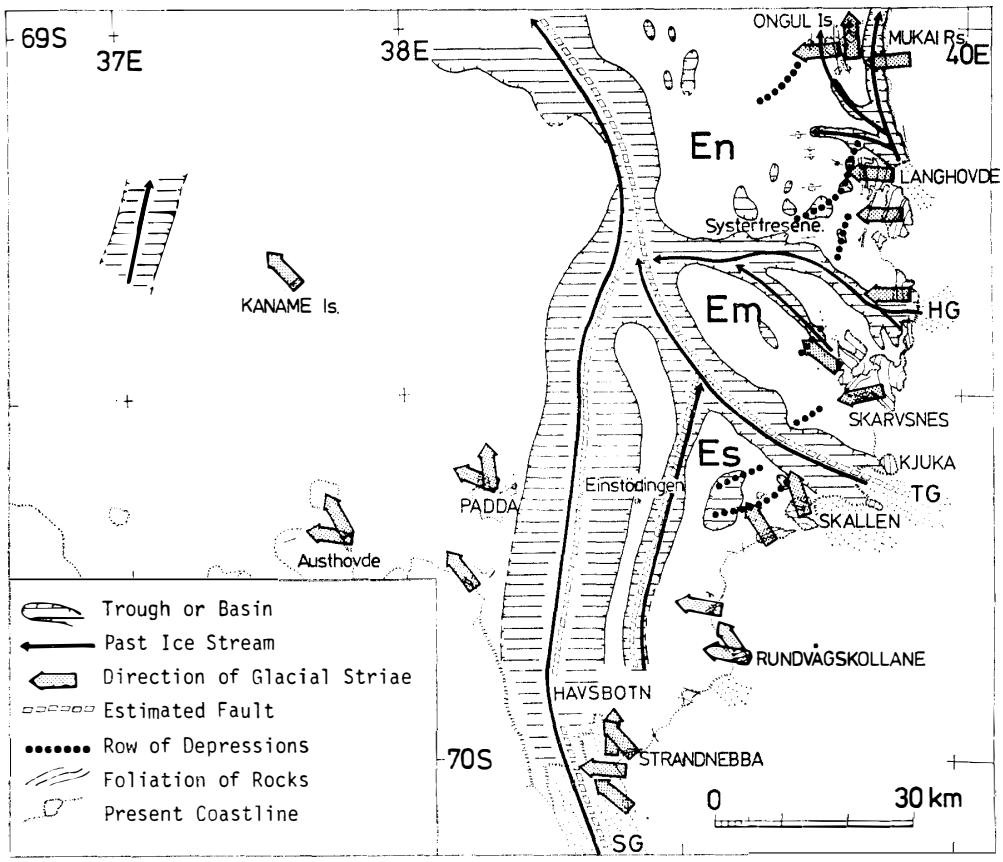

Fig. 6. Relation between glacial depressions and gelogical structures, and directions of past ice flow. Strikes of foliation of gneissic rocks were quoted from ISHIKAWA (1976) and M. YOSHIDA (1975, 1979). En: northeastern section, Em: middle east section, Es: southeastern section, HG: Honnör Glacier, TG: Telen Glacier, SG: Shirase Glacier.

3.3. The central trough

A depression over 600 m deep exists in the central part of Lützow-Holm Bay. It was inferred to be continuous with the Shirase Glacier previously (YOSHIDA *et al.*, 1964; MORIWAKI, 1979). After the floating tongue of the Shirase Glacier flowed away by sea ice breakout in 1980–1981, the sounding of the waters off the Shirase Glacier became possible in JARE-22. It clarified features of the depression in relation to the Shirase Glacier (Fig. 4). The depression is a huge glacial trough with basin and sill topography. The trough extends about 100 km toward north off the Shirase Glacier and then it turns to northwest in the vicinity of 38°45′E, 69°10′S. It is named here "central trough" of Lützow-Holm Bay. The central trough is 18 km in width between Padda (island) and Einstödingen, and about 15 km in width at the depth of 600 m.

The width is constant almost from the terminal of the Shirase Glacier to the turning point.

The deepest point of the trough sounded in JARE-22 is 1560 m and situated near the end of the Shirase Glacier. This is the deepest trough next to that of Vincennes Bay, of known drowned glacial troughs in the world (CAMERON, 1965; EMBLETON and KING, 1975). The central trough deepens toward the confluence with troughs off the Telen Glacier and off the Honnör Glacier after it becomes shallow gradually toward north from this deepest point. The trough becomes shallow again in the same manner to the north of the confluence, then it forms another basin in the trough at the bend near 69°05′S. The form of extension of the trough north of 69°S is not clearly known, but it seems to join the embayment of shelf break in the vicinity of 37°30′E, 68°30′S (Fig. 2). On the other hand, it is doubtless that the upstream part of the central trough joins a trough occupied by the Shirase Glacier as is clarified by the aeromagnetic survey (SHIBUYA and TANAKA, 1983). The trough bends to the southeast toward upstream near the mouth of the Shirase Glacier (Fig. 6).

Cross profiles of the central trough show a symmetric form in its southern part, but an asymmetric form in its northern part (Fig. 5). The east wall of the northern part is steep (8–11 degrees) and its upper edge is distinctly identified. On the other hand, the west wall is gentle and the edge is obscure (MORIWAKI, 1979). One or two steps in the trough are recognized on both sides of trough walls by one or two breaks of slopes especially in the southern part (Fig. 5). Such features are also distinguished in the drowned glacial trough in the Ongul Strait (FUJIWARA, 1971) and in that off the Honnör Glacier. These features seem to have been formed by multiple glaciations.

The central trough south of 69°10′S extends straight in the north-south direction. The ridge and the trough of the Es section east of the central trough run parallel with one another. These features seem to indicate that the both troughs are glacial troughs controlled by fault. Abrupt bending of the central trough toward northwest near 69°10′S seems to indicate that another inferred fault extends in the direction of northwest from the Telen Glacier (Fig. 6). It seems to indicate the following: At first, the main faulting occurred on the sea floor across the continental shelf in Lützow-Holm Bay from the Telen Glacier to northwest. Then the N-S trending parallel faults occurred in the north-south direction, the one merging into the main faulting in the north and the other being obstructed by the main fault. Drowned glacial troughs off the Shirase Glacier and off the Telen Glacier were formed by one or more glaciations along those faults.

Glacial striae not only on exposed rocks in the vicinity of the mouth of the Shirase Glacier but also on rocks and islands in and around the western part of Lützow-Holm Bay indicate SE-NW movement of the ice in the past (YOSHIDA, 1973, 1983; M. YOSHIDA, 1975; MORIWAKI, 1976; HAYASHI, unpublished; Fig. 6). The general direction of ice movement is thought to follow the direction of maximum surface slope of the past ice sheet. Therefore, the upper part of the ice sheet would have flowed in the direction different from that of the ice in troughs, and contour lines of the past ice sheet would have been almost parallel with those of the present ice sheet of the Prince Olav Coast (Fig. 2).

3.4. The western part of Lützow-Holm Bay

There are few exposed rocks on the west coast of Lützow-Holm Bay. Coastlines of this area drawn in any customary maps are inaccurate with regard to position and shape. Interpretation of the satellite image of ERTS shows that there are sub-ice mounds in the vicinities of the north end of the Riiser-Larsen Peninsula, Karamete Point, the west of Fletta, and Botnneset from the northwest to the southeast near the coast, and the grounding line of the ice sheet shapes embayments correspondingly with those mounds. Ridges of gentle slopes seem to extend from those mounds to the north or north-northeast to form shallow waters. Padda and Kaname Island seem to be located on these ridges (Fig. 2).

Considerably unknown parts still remain in the western part of Lützow-Holm Bay, though several soundings were carried out there in JARE-5 (OURA, 1965) as well as in JARE-22. It is clarified, however, that the slightly undulating continental shelf extends to the east of 36°E. The sea floor is in general about 300 m deeper than that of the eastern Lützow-Holm Bay (Figs. 3, 4, 5).

A depression deeper than 800 m regarded as a drowned glacial trough exists near 37°E, 69°15′S. But distribution density of troughs in the western Lützow-Holm Bay ever sounded is very small in comparison with that of the eastern Lützow-Holm Bay. It seems difficult to consider that the sea floor of the western Lützow-Holm Bay became 300 m deeper than that of the eastern due to glacial erosion. Therefore, it is inferred that the difference of depth between the sea floor of the eastern Lützow-Holm Bay and that of the western was caused by faulting which occurred in the position of the central trough (Fig. 6).

4. Conclusion

The sea floor of Lützow-Holm Bay is divided into the eastern and the western parts by the central trough off the Shirase Glacier.

Many drowned glacial troughs exist in the eastern part of Lützow-Holm Bay. Undulating surfaces in the vicinities of confluences of those troughs were deepened also by the areal glacial scouring by concentrated ice around troughs. On the other hand, the geomorphic surface 100–300 m deep exists in the northeastern part of Lützow-Holm Bay without a conspicuous trough. It is a glaciated surface with little deposits, which seems to be originated from a former peneplain.

Huge troughs off the Shirase Glacier and off the Telen Glacier were formed probably by glaciation along faults. Other conspicuous troughs are glacial troughs which were eroded selectively by ice streams conformably with the strike of gneissic foliation of basement rocks. Several rows of circular depressions appear to have been formed also along the strike of foliation of rocks by the plucking of the ice sheet.

Cross profiles of some troughs indicate the possibility of occurrence of multiple glaciations.

There are a few depressions considered to be glacial troughs in the western part of Lützow-Holm Bay. The greater part of the sea floor in the western part is 400–600 m in depth which is 300 m deeper than that of the northeastern part. It is probably not due to the difference in mode of glacial erosion but is a result of faulting.

Any fault is not confirmed as yet, but existence of faults off the Telen Glacier and off the Shirase Glacier can be inferred from the features and arrangement of troughs. The former seems to cross Lützow-Holm Bay in the direction of NW from the Telen Glacier, and this direction may be the predominant trend of tectonic structure in the Lützow-Holm Bay region. The latter seems to extend toward north from the Shirase Glacier and to have been obstructed by the former.

Glacial striae which remained in coastal ice-free areas and islands indicate that the past ice sheet which covered completely Lützow-Holm Bay had increased its elevation from NW to SE, in the same manner as the present ice sheet of the Prince Olav Coast. In that period, part of lower ice in troughs flowed in the different direction from the upper part of the ice sheet and it deepened troughs furthermore.

Acknowledgments

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