

# Glacial lineations and recessional moraines on the continental shelf of Northeast Greenland

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The Northeast Greenland continental shelf is only sparsely mapped due to its remoteness and harsh year-round sea-ice conditions. Mapping the distribution of submarine glacial landforms relies mainly on single track lines of multibeam echo sounder bathymetric data with only occasional systematic surveys. Ice streams drain the modern Greenland Ice Sheet [GrIS] to its northeastern margin in several fjords near the head of the Westwind Trough (Fig. 1a). The presence of glacial lineations and recessional moraines in the inner to middle trough indicates that the GrIS extended onto the continental shelf probably during the Last Glacial Maximum (Evans et al. 2009; Winkelmann et al. 2010).

## Description

Multibeam bathymetry and sub-bottom profiler data showing glacial landforms were acquired along several transects transverse to the orientation of Westwind Trough (Fig. 1a) (Evans et al. 2009). The multibeam bathymetry reveals the presence of numerous, parallel to sub-parallel and elongated ridges or lineations forming positive relief relative to the surrounding seafloor (Fig. 1b). The orientation of the lineations is sub-parallel to the long-axis of Westwind Trough. The lineations are well-defined in some areas of the trough but are more subtle elsewhere. Lineations often exceed 2.5 km in length and can approach 10 km. They are up to 10 m in height, about 350 m in width, with elongation ratios of 12:1 to 33:1 (Fig 1c, d).

Sub-bottom profiles show that the lineations are sedimentary, and comprise acoustically transparent and homogenous sediment with a distinct, flat to undulating basal reflector (Fig. 1c, d). The thickness of this uppermost sedimentary unit is up to 30 m but, in some areas of the trough, the unit is <10 m thick or appears to be absent or below the vertical resolution of the TOPAS system. The acoustically-transparent sediment is either: (a) confined to the lineations; or (b) occurs as a semi-continuous layer in which lineations are formed in the surface and sediment extends beneath the intervening grooves.

A 160 km<sup>2</sup> area of the central Westwind Trough (Fig 1a) was surveyed systematically by Winkelmann et al. (2010). A number of ridges are visible in water depths between 270 to 350 m (Fig. 1e), and are generally oriented roughly orthogonal to the lineations mapped further west in the trough (Fig. 1b). They are between 10 to 25 m high relative to the surrounding seafloor and up to 7 km long. Most of the ridges are arcuate, a few are more elongated and smaller in height (< 10m). Further, most ridges are asymmetrical in cross-section with the majority having a steeper west-facing slope (Fig. 1f, g). Sub-bottom profiler data shows a rather flat surface representing the surface of an acoustic unit extending underneath the ridges (Fig. 1g). The internal structure of the ridges consists of an acoustically-transparent unit, and both the ridges and intervening flat seafloor are draped by a thin upper acoustic unit.

## Interpretation

The elongated, streamlined sedimentary lineations in inner Westwind Trough (Fig. 1b) are interpreted as subglacial bedforms produced at the base of an active ice sheet. Comparison with sediments of similar acoustic character, found in close association with subglacial lineations on other polar continental shelves

(Ó Cofaigh et al. 2002), indicates that the lineations are formed in the surface of a homogenous soft or dilatant till (Dowdeswell 2004). The distribution of lineations within a cross-shelf trough are often used as indicators of the former presence of ice streams where fast-ice flow is facilitated by substrate deformation (e.g. Ó Cofaigh et al. 2002, Dowdeswell et al. 2004). The fresh appearance of the lineations in Westwind Trough suggest an advance of the GrIS onto the adjacent Northeast Greenland shelf most probably during the last glacial cycle, and that a fast-flowing ice stream was active in Westwind Trough (Evans et al. 2009). The apparent lack of retreat moraines and the presence of only a very thin drape of deglacial/postglacial sediments overlying the subglacial lineations on geophysical records from the inner shelf suggest that ice recession through this part of Westwind Trough was relatively rapid (Dowdeswell et al. 2008).

In contrast, transverse-to-flow moraines imply a stepwise deglaciation with multiple halts and minor readvances of the ice-stream grounding-zone (Dowdeswell et al. 2008). The ridges located further east on the middle shelf (Fig. 1a, e), based on their asymmetric morphology and their inner structure, are probably recessional push moraines formed during episodic still-stands that punctuated the retreat of a Westwind Trough palaeo-ice stream (Winkelmann et al. 2010). These recessional moraines are formed at the ice-sheet terminus by bulldozing sediment during minor re-advances of a grounded ice front or by deposition during significant halts (Golledge et al. 2008). The thin drape of sediments overlying the moraines and adjacent seafloor is probably of Holocene age.

The distribution of lineations on the inner shelf and recessional push moraines on the middle shelf indicate that the speed of the palaeo-ice stream retreat in Westwind Trough was highly variable. In the initial phase of deglaciation, ice retreat was stepwise forming moraines. In a later stage, ice retreat accelerated leaving undisturbed sub-ice stream lineations.

## References

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**Fig.1.** Multibeam bathymetry and cross-profiles of glacial lineations and recessional moraines in middle to outer Westwind Trough on the NE Greenland continental shelf. (a) Location map showing the study area (red boxes) (map from IBCAO Version 3.0). (b) Image showing glacial lineations indicating the past expansion of the Greenland Ice Sheet onto the continental shelf (modified from Evans et al. 2009). Acquisition system Kongsberg EM120. Frequency 12 kHz. Grid-cell size 15 m. (c) and (d) 3.5 kHz sub-bottom profiles transverse to the trough long-axis ( $x-x'$  and  $y-y'$  in Fig. 1b) showing glacial lineations formed in an acoustically transparent sedimentary unit consistent with spatially discontinuous to semi-continuous soft basal till. Acquisition system Kongsberg TOPAS PS 018, secondary beam frequency 0.5-6 kHz. (e) 3D oblique view of swath bathymetry showing arcuate to elongate recessional moraines produced along a retreating ice sheet margin. Acquisition system ATLAS Hydrosweep DS2. Frequency 15.5 kHz. Grid-cell size 20 m. (f) and (g) 4 kHz sub-bottom profiles through recessional moraines ( $z-z'$  in Fig. 1e). The moraines are asymmetric in profile, with steeper west-facing slopes and comprise acoustically transparent sediment consistent with soft basal till. Acquisition system ATLAS PARASOUND, 18 kHz and 22 kHz transmission frequencies. Images in (e), (f) and (g) modified from Winkelmann et al. (2010).

