Eskers formed at the beds of modern surge-type tidewater glaciers in Spitsbergen

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Eskers are sinuous ridges composed of glacifluvial sand and gravel. They are deposited in channels with ice walls in subglacial, englacial and supraglacial positions. Eskers have been observed widely in deglaciated terrain and are varied in their planform. Many are single and continuous ridges, whereas others are complex anastomosing systems, and some are successive subaqueous fans deposited at retreating tidewater glacier margins (Benn & Evans 2010). Eskers are usually orientated approximately in the direction of past glacier flow. Many are formed subglacially by the sedimentary infilling of channels formed in ice at the glacier base (known as 'R' channels; Röthlisberger 1972). When basal water flows under pressure in full conduits, the hydraulic gradient and direction of water flow are controlled primarily by ice-surface slope, with bed topography of secondary importance (Shreve 1985). In such cases, eskers typically record the former flow of channelised and pressurised water both up- and down-slope.

Description

Sinuous sedimentary ridges, orientated generally parallel to fjord axes, have been observed on swath-bathymetric images from several Spitsbergen fjords (Ottesen et al. 2008). In innermost van Mijenfjorden, known as Rindersbukta, and van Keulenfjorden in central Spitsbergen, the fjord floors have been exposed by glacier retreat over the past century or so (Ottesen et al. 2008). Sinuous sedimentary ridges occur orientated along fjord long axes within a few kilometres of the margins of modern tidewater glaciers (Fig. 1). The ridges, which are sub-parallel to former ice-flow direction, are about 10 km long and a few tens of metres wide. Their crests are very well-defined and vary in height at between and between 15 and 40 m in inner van Keulenfjorden (Fig. 1a) and 5 to 15 m above the surrounding seafloor in Rindersbukta (Fig. 1b). Several small gullies are present on ridge flanks (Fig. 1a), indicating possible sediment remobilisation. The long profiles of the ridges have both positive and negative slopes with amplitudes of 10 to 15 m.

Superimposed on the individual relatively large and continuous ridges are sets of much smaller ridges, aligned in sub-parallel groups, that are an order of magnitude smaller at only a few metres wide and <5 m high (Fig. 1a, b). This superposition implies that the smaller ridges must have formed subsequent to the deposition of the larger ridges.

Interpretation

The sinuous ridges imaged in Figure 1, whose long profiles have both up- and down-slope sections, are interpreted as subglacial eskers. The eskers formed by deposition in 'R' channels beneath Paulabreen and Nathorstbreen, both tidewater glaciers about 20 km-long with known histories of surging (Ottesen et al. 2008). The eskers have been exposed recently at the seafloor due to the retreat of these surge-type glacier termini during their quiescent phase (Meier and Post, 1969). Although these submarine eskers have not been cored, a subaerial esker on the coast adjacent to Rindersbukta, deposited during the recent retreat of Paulbareen, is made up of interbedded sands and gravels (Fig. 1c, d).

A subglacial origin is confirmed by the superimposition of sets of much smaller ridges on the esker flanks (Fig. 1a, b). These sets of smaller ridges form at the retreating termini of tidewater glaciers as they undergo minor readvances each winter and push up sediments which are then abandoned during subsequent summer retreat (Boulton 1986; Ottesen & Dowdeswell 2006). If the ridges had formed in an englacial position, and had been deposited subsequently on the seafloor by the melting of underlying ice, they would probably have a much more disturbed and irregular morphology. In addition, because much mass-loss from retreating tidewater glaciers is through iceberg calving, any englacial or supraglacial eskers are likely to have been transported away from the ice front in icebergs.

It is notable that these eskers show a close spatial correspondence with persistent, deep embayments in the tidewater termini of Nathorstbreen and Paulabreen (Ottesen et al. 2008). Such embayments in the terminal cliffs of Svalbard tidewater glaciers typically coincide with upwelling turbid meltwater, marking the position of subglacial stream effluxes (Elverhøi et al. 1980; Dowdeswell et al. In Press). Upwelling water undercuts the ice margin, locally enhancing calving and ice-margin retreat and producing the embayments.

The existence of channels at former glacier beds in Spitsbergen fjords is indicated by the presence of eskers. The eskers demonstrate efficient subglacial drainage (Röthlisberger 1972; Shreve 1985). All theories used to explain the rapid glacier velocities observed during the active phase of the surge cycle require, however, that water is retained over large areas of the bed and that the subglacial hydrological system is inefficient (Kamb et al. 1985). Thus, eskers beneath surge-type glaciers are likely to have formed at or after surge termination, during the subsequent stagnation phase of the surge cycle. They are then revealed at the seafloor as ice retreats. Eskers are part of the assemblage of landforms that together characterise the presence of surging glaciers in the geological record (Evans & Rea 2005; Ottesen et al. 2008). They are also found in association with non-surging glaciers and, alone, are not thought to be diagnostic of surge activity.

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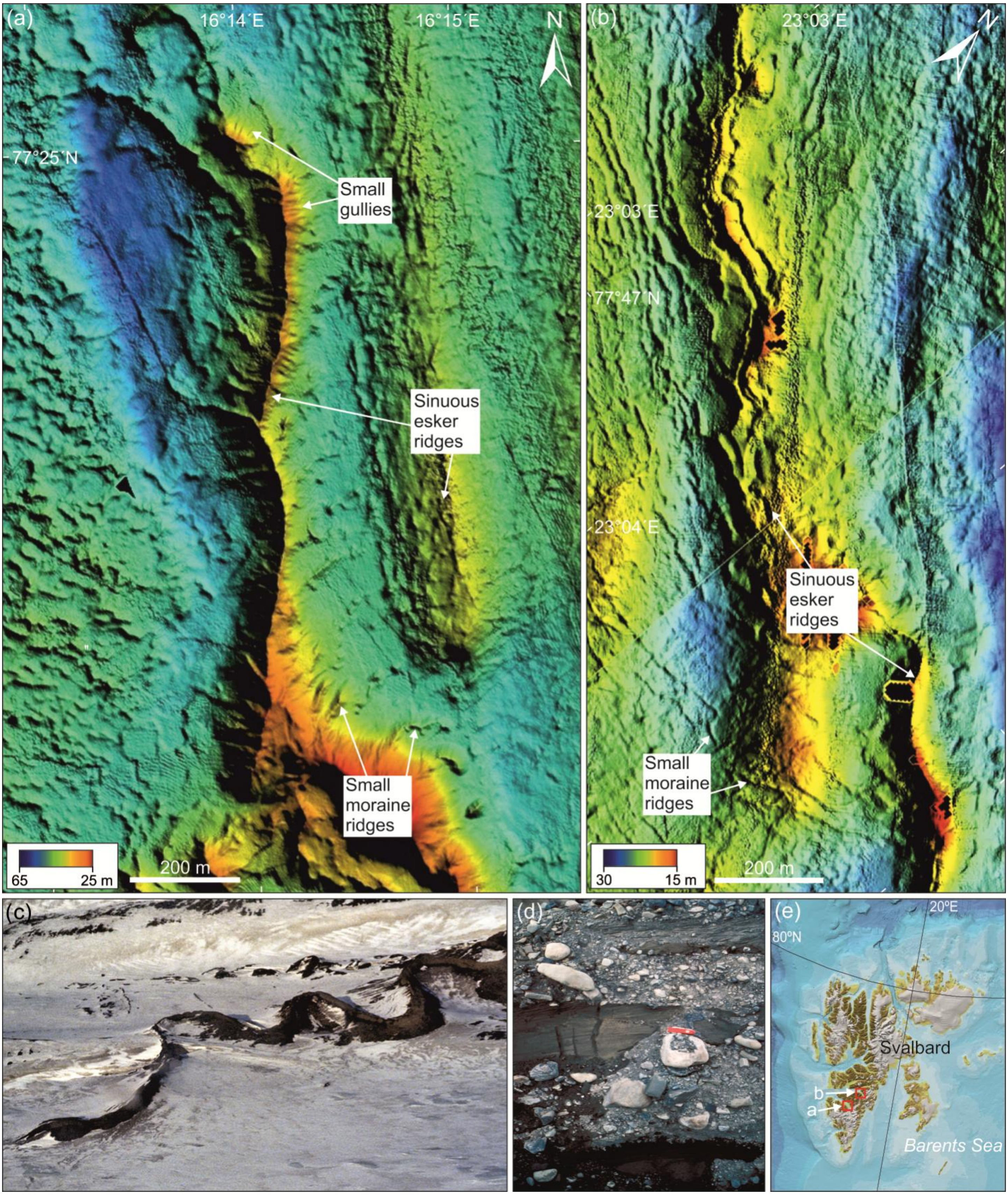
Fig. 1. Swath-bathymetric imagery of esker ridges in two Spitsbergen fjords (modified from Ottesen et al. 2008; data courtesy of the Norwegian Hydrographic Service, Permission 598/08). (a) Innermost van Keulenfjorden. (b) Rindersbukta, innermost van Mijenfjorden. Acquisition system: Geoswath. Frequency 250 kHz. Grid-cell size 5 m. (c) Oblique photograph of a sinuous subaerial esker close to the modern margin of Paulabreen, onshore in Rindersbukta. The ridge is about 1-2 m high, approximately 150 m long, and is composed mainly of interbedded sands and gravels. It was probably formed englacially and deposited on land as the retreating glacier melted. (d) Photograph of sediments within an esker (penknife for scale). (e) Location of study areas (red boxes; map from IBCAO v. 3.0).


(a)
16°14´E
16°15´E
N
77°25´N
Small
gullies
Sinuous
esker
ridges
Small
moraine
ridges
65
25 m
200 m
(b)
23°03´E
N
23°03´E
77°47´N
23°04´E
Sinuous
esker
ridges
Small
moraine
ridges
30
15 m
200 m
(c)
(d)
(e)
20ºE
80ºN
Svalbard
b
a
Barents Sea