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Internal structure of stone-banked lobes and terraces on Rink Plateau, James Ross Island, Antarctic Peninsula region

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Abstract: Large-scale stone-banked lobes and terraces are distributed over an area of 1 km^2 of gentle slope on Rink Plateau in the northern part of James Ross Island, Antarctic Peninsula region. Topographically, there are two main features: relatively high risers up to 5 m high and distinct frontal ridges. In order to understand the processes responsible for these lobes and terraces, the authors have monitored air and ground temperatures and movement of stones on the surface over the period 1995–2005. In February 2005, the subsurface structures were surveyed by ground penetrating radar and drilling. The ground penetrating radar profiles identified the bedrock surface. The surface morphology of the lobes corresponds closely with that of the bedrock. The relatively high risers of these lobes are presumed to be due to a cessation of frontal advance.

Key words: Antarctic Peninsula, James Ross Island, ground penetrating radar, stone-banked lobe, solifluction.

Introduction

Numerous stone-banked lobes are present on Rink Plateau, northwestern James Ross Island, Antarctic Peninsula region (Strelin and Malagnino 1992, Figs 1, 2). Topographically, two main features were identified: the high risers despite the gentle slope gradient with an average 4° and distinct frontal and lateral ridges (Mori *et al*. 2006a).

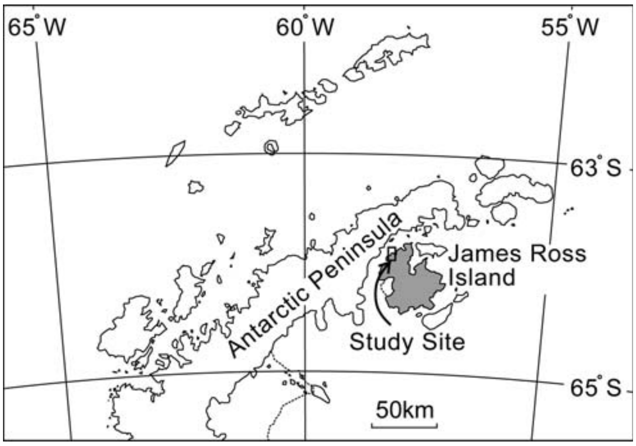

Fig. 1. Site map. Rink Plateau is situated in the rectangle, indicated as "Study Site".

The relative velocity of the solifluction movement, which locally develops into the lobate forms and the frontal advance, appear to affect the topography and its internal structure. Deceleration of lobate flow should produce the high risers (*e.g*. Benedict 1970; Smith 1988; Matsuoka 2001).

Monitoring of marker lines painted across three lobes indicates that lobe movement is rapid on the central, upper parts of the treads and decreases downslope (Mori *et al*. 2006a). However, movement of material on the tread surface is apparently faster here than that described in previous studies of lobes located on similarly gentle slopes (Matsuoka 2001).

Despite the rapid movement on the tread surfaces, there was no discernible movement on the front and sides of the lobes. Frontal advance velocities, which have been reported in previous studies, have ranged from 0.1 to a few cm/yr (Matsuoka 2001). At the lower velocities, it is very difficult to detect movement by means of ground survey. These slow advances have been measured by buried organic materials and the internal structure (Benedict 1970; Harris 1981; Matsuoka 2001). However, organic materials are not sufficient for dating in the region of present study.

Only limited descriptions of the internal structure of stone-banked lobes and terraces exist. Mori *et al.* (2006a) described internal structure of frontal part of the lobes on Rink Plateau, but the description was limited to the topmost 60 cm. Deeper excavation is difficult here because of the existence in permafrost. In order to determine the subsurface structures of permafrost regions, ground penetrating radar (GPR) has been applied elsewhere (*e.g.* Moorman *et al.* 2003). It also appears to be useful in studies of solifluction deposits in non-permafrost areas, where the layering of such sediments was easily demonstrated (Sauer and Felix-Henningsen 2004). However, periglacial landforms such as stone-banked lobes have yet to be investigated by this technique. We therefore decided to apply the technique to the stone-banked lobes of James Ross Island.

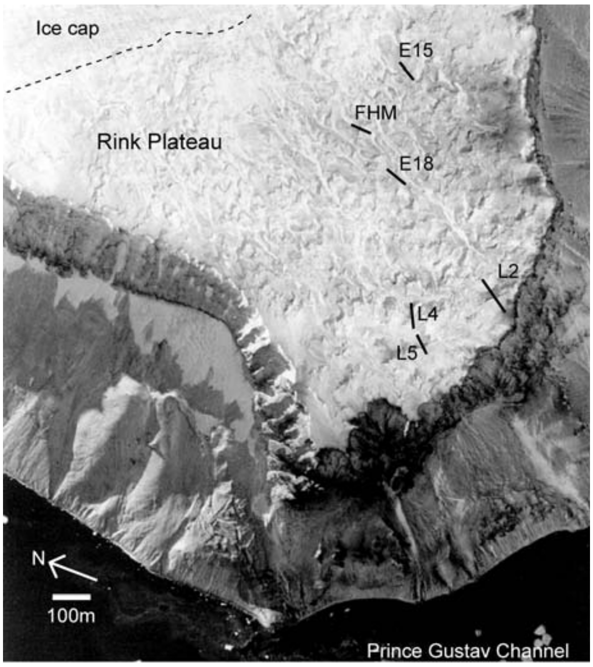

Fig. 2. Air photo of the Rink Plateau. The photo was taken from the northwest. Black lines denote transects, which were sounded by means of the GPR method.

Study area and climatic conditions

Rink Plateau (63°55'S, 58°10'W; Fig. 1) is situated on the northwestern part of James Ross Island, Antarctic Peninsula Region, and has a mean altitude of 400 m above sea level. The geology of the plateau consists of Cenozoic lavas and pyroclastites underlain by more easily-eroded Cretaceous sedimentary rocks (Strelin and Malagnino 1992; Carrizo *et al*. 1998). Unconsolidated tuff layers are occasionally present between the lava sheets. The upper part of the plateau is covered by a small ice cap. Rock glaciers and protalus ramparts develop on the talus slope of the crags.

Solifluction lobes and terraces are widely developed on the plateau (Fig. 2). They have stony frontal risers and are classified as either stone-banked terraces or lobes according to the classification of Benedict (1970). However there being no difference between them except for the ratio of width and length, we regard them all as lobes herein.

The mean annual air temperature of the study area is –6.7°C (1996–2004). Annual precipitation occurs mostly as snow and, at Lachman Crags, about 20 km east of the study site, it is estimated to be around 200 mm water equivalent (Strelin and Sone 1998). Snow-accumulation monitoring indicates that snow

Fig. 3. Side view of L2 lobe. As a scale, a person stands on the tread surface. The height of this lobe is about 5 m. Average slope gradient (4°) is shown with white broken line.

depth is greatest on the riser slope of lobes, reaching more than 1.4 m in depth. Nivation hollows occur on the foot of the frontal riser slopes of some of the lobes. On the treads of the lobes, maximum snow depth is generally less than 0.2 m (Mori *et al*. 2006b).

James Ross Island is located in continuous permafrost area (Borzotta and Trombotto 2004). On Rink Plateau, the active layer depth for the period 1999 to 2003 has been estimated at 42–75 cm (Mori *et al*. 2006b).

Methods

In January 2005, 6 lobes (L2, FHM, E15, E18, L4 and L5; Fig. 2) were sounded with GPR method. The GPR system used was the Noggin 250, manufactured by Sensor and Software Inc., Canada, which uses a frequency of transmitter and receiver units and antennas of 250 MHz.

On the transect of lobe L2, two boreholes were sunk and the cores were analyzed for comparison with the GPR data. Borehole 1 (BH1) was drilled down to a depth of 2 m on February 16th, 2005, and borehole 2 (BH2) to 0.6 m on February 17th, 2005. BH1 was situated on the tread surface, the distance from the top of the frontal riser being 0.7 m. BH2 was 12.4 m upslope from BH1.

Results

All GPR profiles of lobes show clear reflections down to a depth of 3 m. Figure 4 shows the GPR profiles of L2 and FHM lobes. The riser height of L2 lobe is 50 cm and that of FHM lobe 2.6 m. Figure 5 shows the profile of L2 fitted to topography.

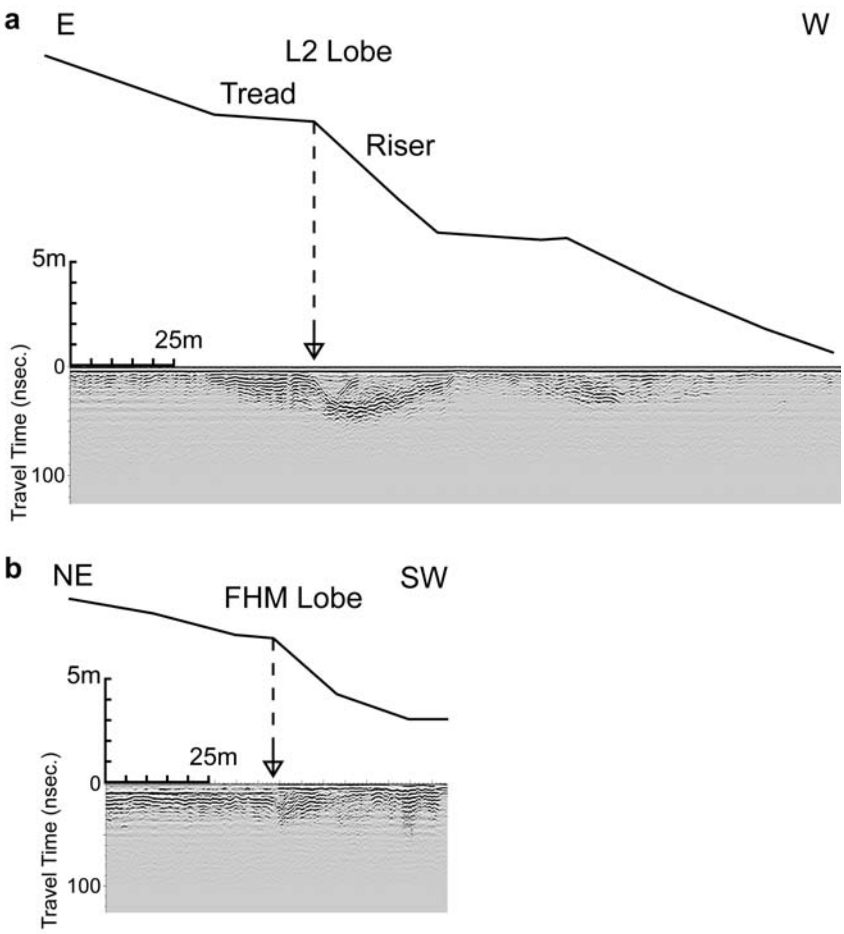

Fig. 4. GPR profiles and surface topography of (a) L2 lobe and (b) FHM lobe. The arrows indicate the corresponding position (top of the frontal riser) on the GPR profiles.

The depths of the deepest reflection are variable and greatest below the lobes (Figs 4 and 5). Beneath the upper riser, the boundaries are the deepest. They are shallower both upslope and downslope and are formed to be stepped. Beneath the frontal riser slope, another boundary was recognized between the surface and the deepest reflection. These relationships between boundaries and surface topographies are independent of lobe size (Fig. 4).

In BH1, from the surface to 1.22 m depth, the sediments are sandy-silts with gravels. From 1.22 m to 2.00 m deep, the sediments consist of gravels with finer matrix and the surface of bedrock is at 2.00 m depth. Thaw depth is 0.63 m and the frozen soil has a high water content. In BH2, from surface to 0.45 m, the sediments are similar to those in BH1. From 0.45 m to 0.62 m, sediments consist of gravels with fine matrix and the surface of bedrock is at 0.62 m. Thaw depth is 0.35 m (Fig. 6).

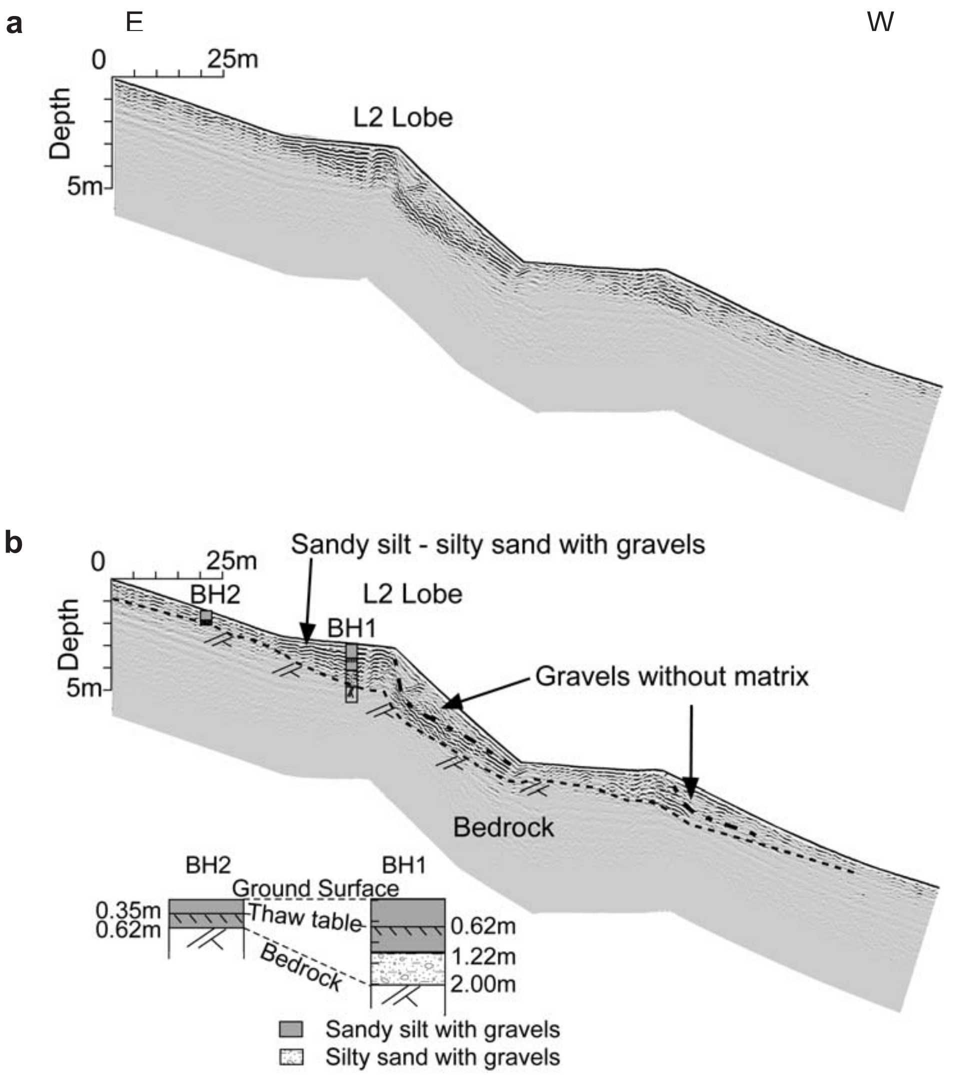

Fig. 5. GPR profile of L2 lobe fitted to the surface topography (a) and its interpretation (b). The positions of boreholes BH1 and BH2 are indicated on the modified GPR profile.

Discussion

Interpretation of the GPR results. — Given the control afforded by BHs 1 and 2, the clear reflections in GPR profiles are interpreted as coming from the bedrock surface (Fig. 6). Over the bedrock, there are sediments with fine materials. Excavations of the frontal part or the lobe (Mori *et al*. 2006a), show that the internal boundaries beneath the frontal slopes are best interpreted as the boundaries between fine sediments and coarse sediments without finer-grade matrix.

Internal structure and lobe movement. — Studies of the movement of the stone-banked lobes and their internal structure provide information about the processes which brought them into being. There are two types of movement in the downslope movement of stone-banked lobes; the tread surface movement and the frontal advance. The combination of these movements determines topography and structure of stone-banked lobes. In the Andes of Peru and Bolivia, where they have relatively rapid frontal advance velocities (up to 3 cm/y), riser heights are less than 1 m (*e.g*. Francou 1990), whereas the Rink Plateau risers are as much as 5 m. In the Rink Plateau, surface movement of the tread surface was rapid but frontal advance velocities could not be detected by ground survey (Mori *et al*. 2006a).

Some authors have described solifluction rates on the tread surface. These are highest in the axial zone of the treads of solifluction lobes, and decrease toward the sides and towards the lobe front (*e.g*. Harris 1981; Benedict 1970). Lines painted across the lobes in our study site also showed this movement pattern (Mori *et al*. 2006a). Sedimentation should occur where the flow speed becomes slower. In spite of the solifluction activity on the tread, the frontal advance is minimal. Hence, the sediments should be deposited at the front of the tread. In fact, the internal structures, as determined from the GPR soundings, show that the thickness of the sediments is greatest at the top part of the riser, and they become thinner upslope (Figs 4 and 5).

Just beneath the top of each riser slope, a step on the bedrock was identified. This structure is confirmed in the profiles of both small (FHM) and large lobes (L2) (Fig. 4). It seems likely that the step of bedrock was the trigger for the development of stone-banked lobes. We consider that the lobe fronts do not advance and that the lobes simply grow higher at the nearly same position. We suggest that the frontal parts hardly move from the early stage of the development of lobes in this study area, and, as a result, the lobes grow higher than it is typical for this landform.

Conclusions

The internal structure of stone-banked lobes on Rink Plateau, James Ross Island, Antarctic Peninsula region, have been investigated by a GPR method and drilling.

- The bedrock surface below the lobe was located by GPR. The surface topography is determined by the thickness of sediments and the shape of the bed rock surface.
- The top parts of the lobe risers are situated just above a bedrock step, from which we deduce that the development of the lobes must be controlled by the feature. It is likely that the frontal parts hardly move from the early stage of lobe development.

- Owing to rapid surface movement of riser part and a lack of frontal advance, the sediments must be deposited at the frontal part of the tread. This may explain the high elevation of the stone-banked lobes on Rink Plateau.

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