—研究ノート—
Scientific Note

Preliminary Report on Rock Glaciers at the Foot of Mt. Riiser-Larsen in Enderby Land, East Antarctica

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東南極エンダビーランド，リーセルラルセン山麓の岩石氷河

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要旨: 東南極，エンダビーランドのリーセルラルセン山麓において従来山岳モレーンとして解釈されてきた地形の一部は，風化程度の小さい安息角をなす前縁斜面と上部斜面の畝と溝を持つ微地形の存在および他の地域で報告されている現成の岩石氷河の縦断面形態との類似性から，現成の岩石氷河であると考えられる．現地調査と空中写真判読から岩石氷河の可能性をもつ地形は，崖錐の基部，上部に大きな雪渓・氷河を持つモレーンの末端，およびカール底に集中して分布する傾向が明らかになった．これまで南極における現成の岩石氷河の記載は少なかったことから，南極沿岸域の地形形成環境を明らかにする上で今後，継続した気温・地温，岩石氷河の流動に関する観測が望まれる．

Abstract: Part of the debris slopes previously defined as alpine moraines at the foot of Mt. Riiser-Larsen were considered to be active rock glaciers in terms of longitudinal profiles, degree of weathering, size of surface boulders and morphological similarities with active rock glaciers in other regions. Possible rock glaciers tend to occur at the foot of talus, the bottom of cirques and the tips of moraines below snow patches and/or alpine glaciers. Descriptions of rock glaciers in Antarctica have so far been few. Continuous monitoring of the movement and thermal regime of rock glaciers will be necessary to understand geomorphic environments and processes in the Antarctic coastal regions.

1. Introduction

Mt. Riiser-Larsen (Fig. 1) is located on the east coast of Amundsen Bay, Enderby Land, East Antarctica (66°47′S, 50°40′E). In this region, preliminary surveys on

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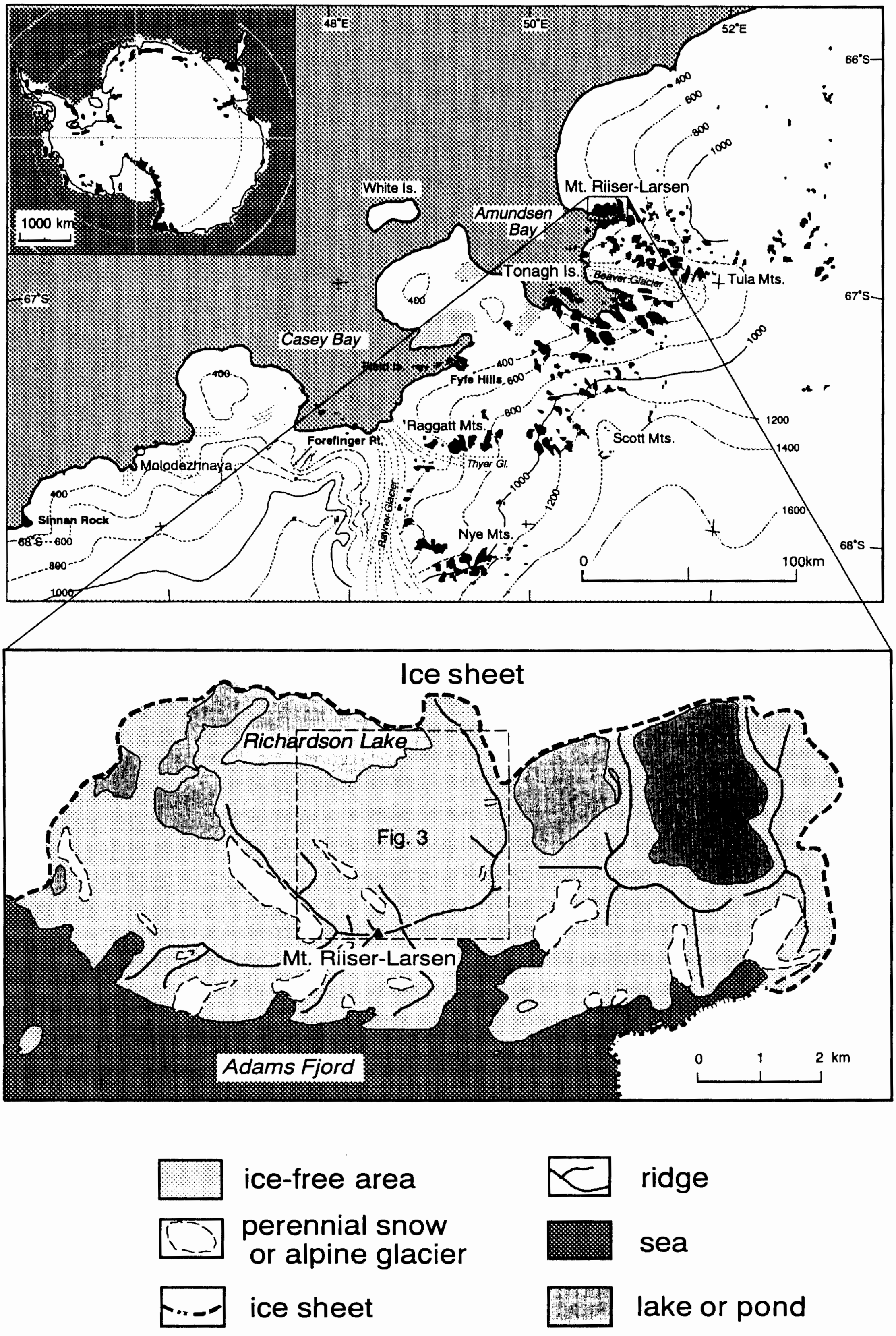


Fig. 1. Index map of the study area.

geomorphology and Cenozoic glacial geology have been performed by the 23rd Japanese Antarctic Research Expedition (JARE-23) and JARE-29. As a result, moraines in this area were classified into two main categories: one was formed by the continental ice sheet and the other by local alpine glaciers (YOSHIDA and MORIWAKI, 1983; ANIYA, 1989; HAYASHI, 1990). After a reconnaissance survey in JARE-35, however, HIRAKAWA and SAWAGAKI (1994) pointed out that some of the alpine moraines (below about 300 m asl) are possibly rock glaciers, because they have a frontal slope with the angle of repose and a top surface with ridge and furrow topography.

In Antarctica, active rock glaciers have been reported from only a few regions: King George Island (BARSCH *et al.*, 1985; BARSCH and MÄUSBACHER, 1986), Southern Victoria Land (MAYEWSKI, 1979; MAYEWSKI and HASSINGER, 1980) and the Transantarctic Mountains (MJAGKOV, 1980). Active rock glaciers lie above the lower boundary of discontinuous permafrost and below the glacial equilibrium line, and they are the most prominent and visible form of creep of mountain permafrost (HAEBERLI, 1985; BARSCH, 1996). Therefore, rock glaciers can be used as an indicator of permafrost environments and climatic change. The present paper discusses whether or not a debris slope of the Mt. Riiser-Larsen area is a rock glacier, on the basis of morphological and sedimentological measurements, undertaken by JARE-37 in February 1996, and morphological comparison with active rock glaciers in other regions.

2. The Meteorological Condition and Potential for Rock Glacier Formation

Quantitative data on meteorology and ground thermal conditions have not yet been obtained in the study area. However, air temperature records are available at Molodezhnaya Station (67°40′S, 45°50′E, 42 m asl; Fig. 1) and Mawson Station (67°36′S, 62°53′E, 16 m asl), which are about 250 km to the WSW and about 600 km to the ESE of Mt. Riiser-Larsen, respectively. The mean annual air temperatures (MAAT) at each station are −10.9 and −11.2°C (NATIONAL INSTITUTE OF POLAR RESEARCH, 1985). Similarity in both latitude and altitude with these stations suggests that the MAAT at the foot of Mt. Riiser-Larsen is around −11°C. Furthermore, the annual precipitation in the study region has been estimated to be less than 20 cm of water by RUBIN (1962). Active rock glaciers prefer continental, comparatively dry climates with cold winters. BARSCH (1996) presented a modified diagram of the cryosphere structure (Fig. 2), which was originally illustrated by HAEBERLI (1983). This diagram displays the relationship between the nival and cryogenic belts as a function of the MAAT and mean annual precipitation for the Swiss Alps. The stippled area in Fig. 2 shows the potential zone of rock glacier formation, and the solid star shows the expected meteorological condition for the foot of Mt. Riiser-Larsen. According to this diagram, the Mt. Riiser-Larsen region is favorable for the development of active rock glaciers.

3. Morphology and Materials of a Debris Slope: Is It an Active Rock Glacier or Not?

Active rock glaciers are usually characterized by relatively light-colored frontal and

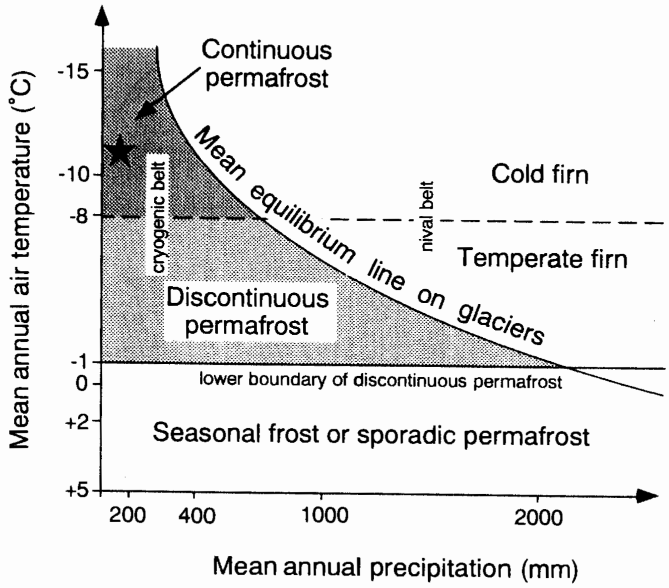


Fig. 2. The cryosphere structure diagram (after Haeberli, *1983) displays the relationship between the nival and the cryogenic belts as a function of mean annual air temperature and mean annual precipitation for the Swiss Alps (after* Barsch, *1996). The stippled area shows the potential zone of rock glacier formation, where debris accumulations exist and can be perennially frozen. The solid star shows the present environment of the Mt. Riiser-Larsen region, estimated from the meteorological data at Molodezhnaya Station and by* Rubin *(1962).*

side slopes, composed of fine materials, with the angle of repose and a top darker bouldery surface with a number of furrows and ridges (Potter, 1972; Washburn, 1979; Barsch, 1988, 1996), so that rock glaciers can be differentiated from moraines in terms of longitudinal profiles (Wahrhaftig and Cox, 1959; Brine and Thom, 1982). For this reason, the longitudinal profile of a west-facing debris slope (A–A′ in Fig. 3) was measured with a hand-level and a 50-m long tape. The longitudinal change in boulder size was also investigated by measuring the maximum diameter of the 35 largest boulders in a square of 10 m × 3 m on the surface at five nick points and one point on the frontal slope. The debris covering this slope has been referred to as Moraine 2 (Yoshida and Moriwaki, 1983), Alpine Till II (Aniya, 1989) and Mt. Riiser-Larsen Moraine II (Hayashi, 1990).

The obtained longitudinal profile is shown in the lower part of Fig. 4. The slope above point A1, with an inclination of 32° at the foot of the free face, is evidently part of a talus slope. The gentle portion between points A1 and A4 consists of slopes with ridge and furrow topography (Fig. 5). The relative height between a ridge and a furrow is approximately 1 m, and the wave length of the ridge and furrow topography is approximately 3 m. The longitudinal profile has a steep slope between points A4 and A6 with an inclination of 35° which indicates the angle of repose (Fig. 6). The relative height of this steep slope is about 12 m. The slope below point A6 shows also a gentle inclination of 20–22° The longitudinal change in boulder size is shown in the upper part of Fig. 4, in terms of the maximum, minimum and average values of the long-axis diameter. The smallest boulder size occurs in the middle part of the frontal slope

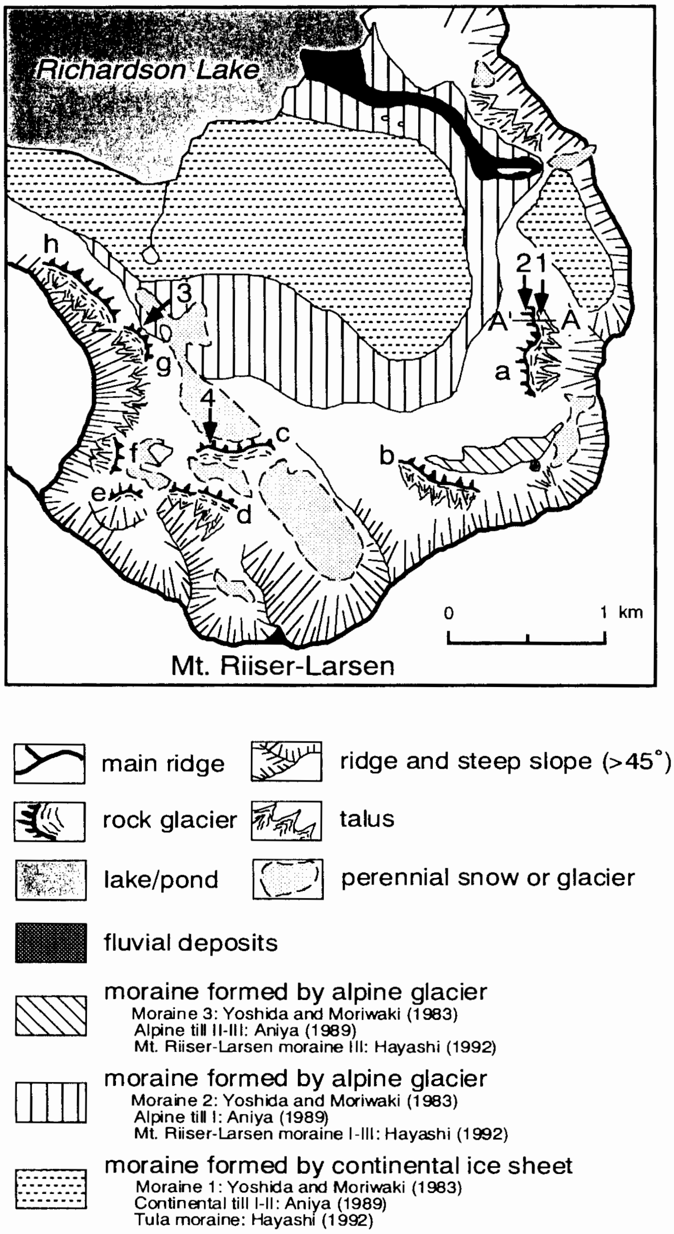


Fig. 3. The study site and distribution of possible active rock glaciers. Line A–A′ indicates the site of the longitudinal profile. The symbols a to g show possible active rock glaciers. The numbers 1, 2, 3 and 4 show the photograph sites in Figs. 5, 6, 8 and 9, respectively.

(point A5) and the largest in the lower part (point A6). This fact suggests that fall sorting (grain size grading) (RAPP, 1960) has occurred on the frontal and side slopes. In addition, the front and side slopes are composed of unweathered fine materials devoid of lichens, and they appear fresher than the upper surface.

As shown in Fig. 7, the longitudinal profile at the foot of Mt. Riiser-Larsen is very similar to those of active rock glaciers in Alaska (WAHRHAFTIG and COX, 1959) and the Falkland Islands (BRINE and THOM, 1982). The slope morphology between points A4 and A6 with the angle of repose appears to be equivalent to the frontal slope of these

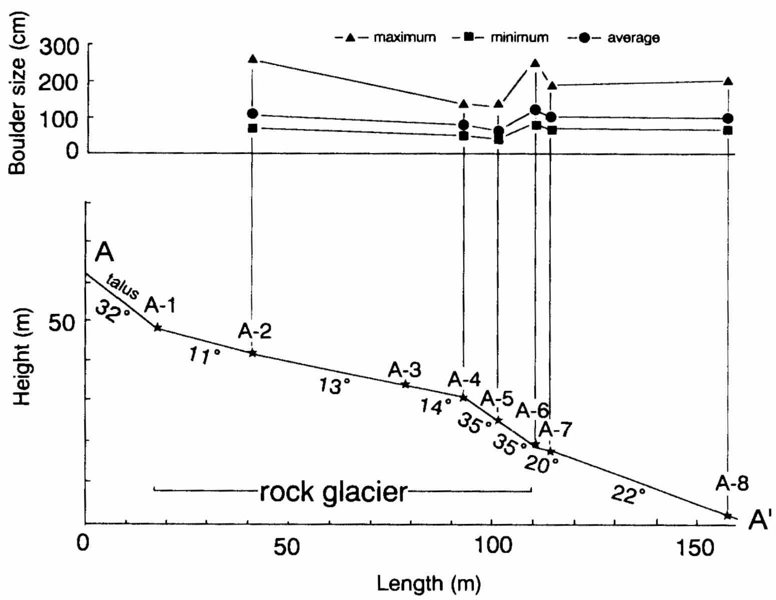
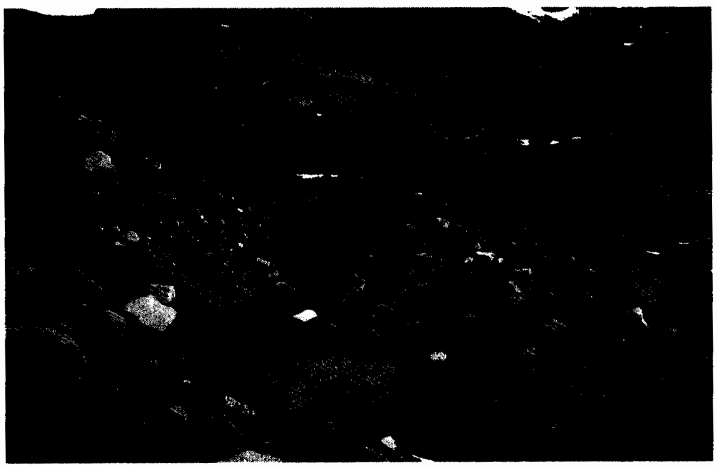


Fig. 4. The longitudinal profile A–A′ and change in boulder size. Boulder size shows the maximum, minimum and average values of the long-axis length for the 35 largest boulders in a square of 10×3 m on the surface.



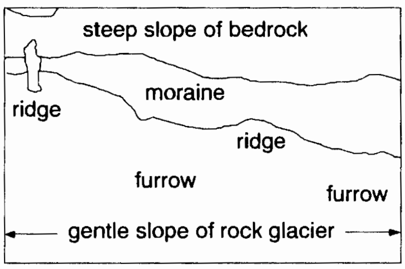


Fig. 5. The ridge and furrow topography on a gentle debris slope of profile A–A′. The photograph site is shown by arrow 1 in Fig. 3.

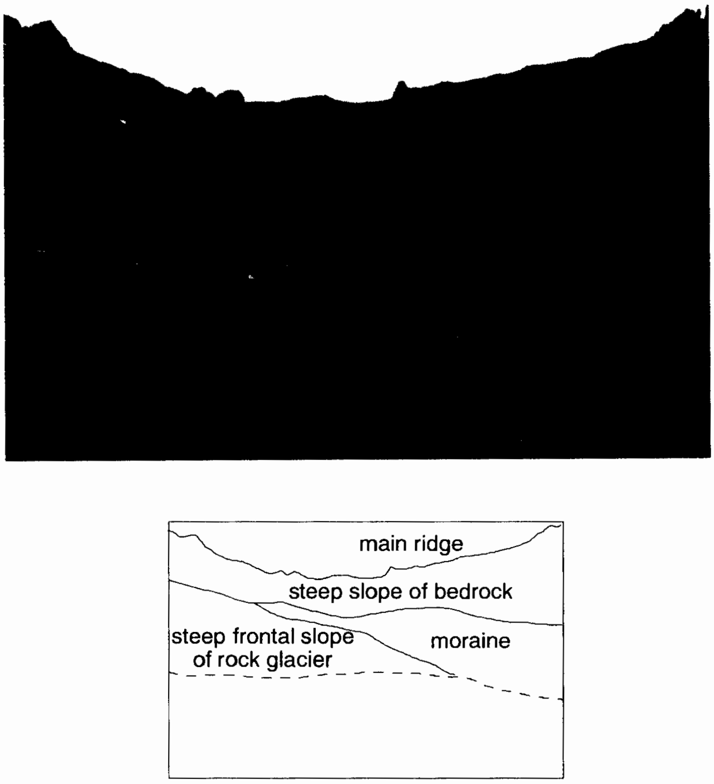


Fig. 6. The frontal slope of a rock glacier (profile A–A′), with the angle of repose. The photograph site is shown by arrow 2 in Fig. 3.

active rock glaciers. The occurrence of fall sorting on the relatively fresher frontal slope also indicates that the slope is active (HAEBERLI, 1985). All of these features suggest that the measured debris slope is an active rock glacier.

4. Distribution of Possible Rock Glaciers at the Foot of Mt. Riiser-Larsen

On the basis of the field observation and air-photo interpretation using Australian air-photographs, SQ39-40/9 MT. RIISER LARSEN, some debris slopes similar to the measured one were found around the foot of Mt. Riiser-Larsen. Such possible active rock glaciers were identified by the following features: (1) a steep slope with the angle of repose at the frontal part (Figs. 8 and 9), (2) ridge and furrow topography on the gentle debris slope above the steep frontal slope (Fig. 8), and (3) accumulation of relatively larger boulders at the foot of the steep frontal slope, suggesting fall sorting (Fig. 9). Figure 3 shows the distribution of possible active rock glaciers in this region. These possible rock glaciers tend to occur below the foot of the talus (a, b, d, f, g, h in Fig. 3), the bottom of the cirques (e in Fig. 3) and the tip of the moraine (c in Fig. 3) below snow patches and/or alpine glaciers. Rock glacier c in Fig. 3 seems to originate from an alpine glacier moraine. Rock glaciers have often been classified into two types, tongue-shaped and lobate rock glaciers, using the length-to-width ratio (DOMARADZKI, 1951; WAHRHAFTIG and COX, 1959). From the morphological viewpoint, all possible

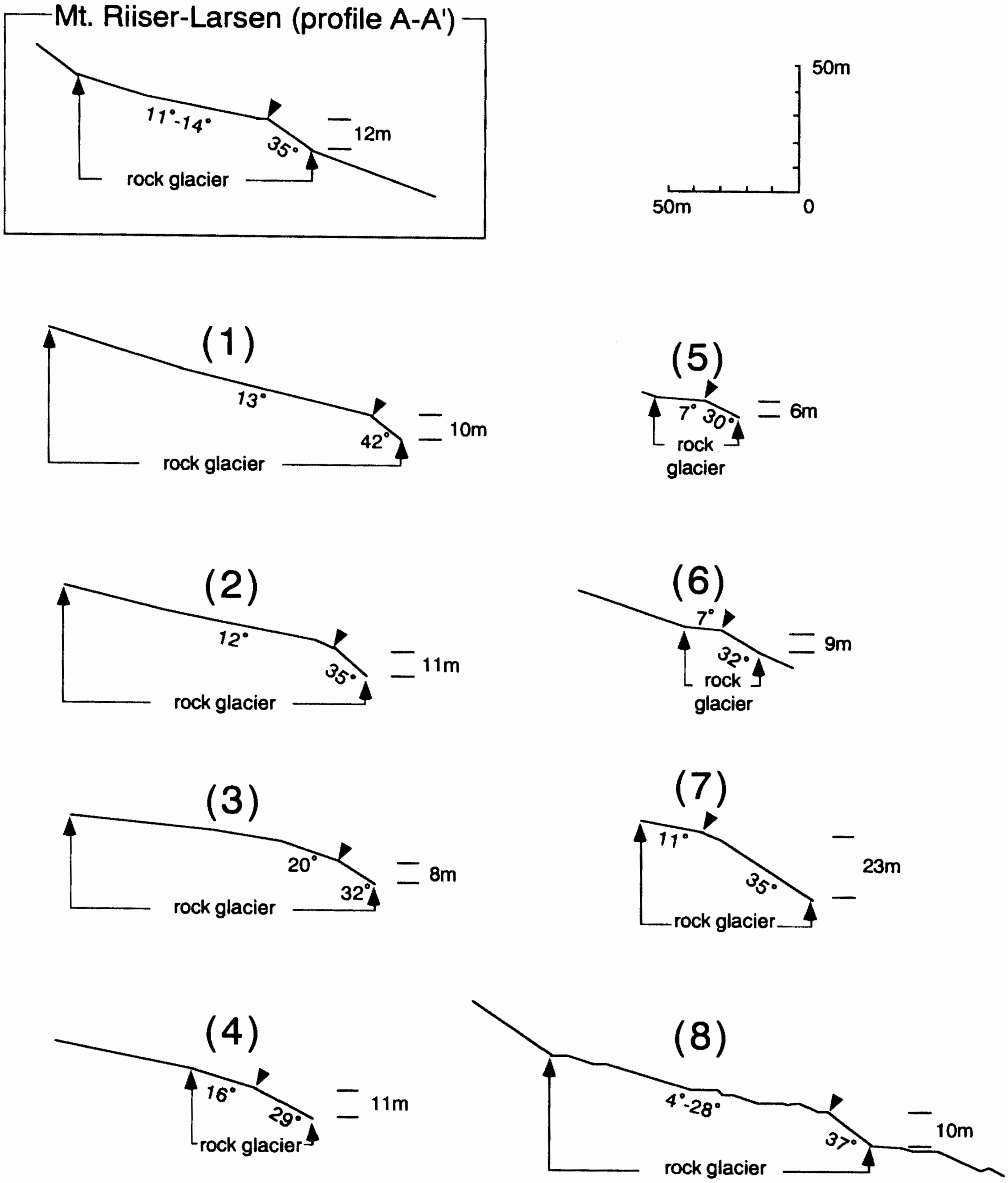


Fig. 7. Comparison of the longitudinal profile of the measured debris slope on Mt. Riiser-Larsen (profile A–A′) with those of active rock glaciers. Profiles 1 to 7 show active rock glaciers in Alaska (WAHRHAFTIG and COX, 1959) and 8 shows an active rock glacier in the Falkland Islands (BRINE and THOM, 1959).

active rock glaciers in this region can be defined as lobate rock glaciers.

5. Conclusion

In terms of longitudinal profiles, size of surface boulders and morphological

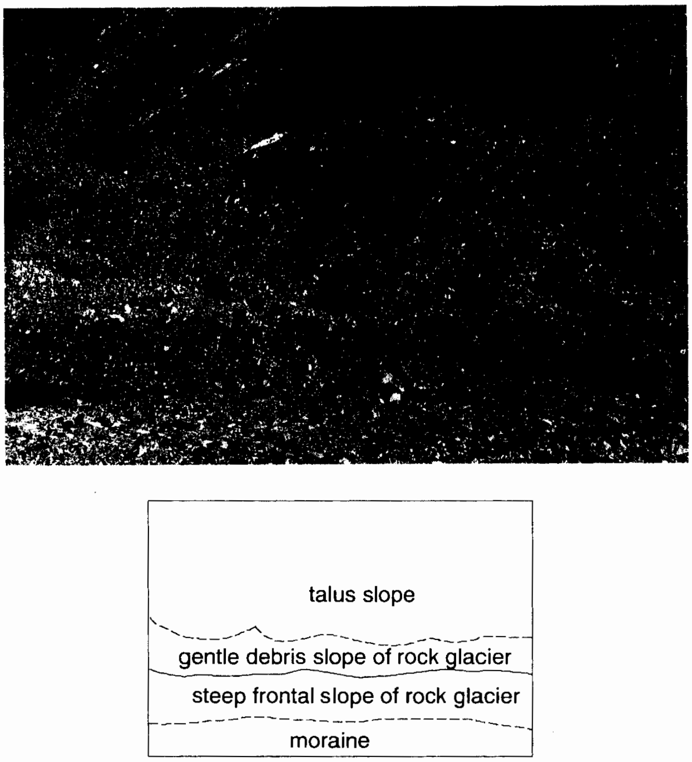


Fig. 8. The ridge and furrow topography on a gentle debris slope above a steep frontal slope. The photograph site is shown by arrow 3 in Fig. 3.

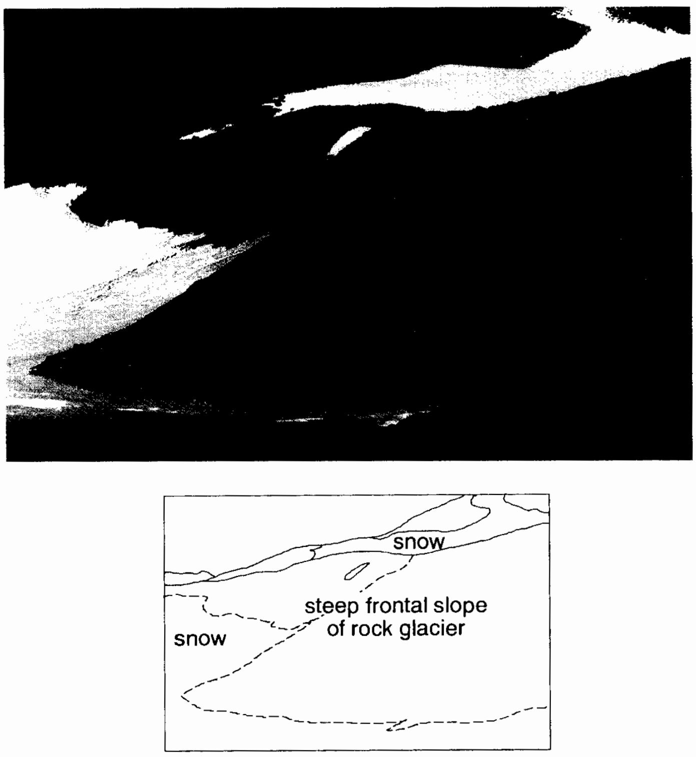


Fig. 9. A frontal slope with the angle of repose. The photograph site is shown by arrow 4 in Fig. 3.

similarities with active rock glaciers in other regions, part of the debris slopes previously reported as moraines at the foot of Mt. Riiser-Larsen were considered to be active rock glaciers. A number of such possible rock glaciers can be found in this region. Descriptions of rock glaciers in Antarctica are rare, so that continuous monitoring of the movement of rock glaciers and related air and ground temperatures are very important for evaluating the contemporary geomorphic environment and environmental change in the Antarctic coastal region.

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