Quaternary Science Reviews 123 (2015) 76–90

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Submarine glacial landforms record Late Pleistocene ice-sheet dynamics, Inner Hebrides, Scotland

Dayton Dove [a, *], Riccardo Arosio [b], Andrew Finlayson [a], Tom Bradwell [a, c], John A. Howe [b]

[a] British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK
[b] Scottish Association for Marine Science, Scottish Marine Institute, Oban PA37 1QA, UK
[c] Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, UK

ARTICLE INFO

Article history:
Received 19 February 2015
Received in revised form
9 June 2015
Accepted 10 June 2015
Available online 30 June 2015

Keywords:
Quaternary glaciations
Submarine geomorphology
Glacial landforms
British–Irish Ice Sheet
Ice-sheet dynamics

ABSTRACT

We use ~7000 km^2 of high-resolution swath bathymetry data to describe and map the submarine glacial geomorphology, and reconstruct Late Pleistocene ice sheet flow configurations and retreat dynamics within the Inner Hebrides, western Scotland. Frequently dominated by outcrops of structurally complex bedrock, the seabed also comprises numerous assemblages of well-preserved glacigenic landforms typical of grounded ice sheet flow and punctuated ice-margin retreat. The occurrence and character of the glacially streamlined landforms is controlled in part by the shallow geology and topography, however these factors alone cannot account for the location, orientation, and configuration of the observed landforms. We attribute the distribution of these elongate streamlined landforms to the onset zone of the former Hebrides Ice Stream (HIS) – part of a major ice stream system that drained 5–10% of the last British–Irish Ice Sheet (BIIS). We suggest this geomorphic signature represents the transition from slow 'sheet flow' to 'streaming flow' as ice accelerated out from an environment characterized by numerous bedrock obstacles (e.g. islands, headlands), towards the smooth, sediment dominated shelf. The majority of streamlined landforms associated with the HIS indicate ice sheet flow to the southwest, with regional-scale topography clearly playing a major role in governing the configuration of flow. During maximal glacial conditions (~29–23 ka) we infer that the HIS merged with the North Channel-Malin Shelf Ice Stream to form a composite ice stream system that ultimately reached the continental shelf edge at the Barra-Donegal Trough-Mouth Fan. Taken collectively however, the pattern of landforms now preserved at seabed (e.g. convergent flow indicators, cross-cutting flow sets) is more indicative of a thinning ice mass, undergoing reorganization during overall ice sheet retreat (during latter stages of Late Weischselian glaciation). Suites of moraines overprinting the streamlined landforms suggest partial stabilization of the HIS prior to the ice sheet retreating to more isolated, topographically confined troughs and basins. Retreat from the shelf towards, and back into the Inner Hebrides may have been rapid due the prevalence of overdeepened troughs. Within the near-shore fjord-like troughs and deeps, basin-aligned streamlined landforms indicate the subsequent flow of thinner topographically partitioned ice masses, and over-printed moraines record further ice margin retreat, potentially along tide-water margins. This work provides the first geomorphological constraints for this large marine-influenced sector of the former BIIS. We also shed new light on the glacial geomorphic record found at the transition from terrestrial to marine continental-shelf settings, and examine the interplay between substrate geology, bed topography/bathymetry, and grounding-line positions – relationships which are important for characterizing contemporary marine ice sheet margins.

1. Introduction

Empirically derived ice-sheet reconstructions based on the extant glacial landform record are important for refining and constraining glaciological models which can in turn help to explain ocean–atmosphere–cryosphere interactions over millennial

* Corresponding author.
E-mail addresses: dayt@bgs.ac.uk (D. Dove), Riccardo.Arosio@sams.ac.uk (R. Arosio), afin@bgs.ac.uk (A. Finlayson), tom.bradwell@stir.ac.uk (T. Bradwell), john.howe@sams.ac.uk (J.A. Howe).

http://dx.doi.org/10.1016/j.quascirev.2015.06.012
0277-3791/

timescales (e.g. Boulton and Hagdorn, 2006; Hubbard et al., 2009; Pollard and DeConto, 2009). Ice streams are of particular interest within the glaciological system as they act as high flux corridors facilitating the discharge of the majority of an ice sheet's mass via a tributary network (e.g. Bamber et al., 2000; Truffer and Echelmeyer, 2003; Bennett, 2003). Contemporary studies in West Antarctica show that these ice stream systems are undergoing rapid change, partly driven by the migration of grounding-line positions, which may fundamentally alter the ice sheet's dynamic behaviour within marine sectors (e.g. Favier et al., 2014).

Several major ice streams have been identified within the former (Pleistocene) British–Irish Ice Sheet (BIIS) based on a combination of onshore and offshore geomorphological mapping, although knowledge is still lacking for key marine sectors owing to a paucity of data. One such area is offshore the central west coast of Scotland discussed in this manuscript, stretching from Skye in the north to Islay in the south and encompassing the ice divide (or saddle) between the Scottish and Irish ice-mass centres (Figs. 1 and 2). Research on the glacial history of the west coast of Scotland spans back at least 150 years (Geikie, 1863), however detailed

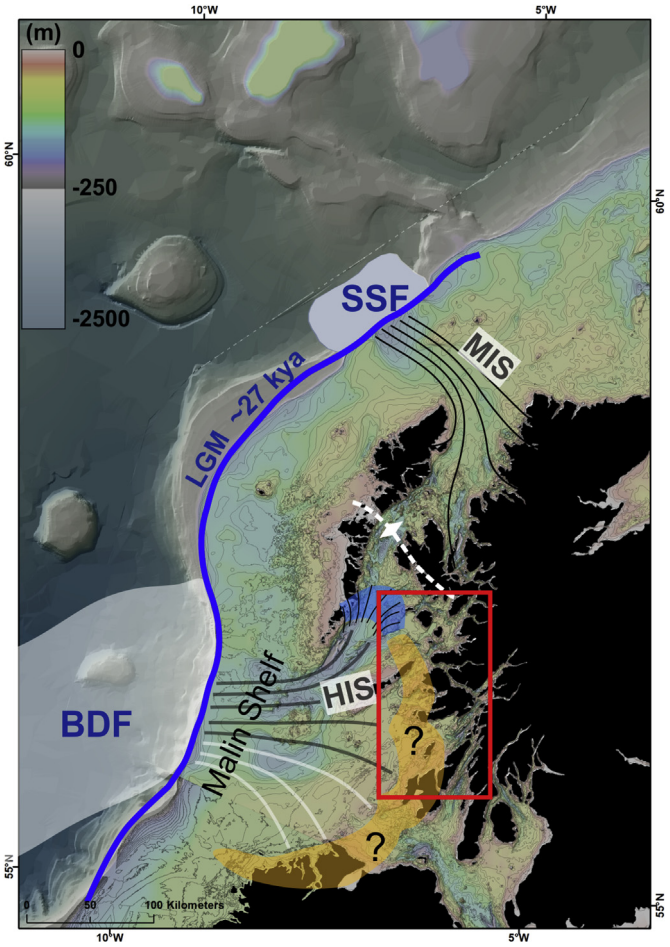

Fig. 1. Regional bathymetry with Inner Hebrides study area delineated in red. Palaeoglaciological reconstruction modified from Howe et al. (2012) where hypothesized ice stream flow paths and trough mouth fan extents were derived from Stoker et al. (1994), Sejrup et al. (2005), Bradwell et al. (2007), Scourse et al. (2009), and Dunlop et al. (2010). Proposed LGM limit taken from Bradwell et al. (2008). Ice stream onset zones proposed by Howe et al. (2012) are shown in blue (observed landforms) and orange (hypothesized) shading. Hebrides Ice Stream (HIS); Minch Ice Stream (MIS); Barra Donegal Fan (BDF); Sula SgeirFan (SSF). Bathymetry from GEBCO and BGS DigBath©NERC. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

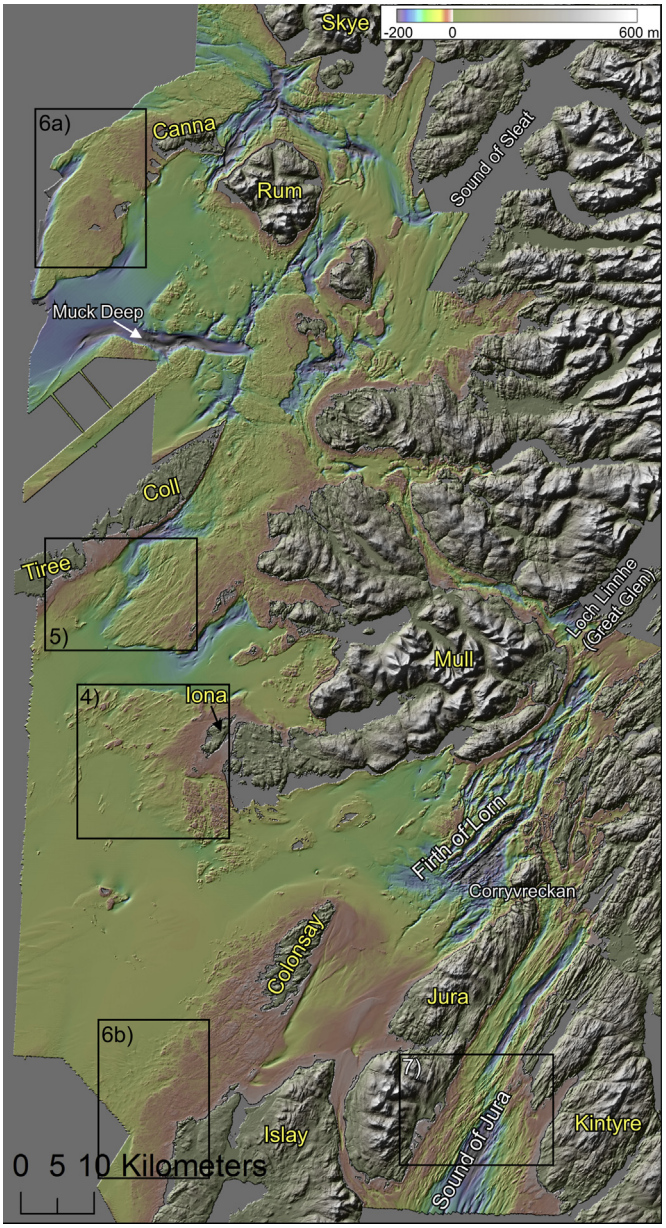

Fig. 2. High-resolution swath bathymetry data from the Inner Hebrides study area combined with NEXTMap digital terrain model. Insets for Figs. 3–6 indicated by black boxes. Bathymetry data provided courtesy of the Maritime & Coastguard Agency's UK Civil Hydrography Programme ©Crown copyright. Terrestrial topography data derived from Intermap Technologies NEXTMap Britain elevation data.

studies of past glaciation have been until recently, focused primarily on terrestrial observations and data (e.g. Gregory, 1927; Dawson, 1982; Sissons, 1983). Not surprisingly, the scarcity of suitable marine data has limited researchers' ability to characterize the incursion of ice into the marine realm. And while a detailed description of offshore Quaternary deposits alongside a seismo-stratigraphic framework was established for the Inner Hebrides by Binns (1974) and Davies et al. (1984), this analysis pre-dated the more recent understanding of how ice streams govern ice-sheet drainage (e.g. Stokes and Clark, 2001), and of their impact on mass balance through dynamic binge/purge cycles (e.g. Hubbard et al., 2009).

It is the application of improved glaciological theory together with the increasing availability of high-resolution marine