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Supraglacial eskers in Antarctica

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ABSTRACT

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This paper describes eskers that form at the edge of the ice sheet in the Vestfold Hills, Antarctica. Eskers are linear ridges that are deposited by streams constrained by glacier ice. Their formation requires a sediment source and the presence of meltwater capable of thermal erosion and penetration of glacier ice. These requirements mean that eskers are generally associated with temperate glaciers and are not usually associated with cold, polar glaciers. The eskers described in this paper form small ridges of gravel adjacent to ice-cored moraines. The form, orientation, sedimentary properties together with consideration of the field relationships suggests they were formed by supraglacial streams that drain moraine-dammed lakes and recycle sediment deposited on ice-cored moraines. The small size of the eskers combined with the active nature of ice marginal processes in the area means the eskers have a low preservation potential and do not occur beyond the ice margin in the Vestfold Hills.

Introduction

Eskers are linear accumulations of stratified gravel and/or sand that are deposited by a stream that was confined by glacier ice (Banerjee and McDonald, 1975). Although Price (1973) suggested that eskers can form in subglacial, englacial, proglacial and supraglacial environments he considered that the form and internal characteristics of the deposits could not reveal in which environment they formed. In contrast, Banerjee and McDonald (1975) and Saunderson (1977) argued that open-channel, deltaic and tunnel eskers can be distinguished on the basis of sedimentary facies.

Eskers are the products of highly organised meltwater flow systems within glaciers and are common where an abundant supply of meltwater is available (Banerjee and McDonald, 1975). The formation of eskers requires that meltwaters are able to thermally erode and penetrate glacier ice and are therefore normally associated with temperate glaciers where the ice is at pressure melting point (Embleton and King, 1975). Although Embleton and King did not give examples of supraglacial eskers on cold, polar glaciers they consider that they would be rare because polar glaciere carry low volumes of supraglacial debris. Stuveir et al. (1981) described eskers amongst the Ross Sea Drift in the Dry Valleys area of southern Victoria Land Antarctica. These eskers from sinuous ridges from 200 m to 2 km long and up to 20 m high. The trend of the eskers is parallel to the axes of the Dry Valleys and they are considered to have been deposited by a grounded ice sheet (Stuiver et al., 1981).

The eskers described in this paper have formed on the surface of cold ice at the margin of the Antarctic ice sheet. The location, orien-

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tation, sedimentary properties and field relationships of the eskers are described and a model of their formation is presented. Taken together, the evidence suggests that the eskers have formed as fills of steep, ice marginal supraglacial channels that are incised by relatively warm meltwater from moraine-dammed lakes. Absence of the features beyond the ice margin suggests that they are ephemeral landforms that do not generally survive deglaciation. The sedimentary fills are derived from an adjacent ice cored moraine.

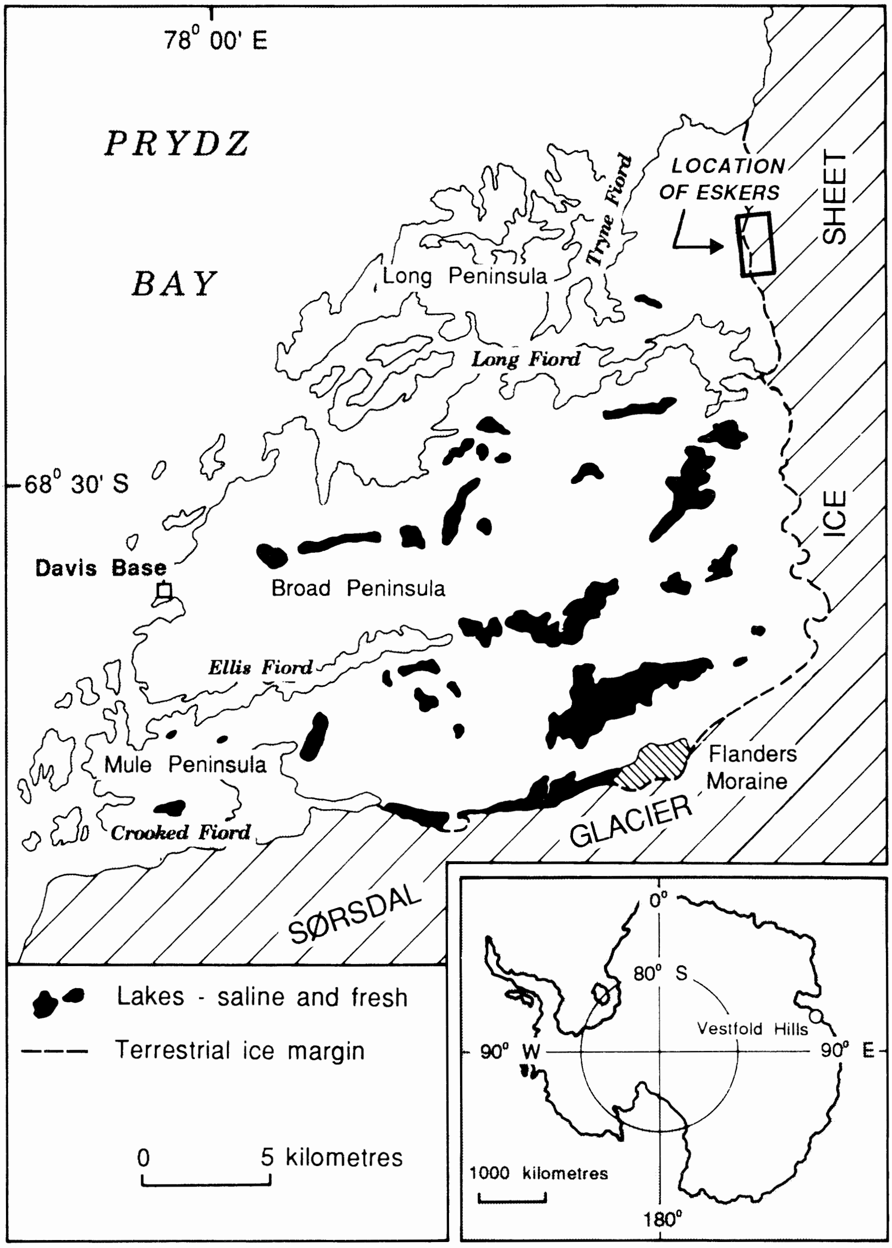

Fig. 1. Location map of the Vestfold Hills. Most of the eskers occur in the shaded area on Long Peninsula.

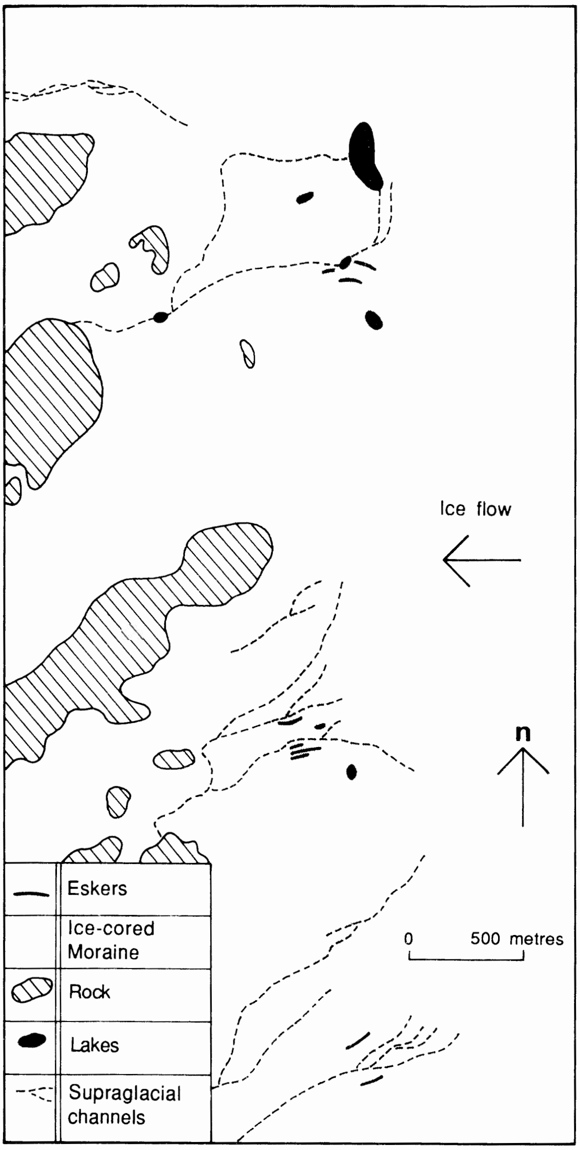

Fig. 2. Map of the eskers and supraglacial drainage network, showing their relationship to the ice-cored moraine and supraglacial lakes.

Field observations

The Vestfold Hills (68°40′S 78°00′E) are an ice free area in Princess Elizabeth Land, Antarctica (Fig. 1). The edge of the continental sheet extends from north to south and the southern limit of the ice-free is the Sørsdal Glacier, which is a local outlet glacier that forms a small ice shelf (Fig. 1). The area has a polar maritime climate with a relatively high mean annual temperature at Davis Station of −10.2°C (Schwerdtfeger, 1970). This temperature is, on average, warmer than other Antarctic stations of similar latitude (Burton and Campbell, 1980). Although there is no precipitation data, snowfall is believed to be light (<250 mm) and rainfall has been known to occur. The climate of the Vestfold Hills is of significance to the formation of eskers because during summer months relatively high temperatures (maximum recorded 13°C, Burton and Campbell, 1980) generate large quantities of meltwater over a short period. At the ice margin the meltwater forms supraglacial streams that often form a dense network. The form and structure of the ice margin of the Vestfold Hills is highly variable. Most of the ice edge terminates in complex topography and is obscured by perennial snow drifts which makes the margin of the ice sheet difficult to distinguish from drift snow. In several areas, superimposed ice formed by in situ metamorphism of drift snow has accumulated at the ice margin and forms an ice and snow wedge as it does at the margin of the Greenland ice sheet (Hooke, 1970). The superimposed ice is more sensitive to thermal erosion because it appears to be warmer than the far-travelled glacier ice (Fitzsimons, unpublished data). The most prominent feature of the north–south trending section of the ice margin is wide ice-cored moraine (Fig. 2). Analysis of recent aerial photographs from 1957 onwards and the common occurrence of lichens up to 120 mm in diameter on the boulders of the moraine indicate that it is in a relatively stable condition.

The eskers occur close to the ice margin on the ice-cored moraine in the northern part of the area adjacent to large supraglacial streams that drain the ice margin. The larger streams cross the ice-cored moraine in broad depressions that form the axes of the drainage system for meltwater. The broad depressions have formed by ablation and the thermal erosion of ice by the meltwater streams over a long pe-

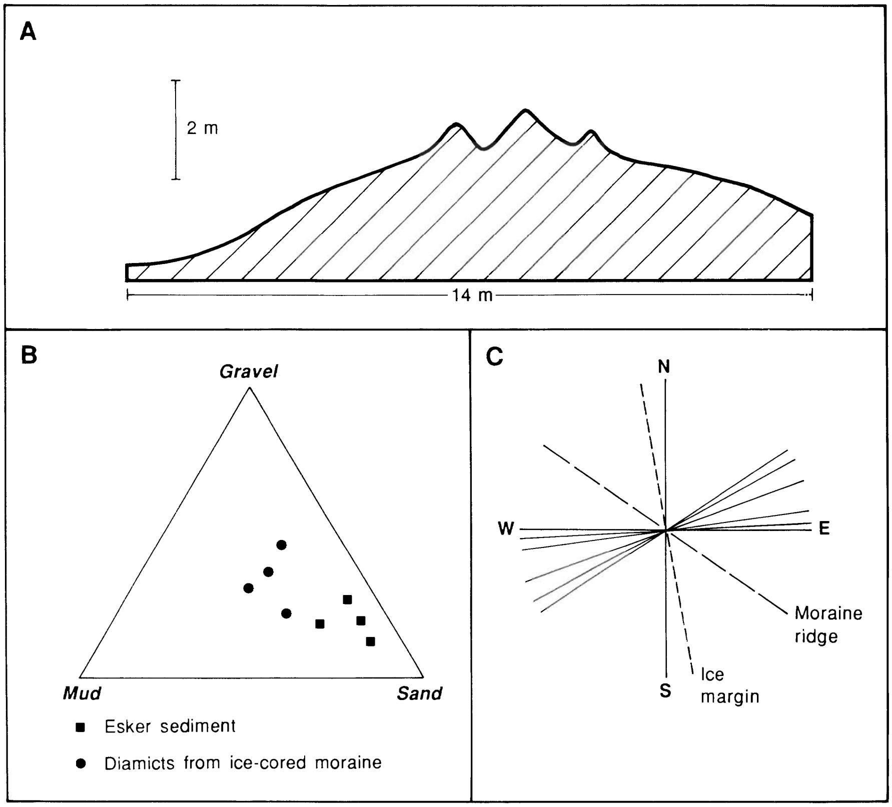

Fig. 3. Characteristics of the eskers. (A) Cross-section of the mound and individual ridge crests. (B) Ternary diagram of the particle size distributions of esker sediments and adjacent diamictons. (C) Orientation of the eskers compared to trend of the ice edge and the ice-cored moraine.

riod. Although the esker ridges occur in the depressions, they lie above the altitude of the contemporary channels which are deeply incised into the superimposed ice and glacier ice.

Compared to the large and long ridges that formed during the Pleistocene in Europe and North America the eskers observed in the Vestfold Hills are very small features. They rise 3 to 6 m above the surface of the ice-cored moraine forming low relief, rounded ridges with small superimposed individual ridge crests 0.5–1.5 m high (Figs. 2, 3A). The ridges form a small-scale network in which individual stream confluences can be identified. Sections of the ridges are relatively short and discontinuous, with the longest sections being about 50 m. The mounds on which the small ridges rest are, however, more continuous and extend up to 100 m into the central part of the ice-cored moraine (Fig. 2). Measurements of the orientation of the features show they are tightly clustered in a direction that is oblique to the trend of the ice-cored moraine and close to perpendicular to the ice-margin (Fig. 3C).

The surface of the rounded ridges consist of sandy gravel with large boulders up to 1.0 m in diameter. Pits dug into the surface of the smaller, sharp-crested ridges showed 0.3–0.4 m of relatively well sorted gravelly sand and sandy gravel (Fig. 3B) overlying ice-cemented gravel. Comparison with the particle size distribution of diamictons from the ice-cored moraine ridge indicate that the sediments are relatively well sorted considering that they have travelled a maximum distance of 300–400 m across the ice-cored moraine (Fig. 3B).

Mechanism of formation

The form, structure and sedimentary properties of the eskers, together with the field relationships suggest that the eskers form as fills of supraglacial channels that carry meltwater and sediment across the ice-cored moraine. Observations of the contemporary processes at the ice margin suggest that the formation of the eskers can be divided into three stages each of which is identified at the ice margin today (Fig. 4).

In stage 1, an ice-cored moraine forms at the margin of the ice sheet. The moraine forms where the basal debris bands are deformed and brought to the surface of the ice. In the area where the eskers form, the moraine is sinuous because it is anchored in places by bedrock hills that protrude from the ice (Fig. 2). In addition to causing the sinuous shape of the moraine, the bedrock hills have caused localised

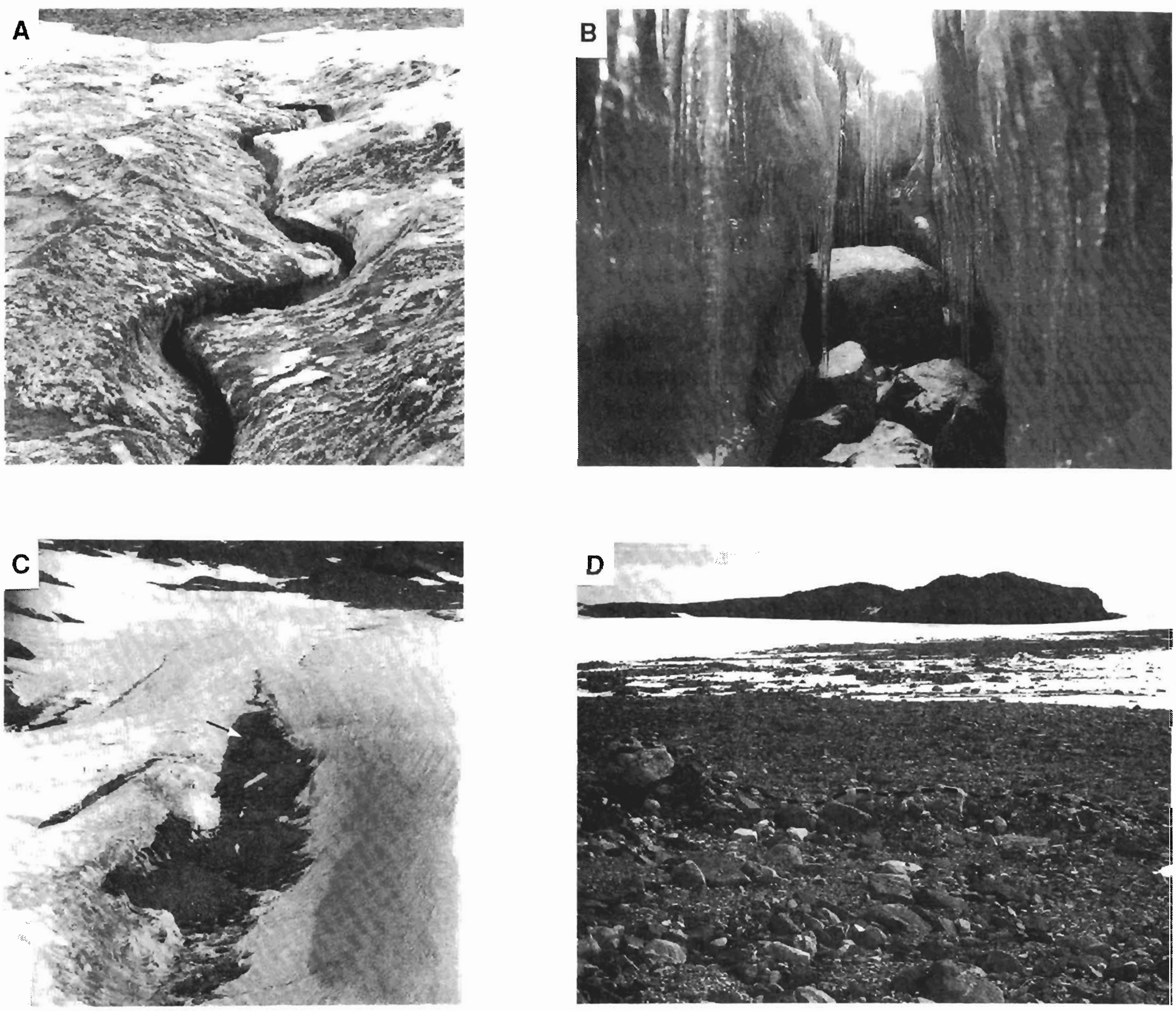

Fig. 4. Supraglacial eskers at different stages of formation at different locations in the Vestfold Hills. (A) Sinuous channel on a low-angle ice ramp. The channel is 0.6 m wide. (B) Narrow, supraglacial channel with vertical walls and a coarse bedload. (C) Fluvial sediments in a broad ablation trough. The sediment fill is 8 m wide and the arrow marks a person. (D) Remnant of an esker ridge with the crests marked by a dashed line.

thickening of the ice margin immediately upstream of the obstructions. This localised thickening gives the ice margin a broad cuspate from which in turn results in concentration of meltwater in the depressions where the ice is free to move (Fig. 2). The direct effects of the ice-cored moraine on the formation of the eskers is that it dams locally produced meltwater and provides a source of sediment. The supraglacial lakes play a key role in the formation of the channels because they provide a relatively warm source of meltwater. Because the lakes are shallow and can become turbid as debris is released during summer, they experience a high radiant heat transfer. Consequently temperatures of the lake waters are relatively high (3.5°C in January) and provide a supply of water capable of significant thermal erosion.

Stage 2 of the mechanism of formation is characterised by release of meltwater from the lakes and incision of the supraglacial channels (Fig. 4A, B). Meltwater is released from the lakes when the dam of seasonal snow that has built up during winter is breached by thermal erosion of the accumulating meltwater. This process occurs in early to mid summer in the months of December and January. Because the water is relatively warm and flows at high velocities when released from the lakes, it rapidly cuts into the relatively warm superimposed ice at the ice margin and the underlying colder glacier ice. Discharges from the lakes are augmented by meltwater that is generated by melting seasonal snow and ice upstream of the ice-cored moraine during the summer months. The process of lake bursts may be repeated over several seasons to produce the narrow, deep channels. Although open-channel eskers are generally braided because they experience high bedload discharges and have steep slopes, the channels at the Vestfold margin are straight or sinuous. Where the ice margin is steep the channels tend to be straight; sinuous channels (Fig. 4A) occur on lower gradient ice slopes. Both straight and sinuous channels are narrow (0.5–1 m) and deep (1.5–3.5 m), with vertical walls (Fig. 4B). Although the channels only operate intermittently, the hydraulic geometry of the channels maintain high velocity streams that are capable of transporting large sediment loads.

During stage 3, sections of the stream network are abandoned as elements of the stream network become further entrenched and/or new channels form. When the channels are abandoned the channel sediment is trapped (Fig. 4B, C). During and after abandonment of parts of the drainage system, relief inversion occurs as the ice surrounding and underlying the channels melts. The relief inversion leaves a broad, rounded ridge of sorted debris along the axis of the former drainage system and individual sharp-crested ridges on the mounds indicate the position of the most recent or larger channels prior to abandonment (Fig. 4D). Although several active channels and channels at various stages of abandonment were observed, the time scale for the formation of the eskers is not clear. However, considerations of the stability of the moraine indicated by analysis of aerial photographs and the occurrence of large lichens suggest that it may have taken several tens to hundreds of years for the present drainage system to evolve.

Conclusion

The eskers described in this paper occur only in the ice marginal area where they rest on a considerable thickness of ice. Observations of ice marginal depositional processes in areas of the Vestfold Hills where the ice margin is unstable indicate that meltwater can become freely available and many deposits are remobilised after deposition (Fitzsimons, 1990). Consequently, the preservation potential of the relatively small esker ridges is low as is demonstrated by the absence of eskers beyond the ice margin. Even though they have a low preservation potential, the formation of the eskers is significant because their formation has generally been associated with temperate glaciers and because they are rarely described in Antarctica. The presence of the eskers demonstrates that they can form in a supraglacial position on cold glaciers when the requirements of a meltwater source capable of penetrating ice and a debris source are met. The occurrence of these eskers support Embleton and King's (1975) hypothesis that supraglacial eskers on cold, polar glaciers would be rare but they can and do form even if they do not generally survive deglaciation.

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