Grounding-zone wedges on the West Greenland shelf imaged from multibeam and seismic data

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Grounding-zone wedges (GZWs) are asymmetrical depocentres built up beneath the grounding-zone of marine-terminating ice streams and fast-flowing outlet glaciers through the delivery of soft, deforming subglacial till from up-glacier. They are typically tens of metres thick, tens of kilometres in length and usually form subdued transverse-to-flow ridges across the long-axes of fjords and troughs on high-latitude continental shelves (e.g. Shipp et al. 1999; Dowdeswell & Fugelli 2012; Batchelor & Dowdeswell 2014). The ridges, representing the relatively steeper ice-distal face of the wedge, usually appear as small scarps or steps in multibeam imagery. The wedges thin in an ice-proximal direction, often becoming difficult to identify except by using acoustic-stratigraphic methods.

Description

Relatively large sedimentary wedges have been identified in swath-bathymetric data from several Greenland cross-shelf troughs (e.g. Dowdeswell et al. 2014). The features generally have a scarp at their ice-distal end, and have very subdued, low gradient ice-proximal slopes which make their termination difficult to pinpoint from bathymetric data. Where a basal reflection can be identified, there is some evidence that the wedges thin progressively over a few tens of kilometres from the former ice margin at their distal end and therefore have a characteristic asymmetry along trough-axes.

A multibeam image of a modern wedge from the outer shelf of Uummannaq Trough, at almost 71°N (Fig. 1b), is shown in Figure 1a. The wedge is about 30 km long and a maximum of about 40 m thick at its ice-distal end, where it terminates as a step in seafloor topography. It is highly asymmetrical, with an ice-distal slope of about 3° and a very low gradient at its ice-proximal end. Acoustic sub-bottom profiling does not always penetrate to the base of the wedge, suggesting the wedge is probably composed of diamictic rather than fine-grained sorted debris. In this example, the slightly raised position of the landform relative to the shelf in general has also resulted in its surface being ploughed by deep-keeled icebergs (Fig. 1a).

Similar asymmetrical wedges have been observed in seismic-reflection records from the prograding Quaternary sedimentary package on the continental shelves west and east of Greenland (Dowdeswell & Fugelli 2012). Examples of seismic profiles through two sedimentary wedges on the West Greenland shelf are shown in Figure 1c and e; one wedge is buried about 30 m below the present seafloor. The profiles are located along the axes of present and former cross-shelf troughs. The two wedges exhibit a typically steeper ice-distal face and thin progressively inshore (Fig. 1c, e). There is some evidence of dipping reflections at their seaward ends, where the seismic character is semi-transparent to chaotic. Elsewhere, reflections downlap onto the underlying sediments and there is onlap above the buried feature. These characteristics are typical of many of the thirty or so wedges so far identified in seismic records from the Greenland shelf (Dowdeswell & Fugelli 2012; Batchelor & Dowdeswell 2014).

Interpretation

Asymmetrical sedimentary wedges, occurring both at the seafloor and buried in the Greenland shelf (Fig. 1a, c, e), are interpreted as GZWs formed during halts in the retreat of past full-glacial ice-sheets that reached to, or close to the shelf edge (Dowdeswell & Fugelli 2012; Dowdeswell et al. 2014). Schematic interpretations of the seismic data are shown in Figure 1d and f. Downlap and truncation of reflections suggest that erosion sometimes takes place at the base of GZWs. An internal downlapping reflection is interpreted to indicate multiple phases of GZW development (Fig. 1e, f). Seaward-dipping reflections at the steeper ice-distal end of the GZWs imply progradation through continuing delivery of deformation till.

Sedimentary wedges of similar geometry have been identified recently at the modern grounding-zone of a West Antarctic ice stream using seismic methods (Horgan et al. 2013). The length of time required to build up several tens of metres of sediment delivered from the basal deformation-till layer of fast-flowing ice streams is estimated as decades to centuries using the very few modern observations of till deformation beneath ice sheets and rare constraining dates from the Quaternary record (e.g. Engelhardt & Kamb 1997; Anandakrishnan et al. 2007).

A simple schematic model summarises the sedimentary setting and development of GZWs (Fig. 1g). Note the presence of an active grounding-zone where even tidal oscillations may lead to regular short-term changes in its exact position given the very low gradients involved. The presence of a floating ice shelf, again of very low basal gradient, seaward of the grounding-zone, also constrains accommodation space for vertical sediment build-up. This may assist in explaining the relatively subdued relief of GZWs.

In an environmental-change context, the development of GZWs during still-stands in marine ice-sheet retreat is important as a possible mechanism acting to restrain the runaway collapse of ice streams. The development of GZWs may help to stabilise the ice-sheet terminus against further rapid retreat, stimulated by thinning and deglacial sea-level rise, through the continuing delivery and build-up of sediment. The glacial debris acts to reduce buoyancy and therefore to limit mass loss by iceberg production (Alley et al. 2007).

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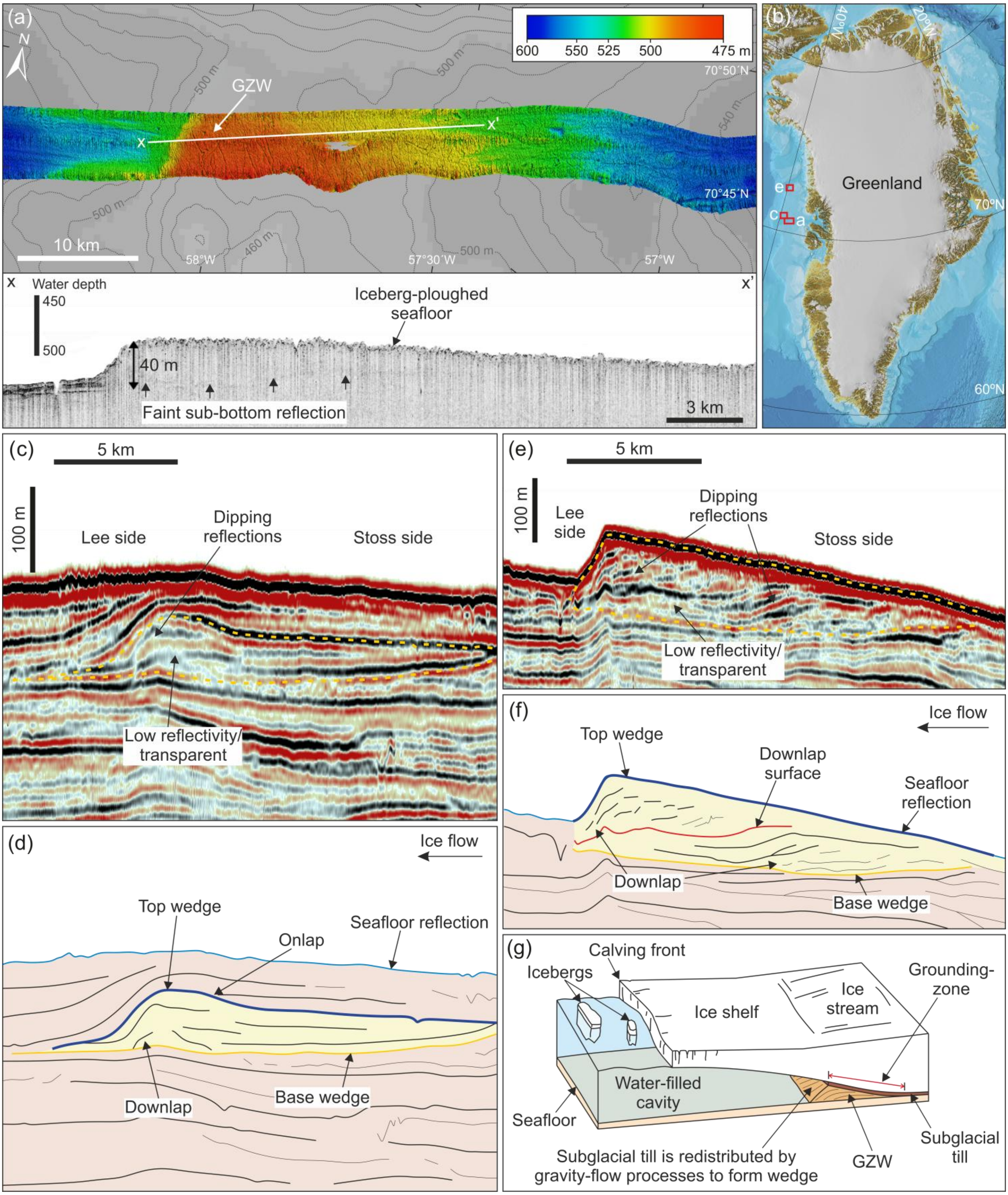
Fig. 1. (a) Multibeam-bathymetric image of a GZW and sub-bottom profile (VE x 50) on the middle shelf of Uummannaq Trough, West Greenland. Multibeam acquisition system Kongsberg EM120. Frequency 12 kHz. Grid-cell size 50 m. Sub-bottom profile acquisition system Kongsberg TOPAS PS 018. A faint reflection beneath the GZW is arrowed. (b) Location of study area (red box; map from IBCAO v. 3.0) showing the locations of (a), (c) and (e). (c) Seismic example of a buried GZW (yellow dashed lines) on the continental shelf off West Greenland (VE x 35) (courtesy of TGS-NOPEC Geophysical Company). (d) Interpretation of the buried GZW in (c) (GZW shown by yellow shading). (e) Seismic example of a GZW (yellow dashed lines) on the seafloor of the shelf off West Greenland (VE x 25) (courtesy of TGS-NOPEC Geophysical Company). (f) Interpretation of the GZW in (e) (GZW shown by yellow shading). Red line is downlap surface within the GZW, suggesting multiple phases of GZW development. (g) 3-D schematic model of GZW formation within a sub-ice shelf cavity.



(a)
N
600
550
525
500
475 m
70°50´N
500 m
500 m
GZW
x
x'
540 m
70°45´N
500 m
460 m
10 km
58°W
57°30´W
500 m
57°W
(b)
40°W
20°W
e
Greenland
c
a
70°N
60°N
x
Water depth
450
500
40 m
Iceberg-ploughed seafloor
Faint sub-bottom reflection
3 km
x'
(c)
5 km
100 m
Lee side
Dipping reflections
Stoss side
Low reflectivity/ transparent
(e)
5 km
100 m
Lee side
Dipping reflections
Stoss side
Low reflectivity/ transparent
(f)
Ice flow
Top wedge
Downlap surface
Seafloor reflection
Downlap
Base wedge
(d)
Ice flow
Top wedge
Seafloor reflection
Onlap
Downlap
Base wedge
(g)
Calving front
Icebergs
Ice shelf
Ice stream
Grounding-zone
Water-filled cavity
Seafloor
Subglacial till is redistributed by gravity-flow processes to form wedge
GZW
Subglacial till