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Sediment failures within the Peach Slide (Barra Fan, NE Atlantic Ocean) and relation to the history of the British-Irish Ice Sheet

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ABSTRACT

The Peach Slide is the largest known submarine mass movement on the British continental margin and is situated on the northern flank of the glacigenic Barra Fan. The Barra Fan is located on the northwest British continental margin and is subject to cyclonic ocean circulation, with distinct differences between the circulation during stadial and inter-stadial periods. The fan has experienced growth since continental uplift during the mid-Pliocene, with the majority of sediments deposited during the Pleistocene when the fan was a major depocentre for the British-Irish Ice Sheet (BIIS). Surface and shallow sub-surface morphology of the fan has been mapped using newly digitised archival paper pinger and deep towed boomer sub-bottom profile records, side scan sonar and multibeam echosounder data. This process has allowed the interpretation and mapping of a number of different seismic facies, including: contourites, hemipelagites and debrites. Development of a radiocarbon based age model for the seismic stratigraphy constrains the occurrence of two periods of slope failure: the first at circa 21 ka cal BP, shortly after the BIIS's maximum advance during the deglaciation of the Hebrides Ice Stream; and the second between 12 and 11 ka cal BP at the termination of the Younger Dryas stadial. Comparison with other mass movement events, which have similar geological and oceanographic settings, suggests that important roles are played by contouritic and glacigenic sedimentation, deposited in inter-stadial and stadial periods respectively when different thermohaline regimes and sediment sources dominate. The effect of this switch in sedimentation is to rapidly deposit thick, low permeability, glacigenic layers above contourite and hemipelagite units. This process potentially produced excess pore pressure in the fan sediments and would have increased the likelihood of sediment failure via reduced shear strength and potential liquefaction.

1. Introduction

Submarine slope failures are a major component of the earth system with significant consequences with regard to tsunami generation (Bondevik et al., 2005; Bryn et al., 2005a), hazards to seabed infrastructure (Bea et al., 1983; Hsu et al., 2008) and possibly climatic change via the dissociation of methane-clathrate (Kennett et al., 2003). Understanding of the mechanisms governing the occurrence of these failures has improved significantly via detailed analysis of individual events (such as Storegga (Bryn et al., 2005a; Solheim et al., 2005)) as well as more extensive studies of multiple events (Canals et al., 2004; Masson et al., 2006; Owen et al., 2007; Chaytor et al., 2009; Lee, 2009; ten Brink et al., 2009; Urlaub et al., 2013). Some of these studies have shown a potential increased frequency of submarine mass movements on glaciated margins during and after deglaciation (Owen et al., 2007; Lee, 2009). However, it is widely acknowledged that there is still a need for detailed studies of submarine slope failures to extend the available database as well as to provide analogues for the potential impact of future climatic change.

Under a business as usual scenario, where it is assumed that future greenhouse gas emission trends follow those of the past, climate models forecast 8.3 °C warming in the Arctic and 3.1 °C warming in the Antarctic between 2081 and 2100 (IPCC, 2013, Chapter 12). Rapid ice melt is already observed in these regions, for

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example Greenland is losing over 200 gigatonnes of ice per year, a six-fold increase since the early 1990s, while Antarctica is losing about 150 gigatonnes of ice per year, a five-fold increase since the early 1990s (IPCC, 2013, Chapter 4), meaning we may face deglaciation on a scale not observed since Termination 1A at circa 14 ka BP. As such, the deglaciation of a marine terminating ice sheet, during the last glacial period, with associated sedimentation, provides a suitable analogue for future submarine slope failures in polar regions.

To further these aims, of extending the database of well studied submarine mass movements and providing analogues for climatic change, this paper presents a detailed analysis of the Peach Slide. This is a large, and relatively unstudied, submarine mass movement complex situated within the Barra-Donegal Fan on the western continental margin of Britain and Ireland. On the basis of seabed and coastal glacial geomorphology it is inferred that during the last glacial period the Barra-Donegal Fan was fed by marine terminating ice streams from the Hebrides, North Channel and northwest Ireland (Scourse et al., 2009; Dunlop et al., 2010; Clark et al., 2012; Howe et al., 2012; Finlayson et al., 2014; Dove et al., 2015; Small et al., 2017).

The Barra and Donegal Fans are frequently referred to as a single fan complex, taken as such the Barra-Donegal Fan Complex covers approximately 10,000 km^2 (location shown in Fig. 1a). It has a thickness of ~650 m (Armishaw et al., 1998), it is the largest deposit of glacigenic sediment on the western British and Irish continental margin and the most southerly of the Trough Mouth Fans on the western European continental margin (Armishaw et al., 1998; Dahlgren et al., 2005). As this paper is concerned with sedimentation affecting the Barra sector of the complex the name Barra Fan is used throughout.

This paper builds on extensive previous work on the Peach Slide and includes a reanalysis of seismic and other geophysical data (see Owen et al., 2015) as well as new foraminiferal $\delta^{18}O$, particle size sedimentology and ^{14}C dates from a core in the Peach Slide headwall area (using methods presented by Owen et al., 2010; Owen, 2013). These new data are combined with key previous work in the area (Armishaw et al., 1998, 2000; Holmes et al., 1998; Kroon et al., 2000; Knutz et al., 2002) and recent studies on the growth, extent and deglaciation of the British-Irish Ice Sheet (BIIS) (Clark et al., 2012; Dove et al., 2015; Hughes et al., 2016; Small et al., 2017) to provide an updated geological model for sedimentation on the Barra Fan. This model is then used to investigate the timing and control of the two most recent slope failures within the Peach Slide complex.

2. Context and previous studies in the area

Fig. 1a shows the Barra Fan location on the continental slope between the Hebrides Shelf and the Rockall Trough. To the north of the Barra Fan is the Hebrides slope and to the south are the Hebrides Terrace Seamount (HTS) and the Donegal Fan.

2.1. Geological setting

Following formation of the northeast Atlantic, the northwest European margin and adjacent deep-water basins have undergone a structural evolution encompassing uplift and subsidence during different periods, which resulted in the strengthening of bottom current circulation in the Rockall Trough (Praeg et al., 2005; Stoker et al., 2005a, 2010). The late-Pliocene to present uplift episode, is associated with the development of the Barra Fan (Dahlgren et al., 2005; Stoker et al., 2005b).

Contourite sedimentation dominates the successions of the northwest European margin from the intra-Miocene to intra-Pliocene unconformities, reflected in the characteristics of the RPb (Rockall and Porcupine Basins), FSN-2a (Faeroe-Shetland area) and Kai (North Sea Fan, Møre and Vøring Margins) formations (Bryn et al., 2005b; Stoker et al., 2005b). Contour current-formed features are visible on the Barra Fan's present seabed, with the Barra Fan drift a notable feature (Howe, 1996; Knutz et al., 2002). The region experiences a low level of seismic activity at the present time, though it is anticipated that this level increases during deglacial periods and for some millennia after (Bungum et al., 2010).

2.1.1. Glacial influence

Ice rafted debris (IRD) from the Rockall Plateau indicates that the margin has accumulated glacially derived sediment since ~2.6 Ma (Thierens et al., 2012), although widespread glaciation of the Hebrides Shelf did not occur until the mid-Pleistocene. Evidence from BIIS sourced IRD supports a Hebrides shelf-grounded ice sheet during the Marine Isotope Stage (MIS) 6 glaciation, between 173 and 128 ka (Hibbert et al., 2010). The slope front glacigenic (post 0.44 Ma) deposits are termed the Upper Macleod sequence and consist of mid-to late-Pleistocene muds. These overlie the pre-glacial shallow marine sands of the Pliocene to early-to mid-Pleistocene Lower Macleod sequence (Stoker et al., 1993; Stoker, 1995). The uppermost unit on the Barra Fan is the Gwaelo Sequence, which overlies glacial debris flows (Stoker et al., 1993).

Indicated in Fig. 1b, the Barra Fan consists primarily of sediments sourced from western Scotland and northwest Ireland (Knutz et al., 2001; Peters et al., 2008; Howe et al., 2012; Ó Cofaigh et al., 2012; Small et al., 2017). The Hebrides Shelf is incised by a number of deep trough features (North, Central and South Stanton Deeps and the Malin Deep shown in Fig. 2a), believed to be eroded by ice-streams (Bradwell et al., 2008). Recent work (Howe et al., 2012; Dove et al., 2015; Small et al., 2017) provides evidence of ice-streams that flowed southwestwards through the Little Minch and the Sea of the Hebrides; and the presence on drumlins on the outer Malin shelf provides evidence of flow from northwest Ireland (Dunlop et al., 2010).

The BIIS is the primary source of the Barra Fan's sediment and glacial and deglacial periods represent key intervals with regards to fan sediment accumulation. Therefore, when considering slope stability on the fan it is necessary to consider the extent of ice-cover, as well as the timing, and nature of advance and retreat of the BIIS. Major growth of the ice-sheet occurred, after Heinrich event 4, from 38 ka cal BP (Peters et al., 2008; Scourse et al., 2009). Marine geophysical mapping on the Malin and Hebrides shelves, provides evidence indicating the period 29–26 ka cal BP as that of maximum ice extent, or the BIIS LGM (Clark et al., 2012; Ó Cofaigh et al., 2012; Hughes et al., 2016). Fig. 1b, shows the shelf-edge northwestern extent of the BIIS as mapped by recent work (Bradwell et al., 2008; Clark et al., 2012; Hughes et al., 2016). There is, however, uncertainty regarding ice thickness on the Hebrides Shelf, with evidence suggesting that St Kilda (location shown in Figs. 1a and 2) was not overrun by the BIIS (Hiemstra et al., 2015; Ballantyne et al., 2017). This implies that it is unlikely to have reached the shelf edge in this west of Hebrides sector during the last LGM (Ballantyne et al., 2017).

Analysis of BIIS-sourced IRD clasts in core samples from the Rockall Trough and its environs provide timings that are broadly consistent with the geophysical mapping. BIIS IRD clast deposition is limited prior to Heinrich event 4, but increases between 30 and 28 ka and persists until 20 to 18 ka (Knutz et al., 2002, 2007; Peck et al., 2007; Peters et al., 2008; Scourse et al., 2009; Hibbert et al., 2010; Hall et al., 2011), reflecting a probable shelf-edge advance and subsequent collapse. Evidence of a number of meltwater pulses