Quaternary Science Reviews 179 (2018) 24–47

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Large-scale glacitectonic deformation in response to active ice sheet retreat across Dogger Bank (southern central North Sea) during the Last Glacial Maximum

Emrys Phillips [a, *], Carol Cotterill [a], Kirstin Johnson [a], Kirstin Crombie [a], Leo James [b], Simon Carr [c], Astrid Ruiter [a, c]

[a] British Geological Survey, The Lyell Centre, Heriot-Watt University, Research Avenue South, Riccarton, Edinburgh, EH14 4AS, Scotland, UK
[b] RPS Energy Ltd, Goldvale House, 27-41 Church Street West, Woking, Surrey, GU21 6DH, UK
[c] Department of Geography, Queen Mary University of London, Mile End Road, London, E1 4NS, UK

ARTICLE INFO

Article history:
Received 5 May 2017
Received in revised form
24 October 2017
Accepted 1 November 2017
Available online 20 November 2017

Keywords:
Large-scale glacitectonics
Dogger bank
North sea
Weichselian glaciation

ABSTRACT

High resolution seismic data from the Dogger Bank in the central southern North Sea has revealed that the Dogger Bank Formation records a complex history of sedimentation and penecontemporaneous, large-scale, ice-marginal to proglacial glacitectonic deformation. These processes led to the development of a large thrust-block moraine complex which is buried beneath a thin sequence of Holocene sediments. This buried glacitectonic landsystem comprises a series of elongate, arcuate moraine ridges (200 m up to > 15 km across; over 40–50 km long) separated by low-lying ice marginal to proglacial sedimentary basins and/or meltwater channels, preserving the shape of the margin of this former ice sheet. The moraines are composed of highly deformed (folded and thrust) Dogger Bank Formation with the lower boundary of the deformed sequence (up to 40–50 m thick) being marked by a laterally extensive décollement. The ice-distal parts of the thrust moraine complex are interpreted as a "forward" propagating imbricate thrust stack developed in response to S/SE-directed ice-push. The more complex folding and thrusting within the more ice-proximal parts of the thrust-block moraines record the accretion of thrust slices of highly deformed sediment as the ice repeatedly reoccupied this ice marginal position. Consequently, the internal structure of the Dogger Bank thrust-moraine complexes can be directly related to ice sheet dynamics, recording the former positions of a highly dynamic, oscillating Weichselian ice sheet margin as it retreated northwards at the end of the Last Glacial Maximum.

1. Introduction

The North Sea (c. 500 km wide, 50–400 m deep) separating the UK from Scandinavia and northern mainland Europe (Fig. 1a) has had a long and complex geological history, commencing with rifting during the Jurassic–Early Cretaceous and followed by subsequent thermal cooling and subsidence (Glennie and Underhill, 1998; Zanella and Coward, 2003). Its more recent history has been dominated by the deposition of a locally thick sequence (over 800 m) of Quaternary sediments (Caston, 1977, 1979; Gatliff et al., 1994). This sedimentary record preserves evidence for the advance of several major ice sheets from the surrounding land masses into the North Sea at different stages during the Quaternary. This glacial history has previously been described in terms of three major glacial episodes, the Elsterian (oldest, Marine Isotope Stage [MIS] 12), Saalian (MIS 10–6), and Weichselian (youngest, MIS 5d–2) stage glaciations, separated by warmer interglacial periods (Eisma et al., 1979; Jansen et al., 1979; Caston, 1979; Balson and Cameron, 1985; Sejrup et al., 1987, 1995, 2000, 2003; Cameron et al., 1987, 1992; Ehlers, 1990; Graham et al., 2007, 2011; Kristensen et al., 2007; Bradwell et al., 2008; Stoker et al., 2011; Stewart et al., 2013; Ottesen et al., 2014; Phillips et al., 2017a,b). However, several recent studies (e.g. Beets et al., 2005; Lonergan et al., 2006; Stewart and Lonergan, 2011) have suggested that there may have been many more glacial episodes. An increasing body of geomorphological and sedimentological data is not only providing the key evidence for the existence of these former Pleistocene ice sheets, but is also being used to demonstrate that

* Corresponding author.
E-mail address: erp@bgs.ac.uk (E. Phillips).

https://doi.org/10.1016/j.quascirev.2017.11.001
0277-3791/

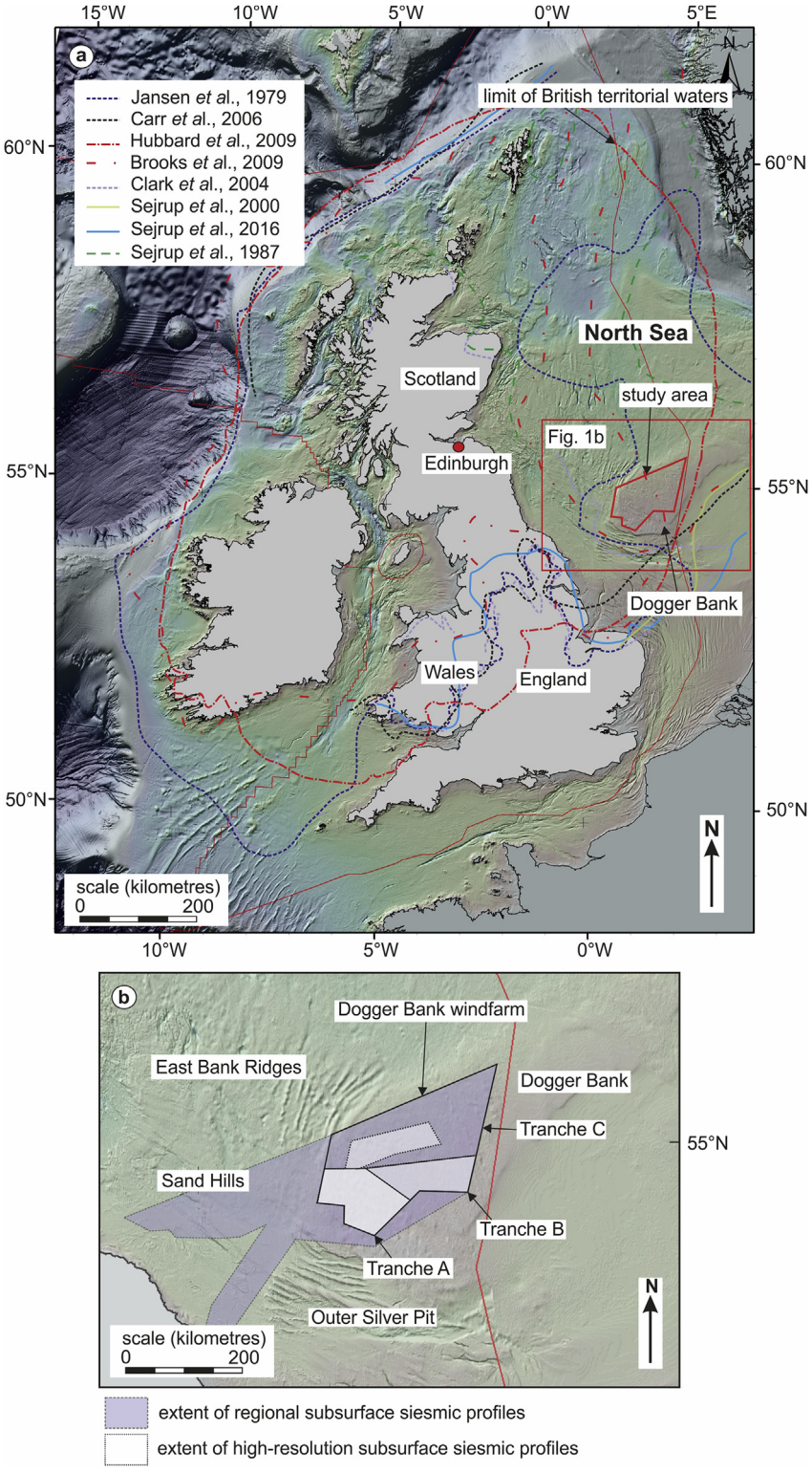

Fig. 1. **(a)** Map showing the location of the Dogger Bank in the southern North Sea Basin, and the Round 3 windfarm zone indicated by the red polygon. The limit of the UK territorial waters is also marked in red. EMODNET DigBath bathymetry (UK waters) and GEBCO bathymetry (Non UK waters); and **(b)** Map showing the location of the Dogger Bank windfarm zone (DBZ) and Tranches A, B and C, as well as the extent of the regional and high-resolution seismic surveys acquired during the site survey. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

they extended across the NW European continental shelves (Graham et al., 2007, 2010, 2011; Bradwell et al., 2008; Dunlop et al., 2010; Howe et al., 2012). Consequently, the Quaternary of the North Sea is critical to our understanding the evolution of the major northern European palaeo-ice masses, such as the British and Irish (BIIS) and Fennoscandian (FIS) ice sheets.

Several models proposed for the Weichselian glaciation within the North Sea (e.g. Boulton and Hagdorn, 2006; Carr et al., 2006;