Unusual iceberg ploughmarks on the Norwegian continental shelf

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Iceberg ploughmarks are produced when the keels of drifting icebergs impinge upon and cut into seafloor sediments. They are common landforms of high-latitude shelves and fjords, especially in water shallower than about 500 m, where they are easily detected using modern multibeam echo-sounding and earlier side-scan sonar systems (e.g. Lien 1983; Dowdeswell *et al*. 1993). In addition, similar buried morphological features have been identified within Quaternary sediments on palaeo-shelves, imaged using 3-dimensional seismic methods (e.g. Andreassen *et al*. 2007; Dowdeswell & Ottesen 2013).

Description

Five examples of rather unusual linear to curvilinear features from the seabed of the Norwegian continental shelf are presented (Fig. 1). One is from offshore of eastern Svalbard (Fig. 1a), three are from the Barents Sea (Fig. 1b–d), and one is a buried feature from the upper continental slope beyond the mid-Norwegian shelf, and is derived from a 3D seismic dataset (Fig. 1e).

The first and rather small feature is from outside Bråsvellbreen (Fig. 1a), which is an outlet glacier of Austfonna, the largest ice cap on Svalbard. The looped feature is about 15 m wide and 1 m deep and has small berms on either side. The diameter of the loop is about 1.2 km. The feature is found on top of a dense criss-crossing pattern of similar features on the seafloor in water depths of around 40 m.

The seabed depressions shown in Figure 1b–d are all from the central Barents Sea (Fig. 1a). The first feature forms a complex zig-zag pattern (Fig. 1b). It is a sharply incised (v-shaped), 150–300 m wide and 1–3 m deep groove with ~60–160 m wide and 1–2 m high berms on either side. A second groove (Fig. 1c) is sharply incised, ~4–8 m deep, ~50–100 m wide and consists of two semi-straight segments and a central part where the groove forms a three-fold circular pattern. The central area is about 800 m across. The third feature imaged in the Barents Sea (Fig. 1d) is a flat-bottomed ~ 250–350 m wide and about 5 m deep groove with ~100–200 m wide and 1–3 m high berms.

The last image shows three large curvilinear features along the slope outside the mid-Norwegian shelf in about 800 m water depth (Fig. 1e). One feature makes several loops, whereas a second appears to cross the whole area (c. 10 km), and the third crosses the left half of the image. The largest feature is 300 m across and about 20 m deep. A seismic-reflection profile shows that the surface on which these features appear is buried approximately 30 m beneath the modern seafloor (Fig. 1f).

Interpretation

The linear to curvilinear depressions presented in Figure 1a–e are interpreted as iceberg ploughmarks, incised by the keels of drifting icebergs where they run aground. They are all from the Norwegian continental shelf (Fig. 1g), but represent different time periods and depositional regimes. The first is from beyond the front of a modern surge-type glacier, Bråsvellbreen, on Svalbard (Fig. 1a). This glacier had a major surge between 1936 and 1938, where it advanced 15 km along a 30 km-long front (Solheim 1991). During this phase, many icebergs calved from the glacier front; one of these probably made this peculiar loop. The looped ploughmark demonstrates the effect of tidal forcing on an iceberg trajectory. This motion has been modelled numerically by Mugford & Dowdeswell, producing a loop of similar predicted diameter (2011).

The following three images (Fig. 1b–d) are of ploughmarks that were probably produced during the last deglaciation of the Barents Sea, 12–15 kyr ago, when large numbers of icebergs were released (Bjarnadóttir *et al*. 2014). The complex ploughmark in Figure 1b shows rapid changes in drift direction of the iceberg, influenced by currents, winds and tidal forcing and appears to have been characterised by movements from N-S and E-W, probably including rotation. Surcharges of sediment at some points of directional change suggest halts in drift and ploughing, perhaps associated with more resistant sediments and/or shallowing water (Fig. 1b). The linear to curvilinear feature in Figure 1c is interpreted to have been formed by an iceberg that floated into the area from the northwest, grounded on a shallower bank and rotated before exiting again towards the WNW. During rotation, more than one keel on the berg may have come into contact with the seabed, thereby forming a three-fold groove. The 250 m-wide flat-bottomed ploughmark in Figure 1d was probably formed by a large tabular or blocky iceberg with a smooth base, possibly derived from a floating ice shelf, in contrast to the more irregular iceberg morphology implied by the v-shaped ploughmarks in Figure 1b and c. This iceberg drifted in from the NW, grounding lightly in unconsolidated sediments, before making a loop to the NE and then W and floating towards deeper water again, in a swirling fashion, probably controlled by tidal forcing.

The last image shows several buried ploughmarks from the upper continental slope outside the mid-Norwegian shelf, based on a 3D seismic dataset (Fig. 1e–f). Depth of burial suggests that these ploughmarks probably date from the Elsterian glaciation about 300–400 kyr ago (Rise *et al*. 2005). The curvilinear features shown in Figure 1e represent ploughmarks made by the keels of several huge tabular icebergs in approximately 800 m modern (maybe 550 m palaeo) water depth on the continental slope outside mid-Norway. The youngest feature is from an iceberg grounding on the slope, which then made several loops before drifting into deeper water. Two other icebergs drifted from SW to NE, producing a series of 'grounding pits'. Both these and the rotating pattern are probably caused by tidal forcing (Mugford & Dowdeswell, 2011).

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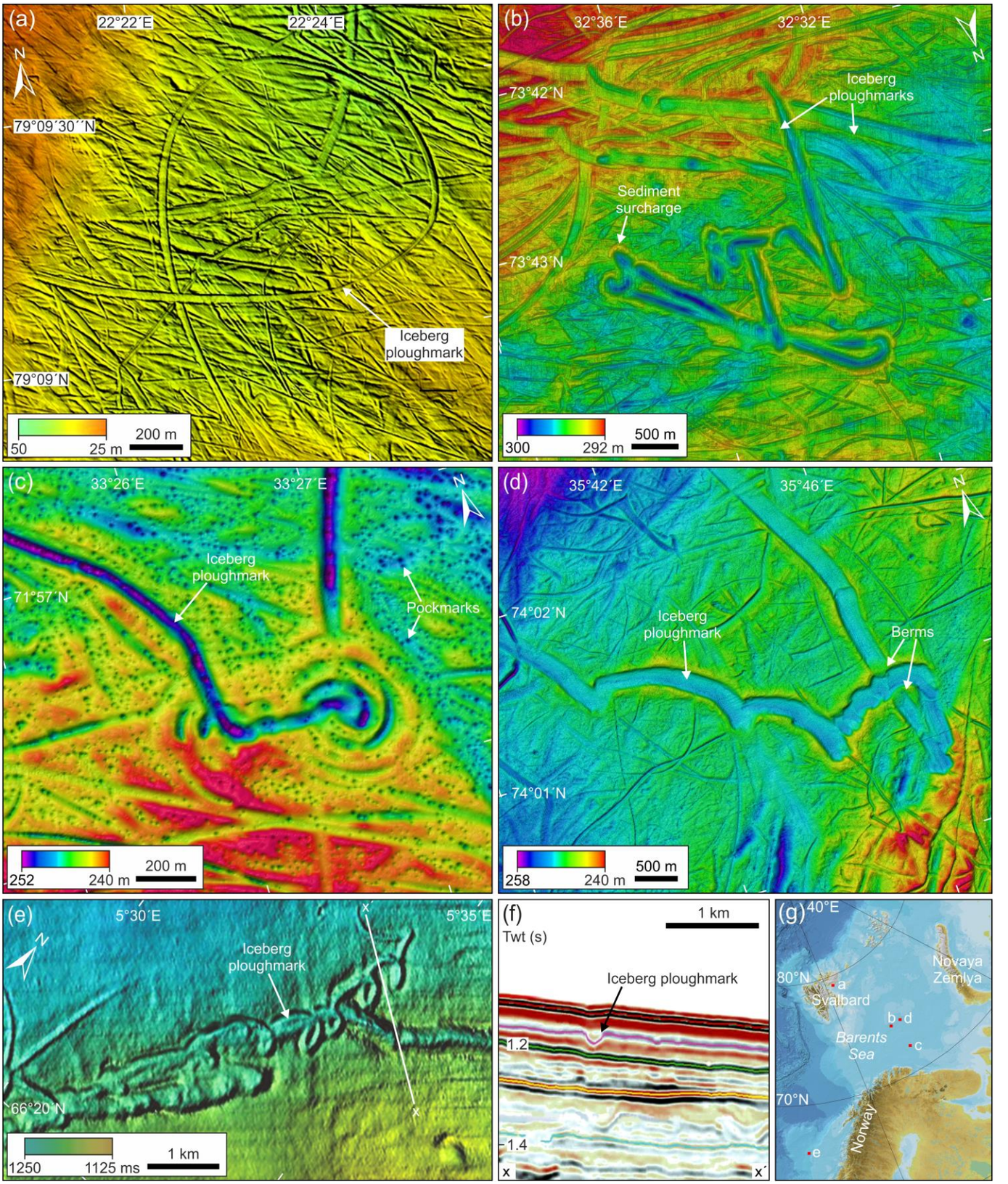

Fig. 1. Iceberg ploughmarks on the Norwegian continental shelf (located in Fig. 1g). (a) An almost circular iceberg ploughmark outside Bråsvellbreen, Austfonna, Svalbard. (b) Peculiarly shaped iceberg ploughmark in the central Barents Sea. (c) Iceberg ploughmark demonstrating rotation, central Barents Sea. The many small round depressions are pockmarks, probably formed by fluid-escape. (d) Ploughmarks produced by unusually flat-bottomed icebergs, central Barents Sea. (e) Ploughmark produced by the corkscrew-like drift of an iceberg, buried below the seafloor at a modern water depth of 800 m on the continental slope, mid-Norwegian shelf. (f) Seismic profile across the ploughmark shown in (e), showing that it is buried below about 30 m of overlying sediment. VE x ?. (g) Location of study areas (map from IBCAO v. 3.0). For b–d: Bathymetric data acquired by the Norwegian Hydrographic Service through the MAREANO mapping programme. Multibeam acquisition system Kongsberg EM710. Frequency 70–100 kHz. Grid-cell size 5 m.