



Ice-rafting from the British–Irish ice sheet since the earliest Pleistocene (2.6 million years ago): implications for long-term mid-latitudinal ice-sheet growth in the North Atlantic region

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ABSTRACT

The Plio-Pleistocene intensification of Northern Hemisphere continental ice-sheet development is known to have profoundly affected the global climate system. Evidence for early continental glaciation is preserved in sediments throughout the North Atlantic Ocean, where ice-rafted detritus (IRD) layers attest to the calving of sediment-loaded icebergs from circum-Atlantic ice sheets. So far, Early-Pleistocene IRD deposition has been attributed to the presence of high-latitudinal ice sheets, whereas the existence and extent of ice accumulation in more temperate, mid-latitudinal regions remains enigmatic.

Here we present results from the multiproxy provenance analysis of a unique, Pleistocene-Holocene IRD sequence from the Irish NE Atlantic continental margin. There, the Challenger coral carbonate mound (IODP Expedition 307 site U1317) preserved an Early-Pleistocene record of 16 distinctive IRD events, deposited between ca 2.6 and 1.7 Ma. Strong and complex IRD signals are also identified during the mid-Pleistocene climate transition (ca 1.2 to 0.65 Ma) and throughout the Middle-Late Pleistocene interval. Radiogenic isotope source-fingerprinting, in combination with coarse lithic component analysis, indicates a dominant sediment source in the nearby British–Irish Isles, even for the oldest, Early-Pleistocene IRD deposits. Hence, our findings demonstrate, for the first time, repeated and substantial (i.e. marine-terminating) ice accumulation on the British–Irish Isles since the beginning of the Pleistocene. Contemporaneous expansion of both high- and mid-latitudinal ice sheets in the North Atlantic region is therefore implied at the onset of the Pleistocene. Moreover, it suggests the recurrent establishment of (climatically) favourable conditions for ice sheet inception, growth and instability in mid-latitudinal regions, even in the earliest stages of Northern Hemisphere glacial expansion and in an obliquity-driven climate system.

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1. Introduction

The Plio-Pleistocene intensification of Northern Hemisphere glaciation, with the first large-scale development of continental ice sheets at ca 2.75–2.55 million years (Ma) ago (e.g. Maslin et al.,

1998), marks an important threshold in Earth's recent climate system. Unravelling the extent and dynamics of early ice-sheet development is crucial to our understanding of its response to, and amplification of, Quaternary climate forcing and its overall impact on global climate variability (e.g. Huybers and Tziperman, 2008; Maslin et al., 1998; Raymo and Huybers, 2008). On-land evidence for these early glaciations is rather limited and fragmented (Fig. 1), due to erosion and overprinting during later glacial phases. As the

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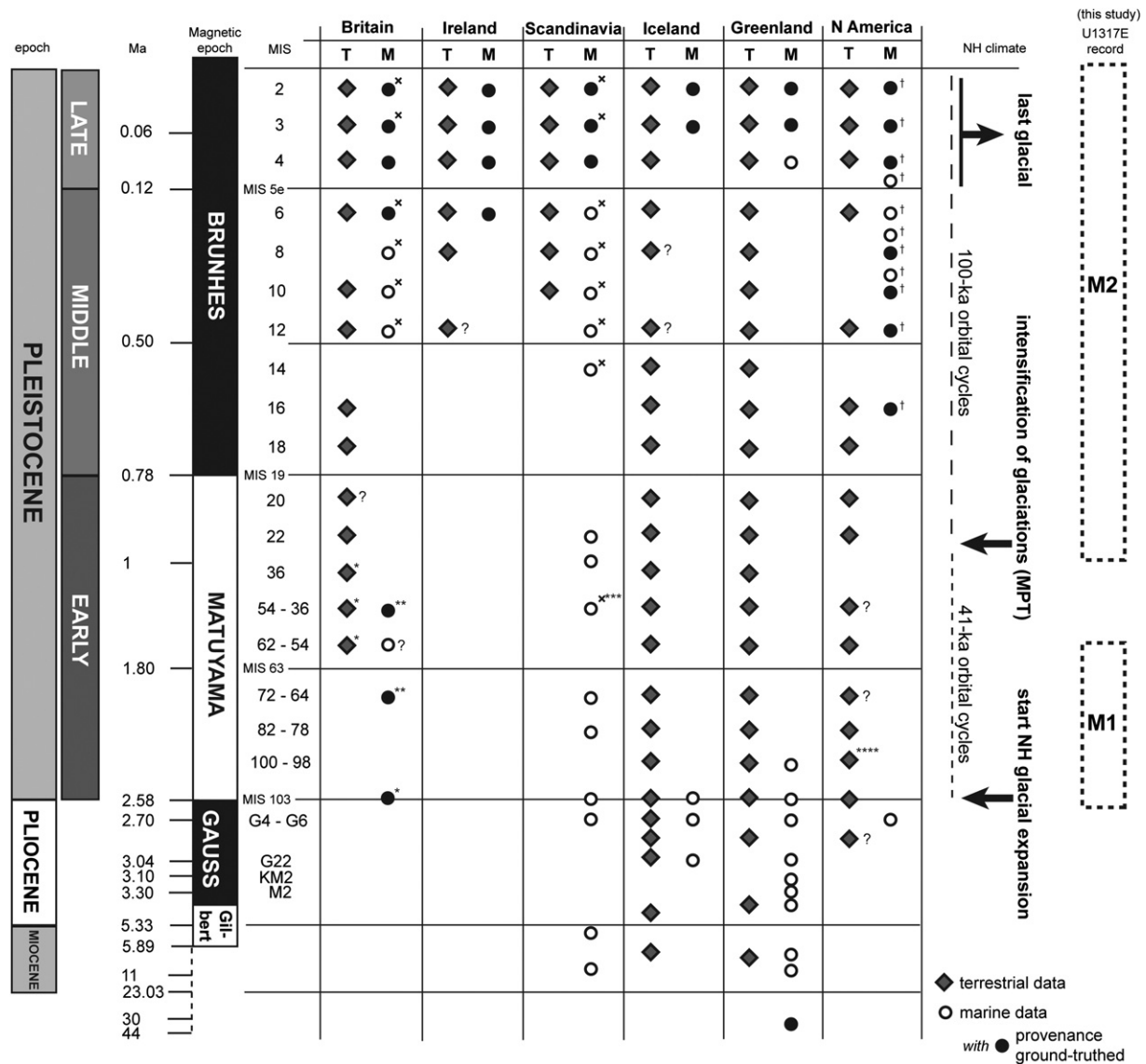


Fig. 1. Cenozoic glaciations of Northern Hemisphere (NH) circum-Atlantic continental terrains. Overview of terrestrial (T) and marine (M; mainly ice-rafted detritus) evidence for ice accumulation on the islands of Britain and Ireland, Scandinavia (mainly Norway), Iceland, Greenland and N America (in this study: the eastern sector of the North American continent). Note that time is not proportionally scaled. Main characteristics of the NH climate system and the temporal extent of the U1317E record (units M1–M2) are given for reference (see text for details). Reports of ice-rafted detritus not linked to distinct source areas are not reported in this overview. MIS = marine isotope stage; MPT = mid-Pleistocene climate transition; * restricted highland glaciations in Wales (see review by Lee et al. (2012)); ** Scottish ice-rafted clasts (Stoker et al., 1994); *** shelf-edge glaciations around Barents Sea/Svalbard (Sejrup et al., 2005); **** 2.4 Ma Atlanta Till (Balco et al., 2005), indicating full southern ice-extent; x including evidence for shelf-edge glaciations from glacial fan complexes along the NW European continental margin (Sejrup et al., 2005); † including evidence for Heinrich events (*sensu strictu* cf. Hemming (2004)). Data compiled from the following literature: Andrews, 2008; Andrews et al., 1994; Andrews and Maclean, 2003; Auffret et al., 2002; Balco et al., 2005; Ballantyne, 2010; Ballantyne et al., 2006; Barendregt and Duk-Rodkin, 2004; Baumann et al., 1995; Bond and Lotti, 1995; Bowen et al., 2002; Bradwell et al., 2008; Chiverrell and Thomas, 2010; Clark et al., 2000, 2004; Clark et al., 2006; Ehlers and Gibbard, 2007; Eldrett et al., 2007; Flesche Kleiven et al., 2002; Geirsdóttir, 2004; Geirsdóttir et al., 2006; Geirsdóttir and Eiríksson, 1994; Greenwood and Clark, 2009; Grousset et al., 2001; Hall et al., 2003; Helland and Holmes, 1997; Hemming et al., 1998; Hemming and Hajdas, 2003; Henrich and Baumann, 1994; Hibbert et al., 2010; Hiscott et al., 2001; Hodell et al., 2008; Hubbard et al., 2009; Jansen et al., 2000; Jansen and Sjöholm, 1991; Jullien et al., 2006; Knies et al., 2007; Knight et al., 2004; Knutz et al., 2001, 2007; Larsen et al., 1994; Lee et al., 2004, 2012; Mangerud et al., 1996; McCabe et al., 2005, 2007; Ó Cofaigh et al., 2012; Ó Cofaigh and Evans, 2001, 2007; Peck et al., 2007; Peters et al., 2008; Principato et al., 2005; Rashid and Hesse, 2003; Revel et al., 1996b; Rose, 2009; Roy et al., 2004; Scourse et al., 2000, 2009; Sejrup et al., 2000, 2005, 2009; Snoeckx et al., 1999; Stein et al., 2009; Stoker et al., 1994; Tripati et al., 2008; van Kreveld et al., 1996; Van Rooij et al., 2007; Verplanck et al., 2009; Whiteman and Rose, 1992.

build-up of considerable ice volumes also strongly affects oceanic circulation and sedimentation (e.g. [Rahmstorf, 2002](#); [Raymo et al., 1992](#); [Ruddiman et al., 1989](#)), records of continental ice-sheet expansion are, however, widely preserved in the marine environment. In the North Atlantic Ocean, ice-rafted deposits demonstrate the first widespread discharge, and melting, of sediment-loaded icebergs into the ocean around ca 2.7–2.4 Ma (e.g. [Flesche Kleiven et al., 2002](#); [Jansen et al., 2000](#); [Shackleton et al., 1984](#)) (Fig. 1). At this time, all major ice sheets located at high northern latitudes (on Canada, Greenland, Iceland and Scandinavia) are assumed to have

developed marine margins, generating iceberg, which deposited ice-rafted detritus (IRD) onto the North Atlantic seabed (Ehlers and Gibbard, 2007; Flesche Kleiven et al., 2002; Sejrup et al., 2005) (Fig. 1). Provenance data linking this Early-Pleistocene IRD to the glaciation of specific continental areas is, however, largely absent (Fig. 1). In addition, the role of any significant Early-Pleistocene ice build-up in more temperate mid-latitudinal regions, such as the British–Irish Isles (BI), especially to an extent that allows ice-rafting, is still poorly understood (Ehlers and Gibbard, 2007; Lee et al., 2012; Raymo and Huybers, 2008; Sejrup et al., 2005) (Fig. 1).

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