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Seismic stratigraphy, sedimentary architecture and palaeo-glaciology of the Mackenzie Trough: evidence for two Quaternary ice advances and limited fan development on the western Canadian Beaufort Sea margin

C.L. Batchelor [a,*], J.A. Dowdeswell [a], J.T. Pietras [b]

[a] Scott Polar Research Institute, University of Cambridge, Lensfield Road, Cambridge CB2 1ER, UK
[b] BP America Production Company, 580 Westlake Park Boulevard, Houston, TX 77079, USA

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ABSTRACT

A comprehensive grid of high-resolution 2-D seismic reflection data from the western Canadian Beaufort Sea margin is used to reconstruct past ice-stream dynamics within the Mackenzie Trough. Eight seismic facies and five sequences, divided into two megasequences, are identified from the Mackenzie Trough stratigraphy. Evidence for two Quaternary ice advances to the shelf break is provided by two sequences of acoustically chaotic to semi-transparent facies, interpreted as subglacial till. Buried landforms interpreted as lateral moraines and a grounding-zone wedge record the positions of still-stands or re-advances in the ice margin. The continental slope beyond the trough is characterised by canyons separated by inter-canyon ridges and thin glacigenic debris flows. Correlation with the onshore record suggests that the older of the two ice advances, which excavated the Mackenzie Trough, probably occurred during the Illinoian or Early Wisconsinan glaciations. The younger ice-stream advance is interpreted to have occurred during the last, Late Wisconsinan glaciation. The onset of cross-shelf glaciation on the western Canadian Beaufort Sea margin is inferred to have been initiated significantly later than on the eastern Beaufort Sea and eastern Canadian Arctic margins, which have a longer history of ice advance and were less peripheral to the ice-sheet centre. The architecture of the slope beyond the Mackenzie Trough reflects this comparatively short history of ice advance and lacks the progradational architecture and major glacial-sedimentary depocentre or trough-mouth fan that is characteristic of slopes seaward of cross-shelf troughs on formerly-glaciated margins.

1. Introduction

Palaeo-ice sheets, including the Laurentide Ice Sheet (Fig. 1A) which developed over North America a number of times during the Quaternary, were partitioned into fast flowing ice streams separated by slower flowing inter-ice stream regions. Ice streams exert a major influence on ice sheet behaviour and have the potential to force abrupt climate change through the rapid drainage of ice and delivery of sediment to the ice sheet margin (Overpeck et al., 1989; Bond et al., 1992; Stokes et al., 2005). Assemblages of glacigenic landforms, including mega-scale glacial lineations (MSGL), drumlins, grounding-zone wedges, moraines and iceberg keel ploughmarks, have been used previously to reconstruct former ice stream configurations and dynamics (Clark, 1993; Stokes and Clark, 1999).

Submarine sediments and landforms preserved on the sea floor of formerly glaciated continental shelves can provide a comprehensive record of past ice activity (e.g. Ottesen et al., 2005; Mosola and Anderson, 2006; Ottesen and Dowdeswell, 2009). Where they advanced across the continental shelf, ice streams formed deep cross-shelf troughs, typically with associated major sedimentary depocentres, termed trough-mouth fans, on the adjacent continental slope (Vorren et al., 1998; Dowdeswell and Siegert, 1999; Rise et al., 2005). Whereas bathymetry and shallow acoustic data can be used to identify glacigenic landforms on the sea floor, these methods typically provide information concerning only the most recent ice advance and retreat. The use of seismic reflection data enables the identification of buried glacier-derived sediments and landforms, providing information about older ice advances across the continental shelf (Dowdeswell et al., 2007).

The Canadian Beaufort Sea margin is characterised by three major bathymetric depressions; the Mackenzie, Amundsen Gulf and M'Clure Strait troughs (Fig. 1B). These three cross-shelf troughs represent the former locations of ice streams which drained the

* Corresponding author. Tel.: +44 01223 336540.
E-mail address: clb70@cam.ac.uk (C.L. Batchelor).

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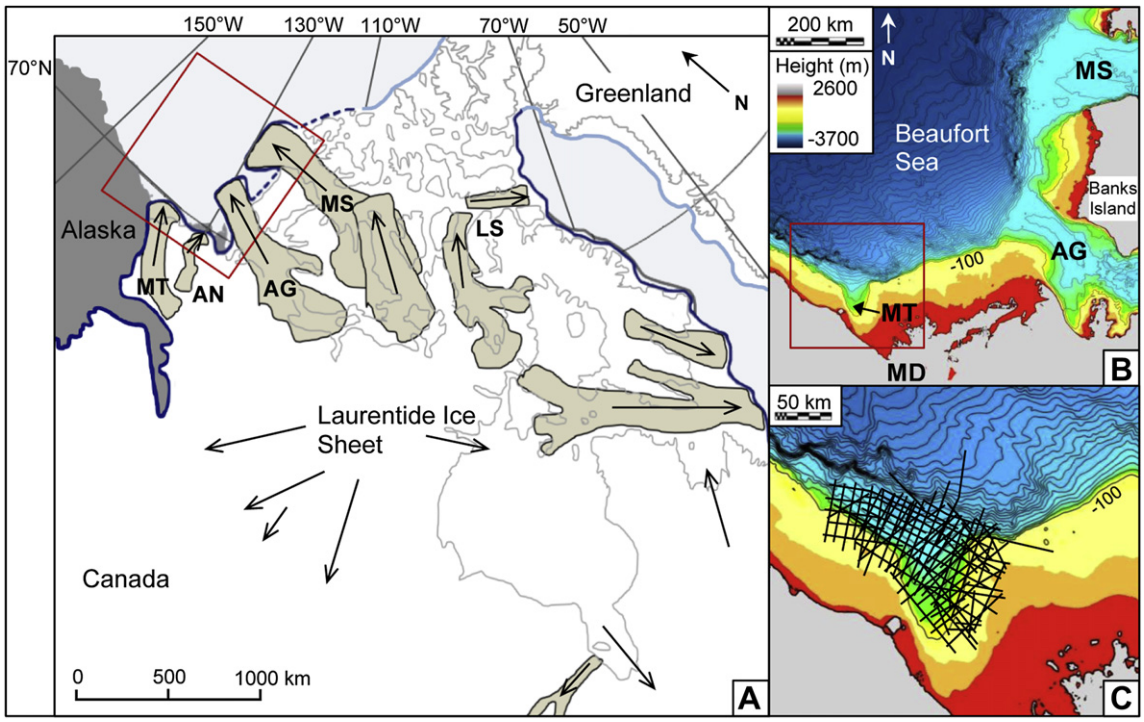

Fig. 1. A: Map of northern Laurentide Ice Sheet extent during Last Glacial Maximum about 20,000 years ago. Locations of ice streams, including the Mackenzie Trough (MT), Anderson (AN), Amundsen Gulf (AG), M'Clure Strait (MS), and Lancaster Sound (LS) ice streams are shown in grey (adapted from Winsborrow et al., 2004; updated to include Banks Island as ice-covered after England et al., 2009). B: IBCAO bathymetry of Canadian Beaufort Sea margin (100 m contours), showing locations of MT, AG, MS and the Mackenzie Delta (MD) (Jakobsson et al., 2012b). C: IBCAO bathymetry of the MT (100 m contours) showing distribution of analysed seismic lines.

north-west margin of the Laurentide Ice Sheet during Quaternary glaciations and served to transfer ice and debris from the ice-sheet into the Beaufort Sea (Sharpe, 1988; Blasco et al., 1990; Stokes et al., 2006, 2009). The Mackenzie Trough on the western Canadian Beaufort Sea margin is a 150 km-long, partially-infilled linear depression, which extends in a NNW direction from the modern Mackenzie River Delta to the continental shelf break at around 800 m below present sea level (Fig. 1B and C).

In this paper, we describe and interpret the seismic sequences, facies and architectural features present within the Mackenzie Trough with a view to furthering our understanding of Quaternary ice advances across the Beaufort Sea shelf. Particular emphasis is placed upon the identification of buried diagnostic glacigenic landforms and sediments within the seismic record. We discuss the implications of these data in relation to ice dynamics at the extreme north-west limit of the Laurentide Ice Sheet (Fig. 1A) and the glacial history of the Beaufort Sea margin of the Arctic Ocean.

2. Data acquisition and methods

The present study uses newly available, high-resolution 2-D seismic reflection data to examine the seismic stratigraphy and sedimentary architecture of the Mackenzie Trough and adjacent continental slope. The seismic reflection data were collected by ION Geophysical between 2006 and 2010 as part of the BeaufortSPAN East survey (http://www.iongeo.com/Data_Library/Arctic/BeaufortSPAN_East), and are supplemented by older seismic data. No well data was made available through the seismic sections in the Beaufort Sea.

The BeaufortSPAN East survey used airgun arrays to image down to the base crust. Acquisition parameters included a streamer length of 9000 m with 360 channels (720 channels per streamer in Phase 2 of acquisition), 18.4 s record intervals and a sample rate of around 2 m per second. Interpretations were made on two-way time seismic profiles in SeisWorks® Interpretation Software and then depth converted using a 3-D velocity model built from Pre-Stack Time Migration (PSTM) imaging velocities. These stacking velocities provide a reasonable time-depth conversion, especially over the interval of interest. Due to restrictions on the use of industrial data, further details of data processing and time-depth conversion models are not included. Structure and isopach maps were gridded in Z-MAP Plus™ Petroleum Mapping Software and imaged in ArcMap. A grid of data covering approximately 30,000 km^2 is analysed from the study area, with spacing of 5–15 km between seismic lines (Fig. 1C).

3. Background

3.1. Quaternary glacial history

The Laurentide Ice Sheet advanced across the western Canadian Beaufort Sea margin during at least one Quaternary glaciation, including the Toker Point Stade (Rampton, 1988; Blasco et al., 1990; Murton et al., 1997). The maximum ice limit during the Toker Point Stade has been partially mapped onshore and has been previously variably assigned to the Early Wisconsinan (Mackey and Mathews, 1983; Rampton, 1988; Vincent, 1989) and Middle Wisconsinan glaciations (Fig. 2A; Lemmen et al., 1994; Dallimore et al., 1997). However, recent evidence, including radiocarbon and luminescence dates from pre-glacial sands in the Tuktoyaktuk Coastlands, suggests that the Toker Point limit was reached during the Late Wisconsinan (Murton et al., 1997; Dyke et al., 2002; Duk-Rodkin et al., 2004; Bateman and Murton, 2006), no earlier than 22 ka ago (Murton et al., 2007). Extensive glaciation of the Beaufort Sea margin during the last, Late Wisconsinan, glaciation is supported by analyses of terrestrial and marine landform assemblages in the western Canadian Arctic Archipelago (Blasco et al., 2005; Stokes et al., 2005, 2006, 2009; MacLean et al., 2012), through numerical modelling (Stokes