Proc. NIPR Symp. Antarct. Geosci., 2, 146-161, 1988

RECONSTRUCTION OF MAXIMUM GLACIAL EXTENT IN THE CENTRAL SØR RONDANE MOUNTAINS, EAST ANTARCTICA

Kazuomi HIRAKAWA[1], Norikazu MATSUOKA[2] and Kiichi MORIWAKI[3]

[1]*Department of Geography, Faculty of Education, Yamanashi University, Takeda, Kofu 400*
[2]*Institute of Geoscience, The University of Tsukuba, Tsukuba 305*
[3]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Glacial landforms and deposits indicating the past expansion of glaciers are described. It is conspicuous that thick erratics form an end-moraine ridge or an extensive depositional surface on the summit, and that roches moutonnées are developed on the sharp ridge. On the basis of these traces, a paleogeographical reconstruction during the time of the maximum glaciation is presented: (1) The southern half of the central Sør Rondane Mountains was mostly covered with the ice sheet from the ice plateau; (2) Ice fall was located 10 km further north than at present; (3) Ice was about 300–350 m thicker than at present; (4) The northern half of the central Sør Rondane Mountains rose relatively widely above the ice sheet and outlet glacier.

1. Introduction

The Sør Rondane Mountains stretch between 22° to 28°E and 71.5° to 72°S, about 200 km south from the coast of Breid Bay. The outlet glaciers from the southern ice plateau divide the Mountains into several massifs which are rising out of the surrounding surface of the ice sheet by several hundred to more than thousand meters. The altitude of the present ice sheet surface is about 1100 m a.s.l. along the northern foot of the Mountains, whereas that of the inland ice plateau to the south attains to nearly 2700 m. This means that the Mountains make a barrier damming the glacier from the inland plateau. Therefore, the outlet glaciers flow down steeply to form icefalls in the uppermost reaches.

Geomorphological and glacio-geological investigations of the Mountains were conducted by the Belgian expeditions. VAN AUTENBOER (1964) thought that the ice sheet of the inland plateau once covered the greater part of the Sør Rondane Mountains at one stage, mainly on the basis of the existence of smoothed summit surface and dry glacial valleys. However, it is uncertain whether the smoothed summit surface was really originated from the areal scouring under the ice sheet, as VAN AUTENBOER illustrated in his figure, because he could not show any direct evidence of glacial erosion of the summit area.

We observed a lot of glacial landforms and sediments along the ridges and on the summit surfaces of the central Sør Rondane Mountains (Fig. 1) during the geomorphological investigation of the 28th Japanese Antarctic Research Expedition (JARE-28)

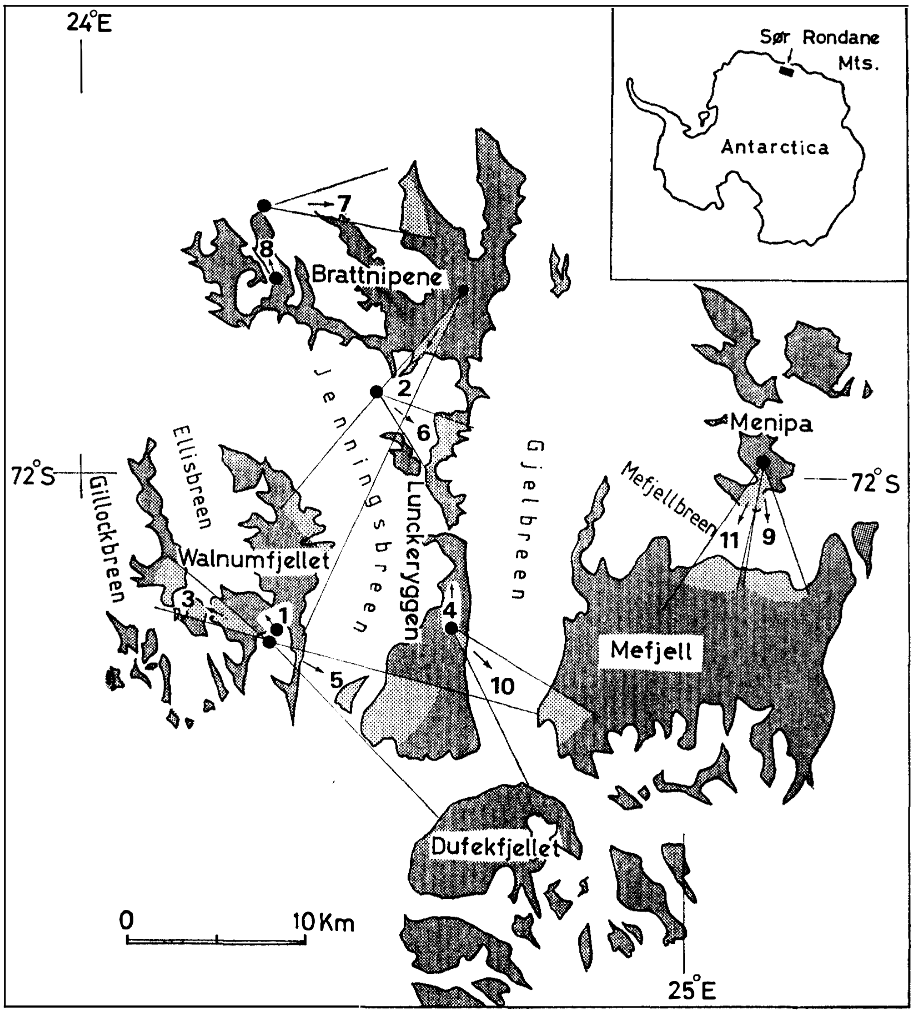


Fig. 1. Map of the studied area. Solid circle: place of photo shot, solid lines with angle and arrow: angle and direction of photo shot.

(HIRAKAWA *et al.*, 1987). The purpose of this report is to describe these glacial landforms and morainic deposits, and then to reconstruct a paleogeography at the maximum stage of the glaciation. Therefore, the description will be restricted to the landforms and deposits in relation to the maximum glacial extent. The photographs will be presented as many as possible. Description of landforms related to glacial fluctuation after the maximum stage, chronology and comparison with the other regions of Antarctica will be given in the next paper.

2. Description of the Glacial Landforms and Deposits

2.1. *Walnumfjellet* (Fig. 2)

Remarkable roches moutonnées stretch on the sharp ridge in the southern Walnumfjellet (3 in Fig. 2 and Plate 1.1). This ridge is between the steep cirque wall to the northwest and the rectilinear debris-covered slope to the southeast (Plate 1.2). The elevation is about 2450 m a.s.l., and it is only about 50 m lower than the highest

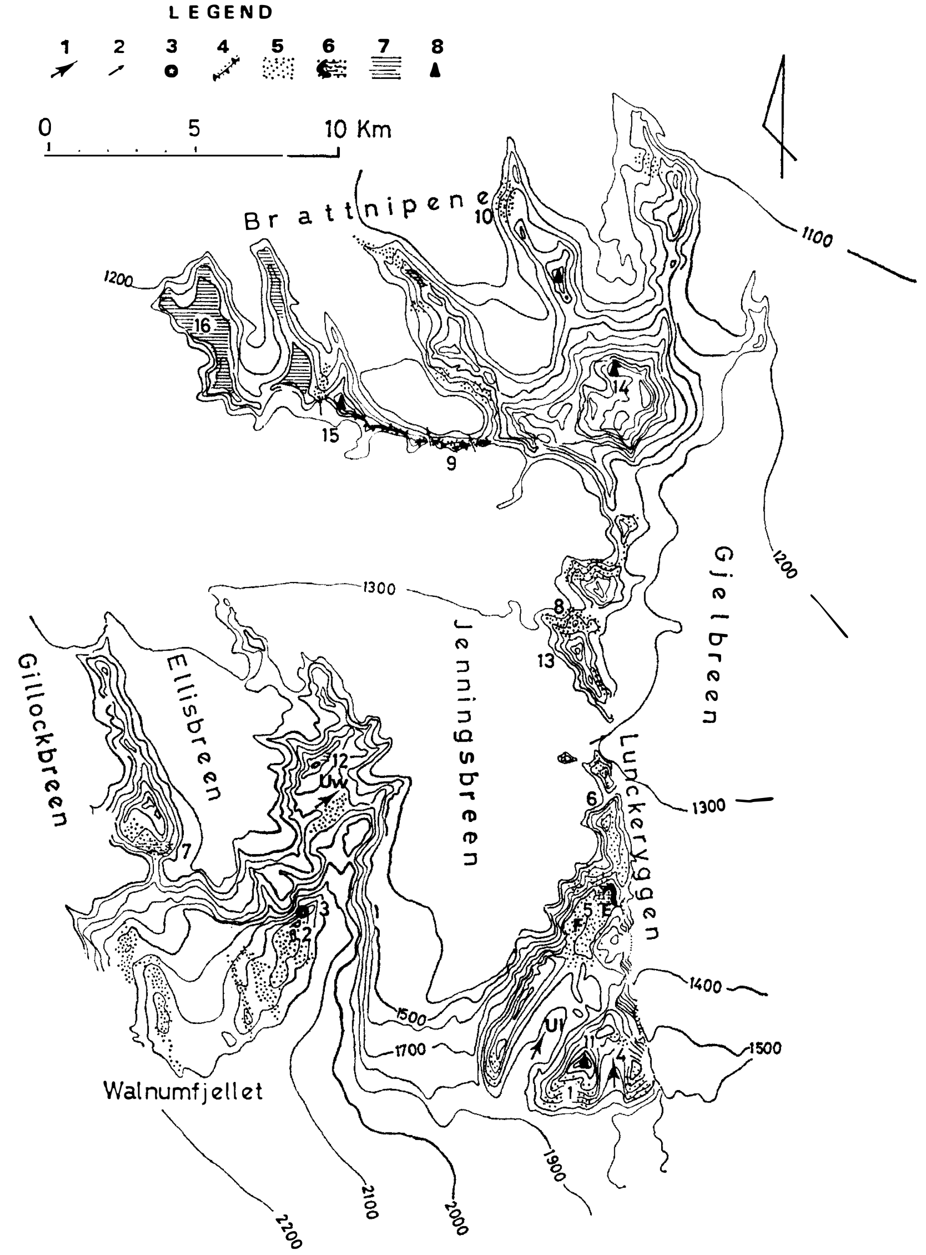


Fig. 2. Distribution of landforms and erratics used for the reconstruction of paleogeography during the maximum glaciation in the Walnumfjellet, Lunckeryggen and Brattnipene. 1: relatively large glaciated valley, 2: glaciated col or place where transfluence occurred, 3: roches moutonnées, 4: knife ridge covered with erratics in the south-western Brattnipene, 5: erratics on the summit, mountain slopes and ice smoothed surface, 6: depositional surface of thick moraines with an end-moraine ridge, 7: very flat summit surface without any erratics, 8: horn and glaciated peak by local glacier. 1–16 and Ul, Uw, E, and F in the figure: see text.

summit of the Walnumfjellet, at 600 m south of the roches moutonnées. The stream line direction of the roches moutonnées and the glacial striation are N 2°W. The highest summit of the Walnumfjellet (2501 m a.s.l.) is conspicuously flat (2 in Fig. 2). These facts indicate that the whole southern Walnumfjellet was subjected to the areal scouring of the ice sheet.

The flat summit surface characterizes the southern margin of the massif between the Ellisbreen and the Gillockbreen (7 in Fig. 2), about 5 km northwest of the ridge and the roches moutonnées above. The height of this surface is about 1800 m a.s.l., 400 m higher than the present surface of the Ellisbreen. This surface is covered with erratics attaining to 20 m or more in thickness (Plate 2.3). They are so strongly weathered by salt segregation that each block is not individually recognized. The height difference between this moraine-covered surface and the roches moutonnées above attain to 500 m.

A roughly U-shaped shallow dry valley, wtih a NE-SW trend, exists at about 4–7 km north of the roches moutonnées as shown in Fig. 2 (Uw) and Plate 1.2. Judging from the valley landform and the scattered erratics on the valley floor, it is evident that the glacier once passed through this valley from SW (Ellisbreen) to NE (Jenningsbreen). However, on the flat surface and the peak on the northwestern side of the valley (12 in Fig. 2), 1900–2000 m and 2052 m a.s.l. respectively, no erratics were found. This fact implies that the surface of glacier, filling the dry valley, at the maximum extent should have been at most 1900–2000 m a.s.l.

2.2. *Lunckeryggen–Brattnipene* (Fig. 2)

The southern part of the Lunckeryggen, with a height of 2000–2800 m a.s.l. and rising 700–1400 m out of the outlet glacier, is topographically characterized by a considerably flat summit surface (F in Fig. 2), a high pyramid-like peak (11 in Fig. 2) and a U-shaped dry valley (Ul) sloping southward. The flat summit surface and the U-shaped dry valley floor are covered with morainic deposits and an endmoraine ridge (E in Fig. 2) showing a loop in plan view is still preserved in one place on the flat summit surface in a height of 2000 m a.s.l. (Plate 2.4). In the U-shaped valley, the moraines form the very irregularly configurated low ridges and shallow depressions. The southernmost mountain slopes of the Lunckeryggen are remarkably smoothened (1 in Fig. 2 and Plate 3.5). Moraine covers including many erratics stretch extensively not only on the flat summit surface and smoothed mountain slopes but also on steep cliffs facing to the present Jenningsbreen. The lithological analysis of the morainic deposits reveals that almost the whole southern Lunckeryggen was overridden by the ice sheet from the inland plateau; a lot of erratics of hornblendite transported from the southern part of the Lunckeryggen are easily found. However, it cannot be determined that the highest peak (Plate 3.5) remained as a nunatak at the maximum glaciation, although the peak shape suggests it topographically. As far as we observed, the highest moraine cover stretches at about 2500 m a.s.l.

In the northern Lunckeryggen and southern Brattnipene remarkable knife ridges (9 in Fig. 2) and isolated pyramidal peak (13 in Fig. 2) are well developed. Some of them are totally covered with the erratics from the southern Lunckeryggen (6 and 8 in Fig. 2), whereas the higher part than about 1600–1700 m a.s.l. shows the steep rock wall and sharp ridge without any erratics (13 in Fig. 2 and Plate 3.6).

In and around the Brattnipene, there are many places where the relatively thick morainic deposits cover the mountain slopes, or form a flat moraine field, as shown in

Fig. 2 (10) and in Plate 4.7. Such erratics as syenite, tonalite and hornblendite, exposing over the southern Lunckeryggen (KOJIMA and SHIRAISHI, 1986), are the definite evidence to determine not only vertically but also horizontally the range of the former outlet glaciers in the Brattnipene. As far as we know from the field survey and the airphoto interpretation, the highest elevation of the erratics ranges between 1350 and 1400 m a.s.l. In several places along the northen margin of the Brattnipene, the upper limit of the erratics on the mountain slope indicates 1350 m a.s.l.

The WNW-trending ridge (9 in Fig. 2) forms, at present, a divide between the Jenningsbreen to the south and a small valley glacier to the north along the southern margin of the western Brattnipene. On this ridge up to 1450 m a.s.l., a lot of erratics from the south are also observed.

In the western Brattnipene, the flat summit surface (16 in Fig. 2) develops most remarkably in the whole Sør Rondane Mountains except Balchen. The elevation of this surface is about 1600 m in the south and 1400–1450 m in the north (Plate 4.8). It should be proved whether this surface was really originated from the areal scouring of glacier, as VAN AUTENBOER (1964) illustrated. For this purpose, we carefully observed the relief and detritus scattered on the surface in the field. However, no fragment of erratics was found. Only the weathering lag remained on the bedrock (Plate 4.8). Taking account of the widely distributed erratics on the slopes around the flat summit surface, this fact strongly suggests that neither outlet glacier nor ice sheet overode the flat summit surface of the Brattnipene. The height difference between the flat surface (1600 m in the south) and the erratic-covered ridge (1450 m at the highest) also supports this idea.

2.3. *Mefjell and Menipa* (Fig. 3)

A variety of glacial landforms are extensively distributed in the Mefjell; U-shaped valley, knife ridge, horn, cirque, morainic field and so on. In particular, U-shaped valleys are well developed. Almost all of them trend in a N-S direction, except a large one in the southern Mefjell with an E-W trend (A in Fig. 3). One U-shaped valley (B in Fig. 3) has an apparent shoulder topography in the eastern Mefjell as shown in Plate 5.9. A N-S trending ridge, dividing this U-shaped valley from the present Komsebreen to the east, becomes a knife ridge in the south and a flat summit in the north. A part of the latter appears to have been formed as a col due to glacial transfluence (C in Fig. 3 and Plate 5.9). On the contrary, mountain slopes around the summit area are remarkably smoothed in the west of the U-shaped valley (D in Fig. 3). Very similar landforms stretch to the southwestern part of the Mefjell (E in Fig. 3 and Plate 5.10). In general, sharp knife ridges trending parallel to the direction of U-shaped valleys are developed at a height of about 2700 m in the southern and 1900–2300 m a.s.l. in the northern Mefjell respectively. The smoothed summit surface is located mainly in the central to southern part of the Mefjell, where the height ranges from 2500 to 2700 m a.s.l.

In the northern margin of the Mefjell dominating over the Mefjellbreen, a conspicuous flat summit surface (F in Fig. 3) is developed as shown in Plate 6.11. This flat surface is covered with morainic deposits attaining to at least 30–40 m in thickness. Since they are strongly weathered, even large blocks cannot be individually recognized on the depositional surface of moraines. The height of the surface is 1700–1800 m a.s.l., that is 500–600 m higher than the present surface of the Mefjellbreen.

An asymmetric ridge (G in Fig. 3) in height of 1800–1900 m a.s.l. borders the western side of the U-shaped valley mentioned above (see front on Plate 5.9). The east-facing cliff forms the upper part of the U-shaped valley wall. On the gentler west-facing slope, erratics are extensively scattered up to the top.

The southern Menipa has a very flat summit (H in Fig. 3) with a height of about 2000 m a.s.l. Not only on this flat summit but also on the col at the south-facing slope (I in Fig. 3), about 1450 m a.s.l., no erratics are found. This col is situated only about 4–5 km in distance from the depositional morainic surface of the northern Mefjell.

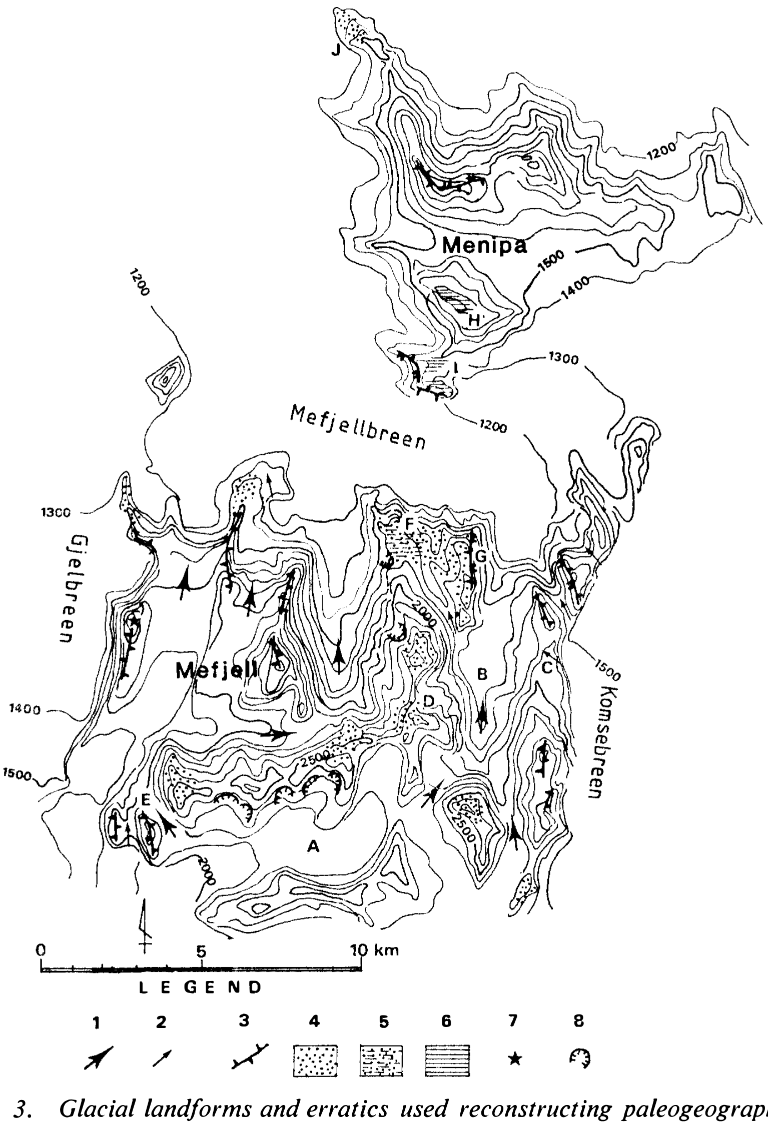


Fig. 3. Glacial landforms and erratics used reconstructing paleogeography of the Mefjell and Menipa. 1: major U-shaped valley, some of which are occupied by local glacier even at present, 2: glaciated col or small glaciated valley, 3: knife ridge, 4: erratic-cover on the summit, and smoothed mountain slope probably due to glacial areal scouring, 5: flat summit surface with thick moraine cover, 6: flat summit surface without any erratics, 7: horn, 8: small cirque, A–J: see text.

The highest moraine cover on the mountain slope in the northwestern extremity of the Menipa (J in Fig. 3) appears to have been formed by an outlet glacier. The upper limit of this moraine cover attains to about 1500 m a.s.l.

3. Discussion and Conclusion

On the basis of a lot of evidence described above, we tentatively present a longitudinal profile of the past outlet glacier along the Jenningsbreen (Fig. 4) and the paleogeography during the stage of maximum glaciation in the central Sør Rondane Mountains (Fig. 5).

3.1. Longitudinal profile of the former ice sheet along the Jenningsbreen

Figure 4 shows the longitudinal profiles of the present and past Jenningsbreen.

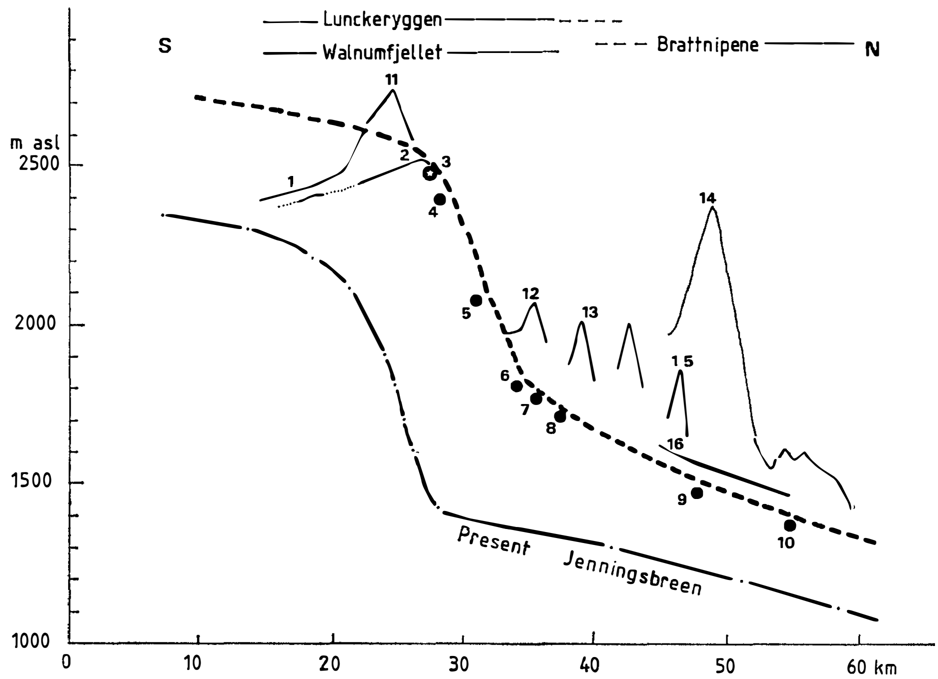


Fig. 4. Longitudinal profile during the maximum glaciation. Thick dashed line is the reconstructed longitudinal profile of the glacier along the Jenningsbreen. 1: ice-smoothed south-facing slope in the southernmost Lunckeryggen, 2: flat summit surface overridden by ice sheet in the southernmost Walnumfjellet, 3: roches moutonnées on the ridge in the Walnumfjellet, 4: the highest moraine cover identified so far on the summit of the southern Lunckeryggen, 5: thick erratics with end-moraine ridge on the summit of the southern Lunckeryggen, 6: moraine-covered peak in the northern Lunckeryggen, 7: depositional surface of thick moraines on the summit between the Gillockbreen and the Ellisbreen, 8: erratics on the summit of the northern tip of the southern Lunckeryggen, 9: erratics on the glaciated col in the southwestern Brattnipene, 10: moraine-cover with erratics on the mountain slope of the northern Brattnipene, 11: peak 2727 m a.s.l. in the Lunckeryggen, 12: peak 2052 m a.s.l. and adjacent flat surface in the Walnumfjellet, 13: pyramidal peaks in the northern Lunckeryggen, 14: the highest peak 2370 m a.s.l. in the Brattnipene, 15: peak 1733 m in the southwestern Brattnipene, 16: extraordinary flat summit surface in the western Brattnipene. Locations of 1–16 are indicated in Fig. 2.

As described previously, the altitude of ice surface of the former outlet glacier was determined by (1) smoothed surface of the southern Lunckeryggen and Walnumfjellet (Locs. 1 and 2, Fig. 4); (2) roches moutonnées on the ridge of the Walnumfjellet (Loc. 3); (3) the highest moraine and erratic covers in the Lunckeryggen (Locs. 4, 5, 6 and 8) and the Walnumfjellet (Loc. 7), and in the Brattnipene (Locs. 9 and 10); (4) steep ridges or peaks without erratic covers (Locs. 11–15) and a very flat summit surface without erratic covers (Loc. 16).

The reconstructed longitudinal profile of the Jenningsbreen is roughly parallel to the present profile. But the ice surface is higher by about 350 m than the latter in the Lunckeryggen and the Walnumfjellet, and higher by about 250–300 m in the Brattnipene. This fact indicates that the decrease of ice thickness was not equal in the whole Sør Rondane Mountains. The height of the former ice sheet in the north of studied area, that is in the Romnaesfjellet about 50 km north of the Brattnipene, was estimated at least more than 350 m higher than the present ice surface (VAN AUTENBOER, 1964). Although he thought that the Romnaesfjellet, dominating over the present ice surface by about 350 m, was subjected to areal scouring of the former ice sheet, no field work was carried out there. The trend of decrease of the former ice thickness to the north suggests the possibility that the Romnaesfjellet remained as a nunatak. However, further research should be necessary.

The ice fall existed at 10 km north of the present ice fall which crosses the Sør Rondane Mountains in the south of the Walnumfjellet and Lunckeryggen (Figs. 2 and 5).

3.2. Paleogeography of the Sør Rondane Mountains during the maximum glaciation

Figure 5 indicates the paleogeography of the central Sør Rondane Mountains during the maximum glacial extent. Not only in the Jenningsbreen, as shown in Fig. 4, but also in other outlet glaciers, the location of ice fall advanced north by about 10 km. As the height of ice sheet lowered down in the north of these ice falls, many nunataks were distributed in the Brattnipene and the Menipa where the transfluence occurred only at the lowest points of the mountains, and local glaciers fed by the drift snow changed the higher mountains to horn-shaped peaks.

The shortage of time for field work prevented us from going to the southernmost part of the Lunckeryggen, southern Mefjell and Dufekfjellet. However, as far as we observed from the Lunckeryggen and Walnumfjellet, the general landforms of the Dufekfjellet are quite similar to those of the southern Mefjell (Plates 3.5 and 5.10). Therefore, we tentatively thought that this mountain massif was mostly covered by the former ice sheet, except the highest summit.

The reconstruction of the former ice surface involves the following two problems:
1) It is still unknown whether all glacial landforms and deposits that are mentioned in this paper were made synchronously; for example, the roches moutonnées on the ridge of the Walnumfjellet appear to be much more fresh in comparison with the strongly weathered morainic deposits and erratics on the flat summit of the Walnumfjellet, Lunckeryggen and Mefjell.
2) As shown in Fig. 4, the elevation of the former ice surface was determined by that of the highest margin of moraine or erratic covers. However, it is possible that some

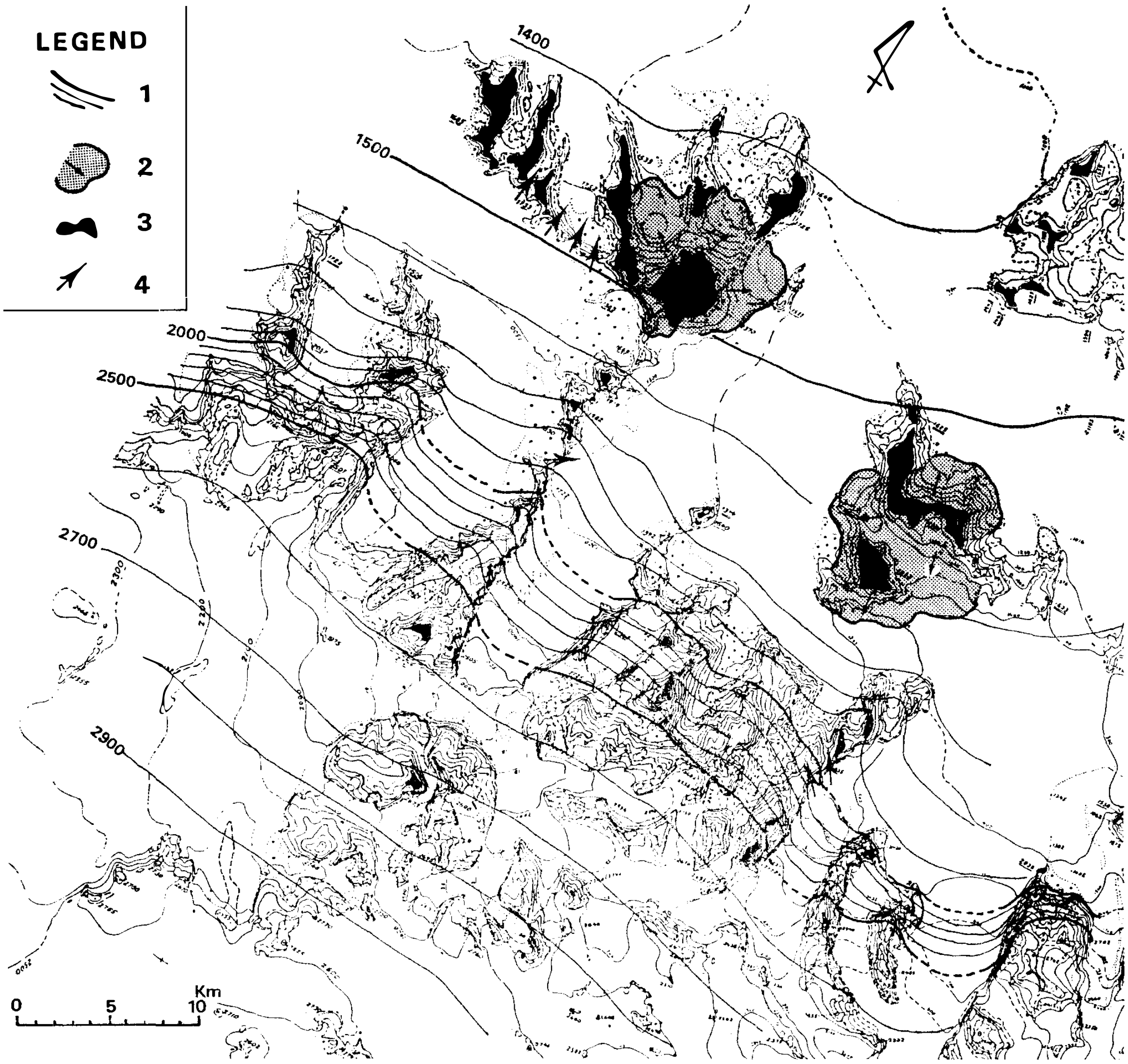


Fig. 5. Paleogeographical reconstruction during the maximum glaciation. 1: contour of the reconstructed surface of glacier, 2: major local glaciers with inferred flow direction (arrow), 3: nunatak, 4: glaciated col or small trough valley where transfluence occurred.

of them were formed under the former ice surface, and therefore, the elevation of the latter might have been higher than that of the highest limit of deposits.

DENTON *et al.* (1983) thought that 500 m of ice was necessary for the areal scouring of the summit in the Transantarctic Mountains. YOSHIDA (1985), referring to this work, estimated that the former ice sheet might have been thicker by about 1000 m than the present one on the Yamato Mountains, 300 km east of the Sør Rondane Mountains.

The lithological and sedimentlogical analysis of the moraine material and erratics will be desirable to determine the former ice thickness more precisely. It will give us new data on the processes of production, transportation and sedimentation of these glacial deposits.

Acknowledgments

We would like to thank all members of JARE-28 led by Prof. T. HOSHIAI, National Institute of Polar Research. We are grateful to Dr. Y. TAKAHASHI, Dr. Y. OSANAI, Dr. T. SAKIYAMA and Mr. K. TANAKA for their collaborations in the field survey.

References

DENTON, G. H., KELLOG, D. E. and KELLOG, T. B. (1983): Ice sheet overriding of the Transantarctic Mountains. Antarct. J. U. S., **5**, 15–21.

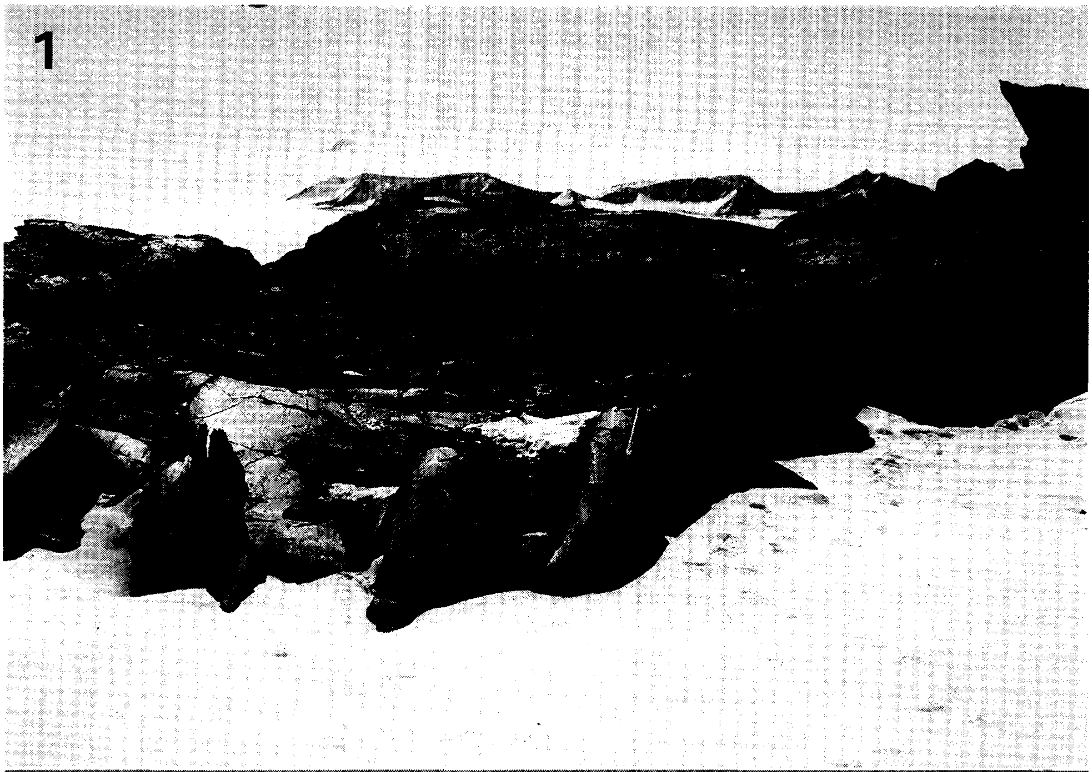
HIRAKAWA, K., MATSUOKA, N., TAKAHASHI, Y., SAKIYAMA, T., OSANAI, Y. and TANAKA, K. (1987): Sêru Rondâne Sanchi chigaku chôsatai hôkoku 1987 (JARE-28) (Report on the geological, geomorphological and geodetic field party in the Sør Rondane Mountains, 1987 (JARE-28)). Nankyoku Shiryô (Antarct. Rec.), **31**, 206–229.

KOJIMA, S. and SHIRAISHI, K. (1986): Note on the geology of the western part of the Sør Rondane Mountains, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue., **43**, 116–131.

VAN AUTENBOER, T. (1964): The geomorphology and glacial geology of the Sør Rondane, Dronning Maud Land, Antarctica. Antarctic Geology, ed. by R. J. ADIE. Amsterdam, North-Holland, 81–103.

YOSHIDA, Y. (1985): A note on the ice sheet fluctuations and problems of Cenozoic studies in Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 187–200.

(Received March 7, 1988; Revised manuscript received May 2, 1988)



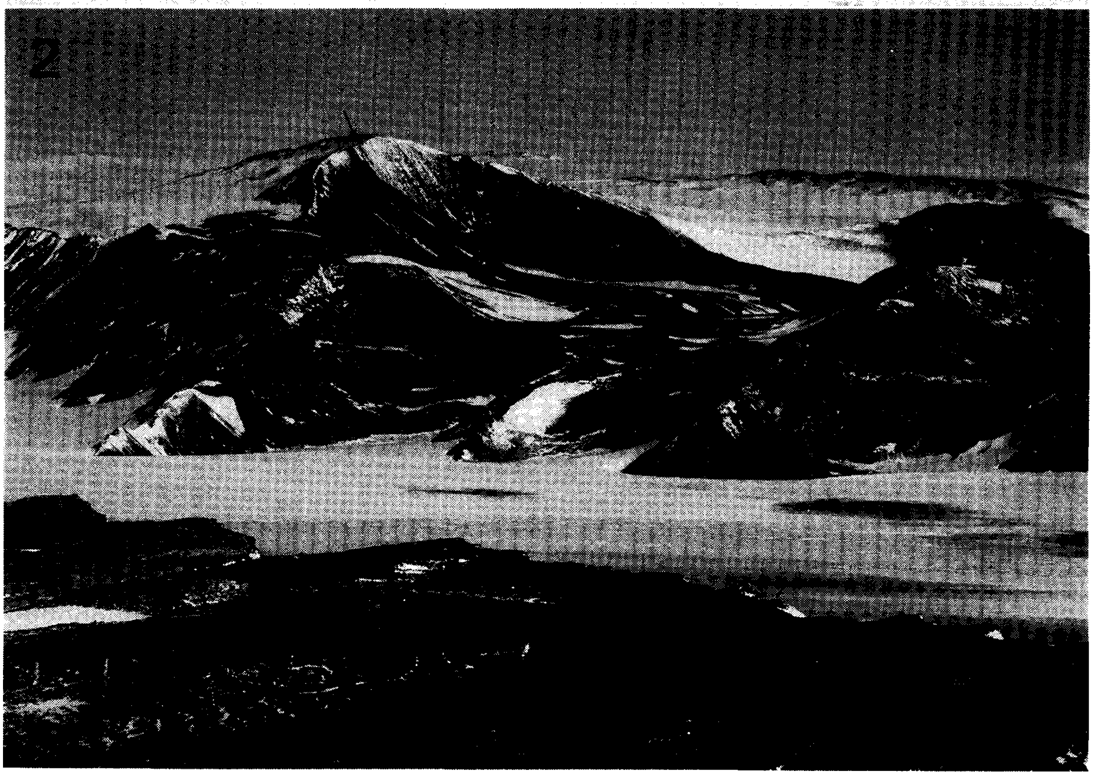


Plate 1. 1: Roches moutonnées, exposed on the ridge of the southern Walnumfjellet.
2: Shallow glaciated valley through the Walnumfjellet viewed from the main peak of the Brattnipene. Arrow indicates the place of roches moutonnées on Photo 1.

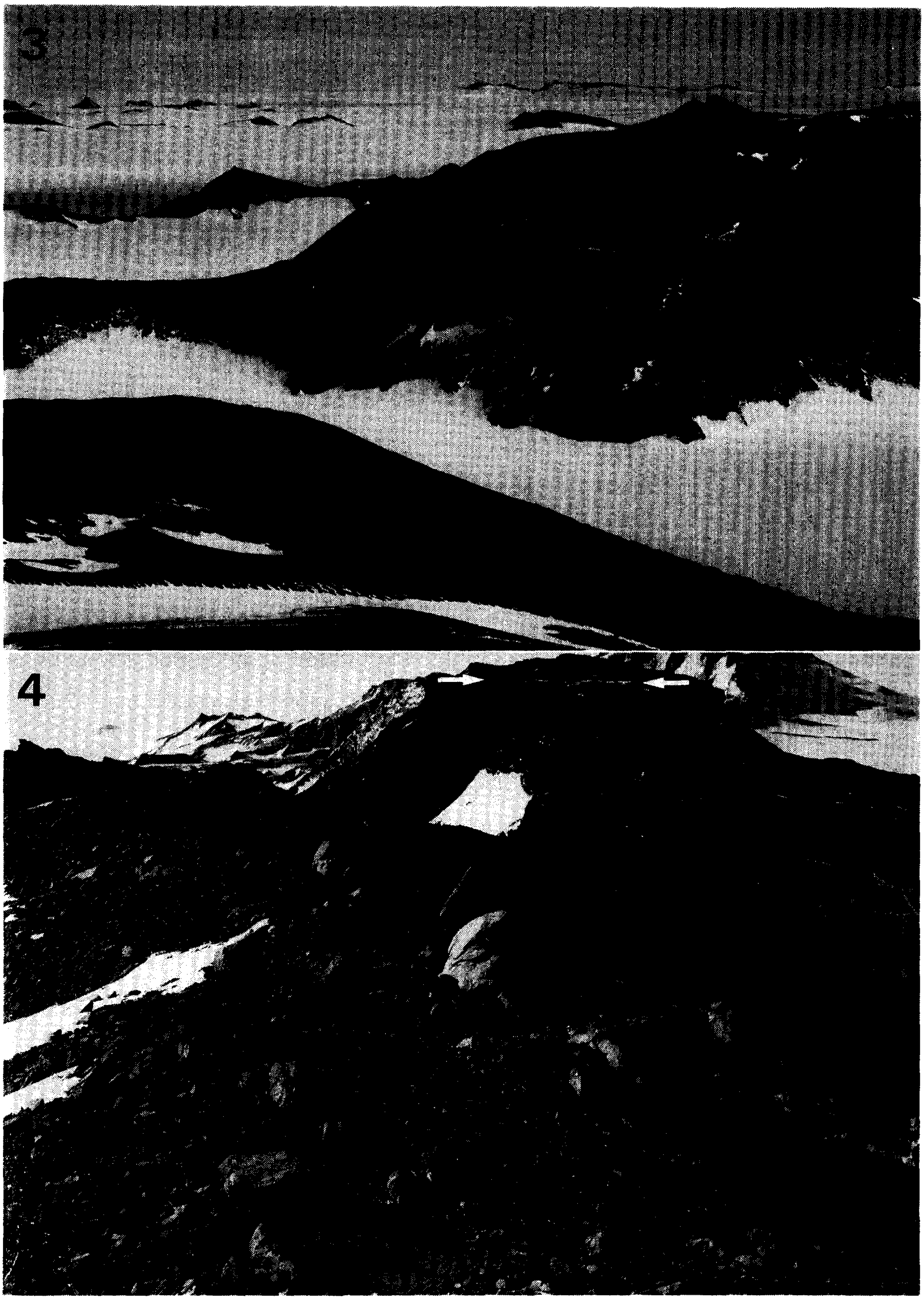


Plate 2. 3: Thick erratic cover on the summit and mountain slope of the Walnumfjellet, viewed from the highest point of the southernmost Walnumfjellet.
4: Thick erratic cover preserving an end-moraine ridge on the flat surface of the southern Lunckeryggen. Attention to the light-colored erratics (arrow) on the summit in the background.

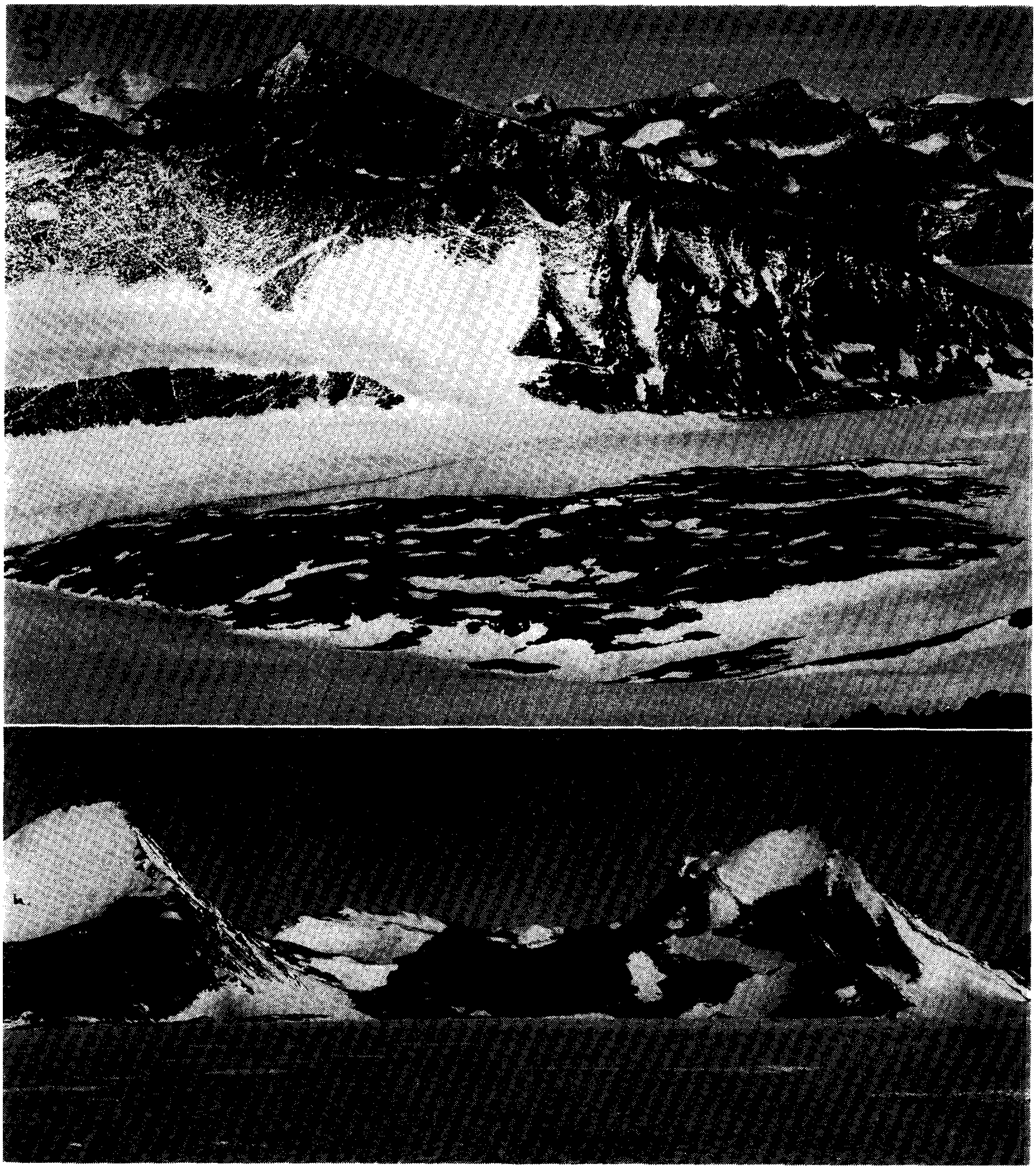


Plate 3. 5: Ice-smoothed mountain slope and the highest peak in the southernmost Lunckeryggen, viewed from the Walnumfjellet. The background is the Dufekfjellet.
6: Isolated peaks in the northern Lunckeryggen. Bare rock walls and erratic-covered slopes are easily distinguished from each other.

Plate 4. *7: Moraine-covered mountain slope and flat surface in the northern Branttnipene. Arrow indicates the highest margin of erratic cover around this area.*
8: Conspicuously flat summit surface without any erratics in the western Brattnipene.

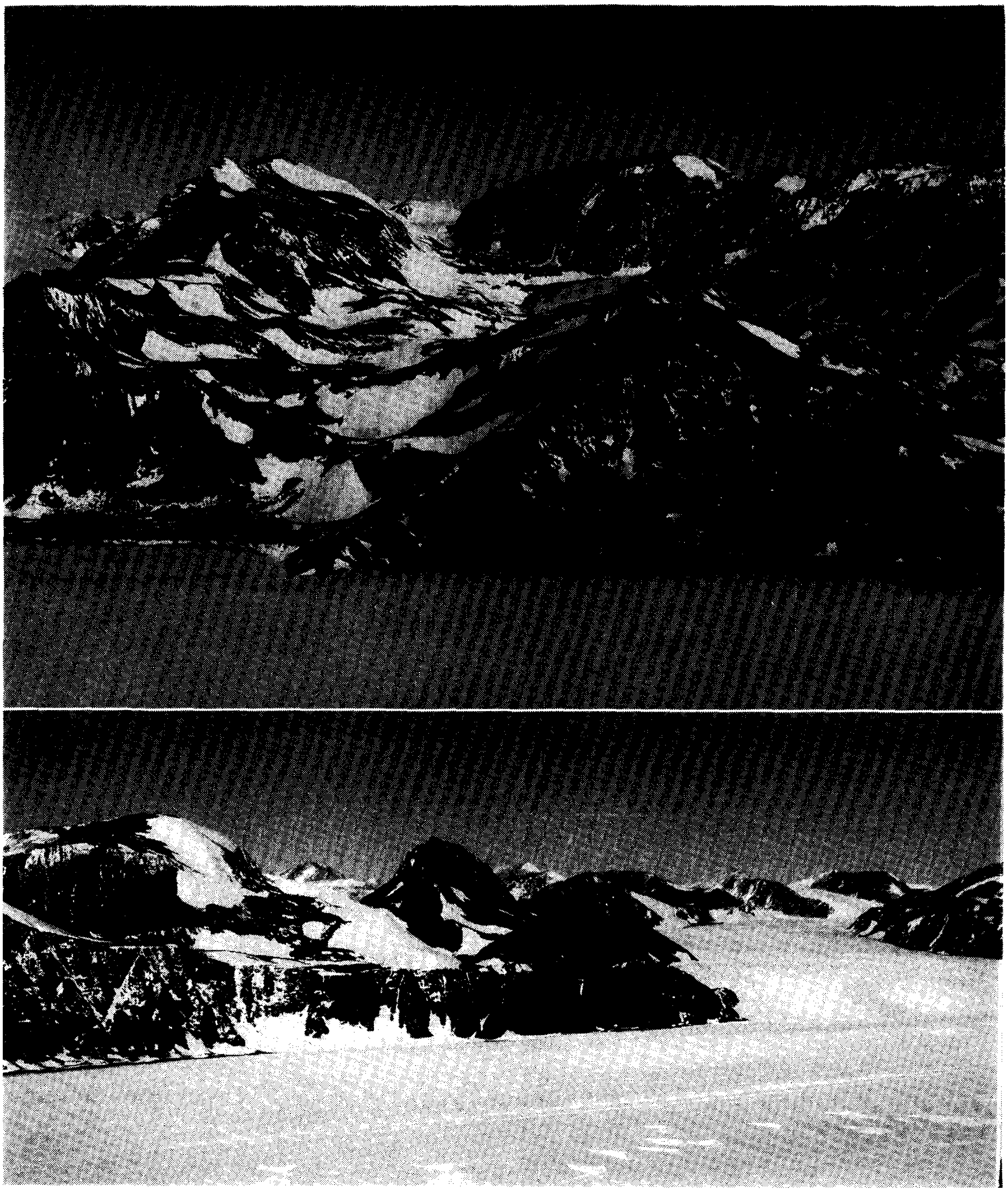


Plate 5. *9: Central and southern Mefjell, viewed southward from the Menipa. A U-shaped valley sloping from the southern inland plateau (center), knife ridge and glaciated col (left; arrow), smoothed summit (center to right in the background) are noticeable. Also attention to an asymmetric ridge (front).*

10: Southwestern Mefjell and eastern Dufekfjellet in the background, viewed from the summit of the Lunckeryggen.

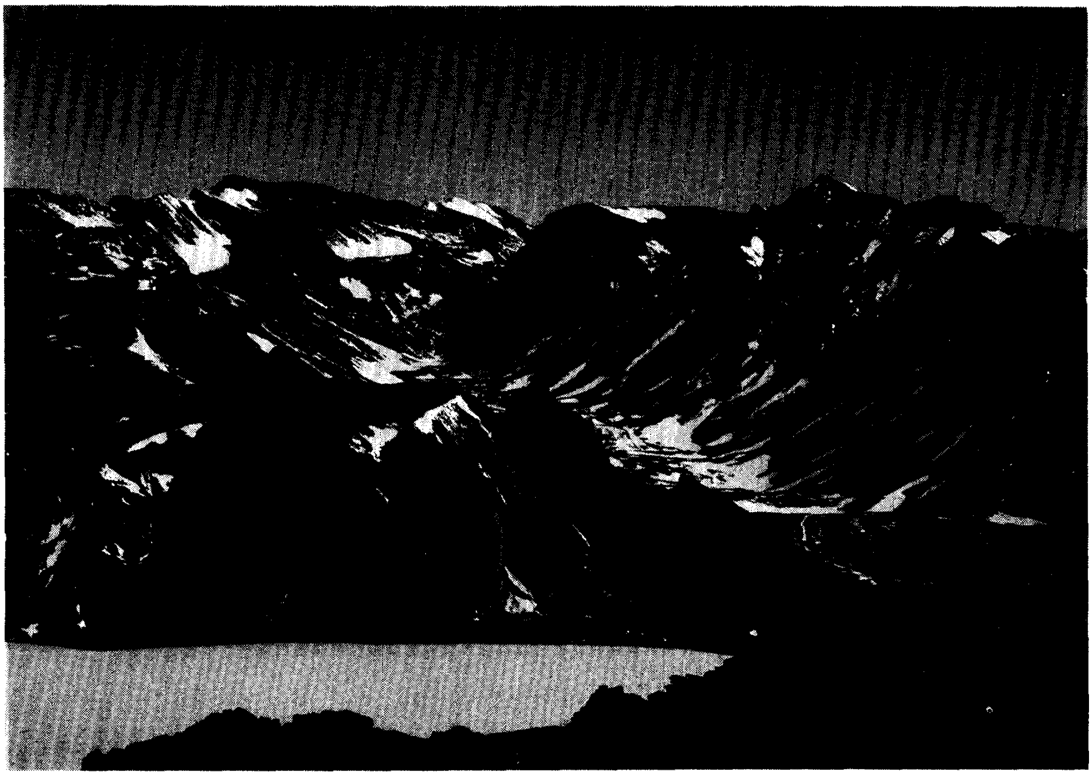


Plate 6. 11: Central Mefjell viewed from the Menipa; the flat surface covered with thick moraines (left) and ridge and peaks on the opposite side of the U-shaped valley (right).