Supraglacial eskers in Antarctica

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ABSTRACT


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 supplied by 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 suggest 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 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 result in which environment they formed. In contrast, Banerjee and McDonald (1975) and Saunderson (1977) argued that open-channel, deaica 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 glaciers carry low volumes of supraglacial debris. Stuive 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 (Stuive 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-
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 rela-

tively 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 cordmoraine.

Fig. 1. Location map of the Vestfold Hills. Most of the eskers occur in the sloped area on Long Peninsula.
polar maritime climate with a relatively high mean annual temperature at Davis Station of \(-10.2^\circ\text{C}\) (Schwerttöger, 1970). This temperature is, on average, warmer than other Antarctic stations of similar latitude (Burton and Campbell, 1980). Although there is no precise data, snowfall is believed to be light (<250 mm) and rainfall has been known to occur. The climate of the Vestfold Hills is of significant to the formation of eskers because of the presence of supraglacial meltwaters. (maximum recorded 13°C, Burton and Campbell, 1988) 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 its margin 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, 70). 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 moraine 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 indicates 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 eges 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.

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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 sediment 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 crest marked by a dashed line.
thickening of the ice margin immediately up\-stream of the obstructions. This localised thickening gives the ice margin a broad cus\-pate from which in turn results in concentra\-tion 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 mel\-twater and provides a source of sediment. The supraglacial lakes play a key role in the forma\-tion of the channels because they provide a rel\-atively warm source of meltwater. Because the lakes are shallow and can become turbid as de\-bris is released during summer, they experi\-ence a high radiant heat transfer. Conse\-quently temperatures of the lake waters are relatively high (3.5°C in January) and pro\-vide 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 ve\-locities when released from the lakes, it rapidly cuts into the relatively warm superimposed ice at the ice margin and the underlying colder gla\-cer ice. Discharges from the lakes are aug\-mented 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 verti\-cal 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 net\-work 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 in\-dividual 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 forma\-tion of the eskers is not clear. However, con\-siderations of the stability of the moraine in\-dicated 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 fresh and available and many deposits are remobilised after deposition (Fitzsimons, 1990). Consequently, the preservation potential of the relatively small esker ridges is low as is demon\-strated by the absence of eskers beyond the ice margin. Even though they have a low pres\-ervation potential, the formation of the eskers is significant because their formation has gen-
erally been associated with temperate glaciers and because they are rarely described in Antarcica. 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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References


