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NERC SCIENCE OF THE ENVIRONMENT

Sea-level change, glacial isostatic adjustment and drowned geomorphology of northern Scotland

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Durham University, Department of Geography
In partnership with British Geological Survey (NERC)

Supervisory Team

- **Prof Ian Shennan, Durham University** https://www.dur.ac.uk/geography/staff/geogstaffhidden/?id=360
- **Dr Tom Bradwell, British Geological Survey** http://www.bgs.ac.uk/staff/profiles/4480.html
- **Prof Antony Long, Durham University** https://www.dur.ac.uk/geography/staff/geogstaffhidden/?id=348
- **Mr David Long, British Geological Survey** http://www.bgs.ac.uk/staff/profiles/0948.html

Key Words **Sea-level change; bathymetry; crustal motions; ice sheet loading; landscape modelling**

Overview

Current highly sophisticated glacial-isostatic adjustment (GIA) models used to predict long-term land and sea-level changes generally show good agreement with empirically derived postglacial sea level curves from around the British Isles (Shennan et al., 2006, 2011) (Fig.1). But these models struggle to predict the relative sea-level variations at sites around the NW margins of the last British and Fennoscandian ice sheets, partly owing to a lack of good empirical data constraints on ice sheet dimensions and thickness and also because of a lack of good quality empirical observations of past sea-level and shoreline positions (Kuchar et al., 2012) (Fig.2).

The NW seaboard and northern isles of Scotland provide unique constraints on both the sea level and ice sheet components relevant for GIA modelling. Between Applecross and Shetland, a distance of 400 km, relative sea level and crustal motions change considerably across a steep spatial gradient (Fig.1). Whilst Applecross experienced overall lateglacial emergence and uplift; Shetland has experienced continuously rising sea levels coupled with the highest current rates of subsidence in the UK and Ireland (~1 mm/yr) (Shennan et al., 2006).

Explaining the contrasting sea-level records across northern Scotland is rooted in the ice sheet history of the wider area. Until relatively recently it was widely thought that parts of northernmost Scotland were largely unaffected by the last British and Scandinavian Ice Sheets – with any evidence of glaciation on Orkney or Shetland related to small, thin local ice caps or to earlier glacial cycles (Sutherland, 1991; Lambeck, 1993).

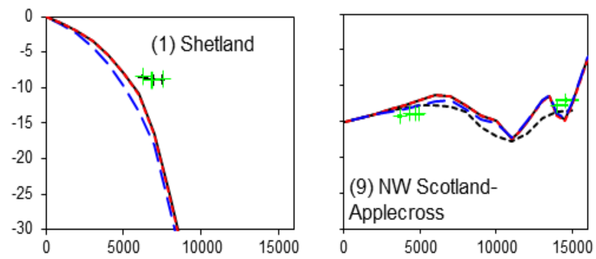

Fig.1: Relative sea level (RSL) curves (observations and model predictions) from the northernmost sector of the British Isles (data: Shennan et al., 2011). Note the continuously rising (submergent) record from Shetland, in contrast to the complex (emergent and submergent) Applecross record.

This model has recently been overturned, largely through the advent of new shelf-wide digital bathymetry data (e.g. Bradwell et al., 2008) showing numerous ice sheet moraines with fresh morphology on the seafloor around northern Scotland. Although not currently dated, seismic stratigraphy and selected offshore cores place this widespread glaciation of northernmost Scotland and the adjacent continental shelf within Marine Isotope Stage 2 (Stoker et al., 1993; Bradwell et al., 2008). Recent ice-sheet modelling experiments support these empirical reconstructions, with a considerably thicker and more extensive ice mass developing over northern Scotland (Hubbard et al., 2009). The maximum British-Irish ice sheet extent, flow configuration and decay history are currently the subject of a major NERC-funded research project – Britice-Chrono.

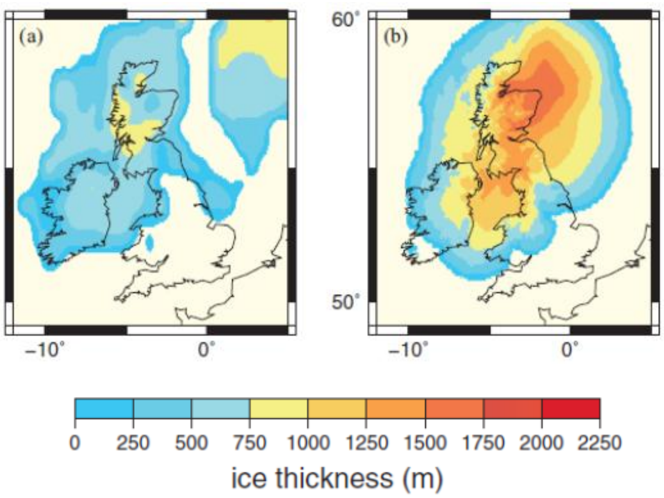

Fig. 2: Differing ice sheet models of the last British-Irish ice sheet for comparison. (a) Brooks et al. 2008; (b) Hubbard et al. 2009 (minimal reconstruction. Note the radically different ice thicknesses over NE Scotland (from Kuchar et al., 2012).

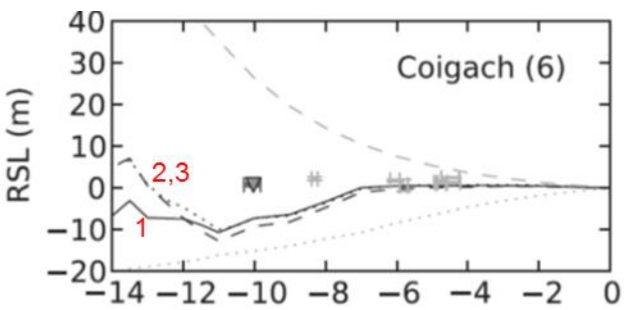

Fig. 3: RSL observations and 3 model predictions for Coigach, NW Scotland, the minimum (1), median (2) and maximum (3) models of Hubbard et al. 2009 (from Kuchar et al., 2012).

Importantly only some of the new, glaciologically realistic, ice sheet models provide reasonable fits with the sea-level records – the *minimum* model of Hubbard et al. (2009) for example, but not the *median* and *maximum* models. Increasing numbers of cosmogenic-exposure ages also point to a thicker ice sheet across NW Scotland, with a younger age for thinning and final deglaciation (e.g. Bradwell et al., 2008; Mathers, 2014). These increased ice-volume scenarios all predict RSL above present ca. 16-12 ka BP in parts of NW Scotland (e.g. Fig.3).

One of the key aims of this doctoral training project is to gather empirical constraints from across northern mainland Scotland to test the hypothesis that RSL was above present during the lateglacial. The student will integrate their new observations with dated ice-sheet margins arising from Britice-Chrono and systematically compile these to produce a geospatial database of palaeo-shoreline information to integrate with Long and Shennan's continuing collaborations with GIA modellers (G. Milne, Ottawa; S. Bradley, Utrecht). In addition, the student will undertake new mapping of the offshore zone, especially the seafloor around Shetland where numerous submarine features have been attributed to marine erosion (Flinn, 1964), and may date from the lateglacial period. This aspect of the project will draw on state-of-the-art high-resolution multibeam echosounder bathymetry data (Fig.4) to extend the geospatial database to drowned sea level features, in order to produce detailed onshore/offshore palaeo-coastline maps from ~20ka to the present day. These maps will be used to target further nearshore marine geophysical surveys (multibeam, sub-bottom seismic, etc), and geological seabed coring within the second half of the studentship to establish the sedimentary architecture and age of the drowned shorelines. Crucially these spatially and temporally constrained palaeo-marine limits will enable a new long-term sea-level curve to be constructed for northern Scotland and will serve as valuable index points to refine future GIA models of the British Isles – reducing uncertainties and improving predictive capability in this weakly constrained sector.

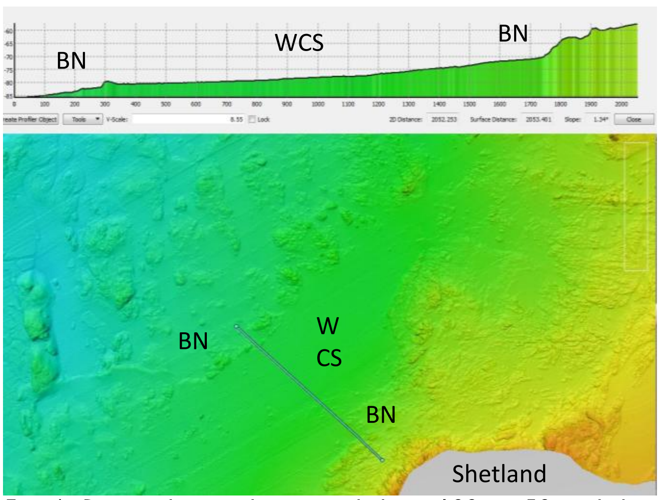

Fig. 4: Drowned coastal geomorphology, 100 to 50 m below present sea level, seen in multibeam imagery from NW Shetland. BN: bedrock notch; WCS: wave-cut shelf. Data acquired by MCA (UKHO).

Methodology

The research methodology will be transdisciplinary, supervised by recognised experts working in sea level research and process geomorphology, marine geology, ice sheet science, and GIA modelling. This studentship will involve fieldwork (terrestrial and marine), geological and geophysical data collection and analysis;

as well as using new and recently acquired bathymetric, geological and geochronological data.

The research methods will include: GIS and database construction, 2D and 3D geomorphological mapping (terrestrial and submarine); geophysical data analysis; geological core analysis; ITRAX sedimentology and geochemistry; C-14 dating techniques; integration of GIS databases with GIA models.

Timeline

Year 1:

Autumn-winter: Doctoral training methods programme at Durham including field techniques; training in sediment analyses methods; training in GIS techniques and database compilation; bathymetric dataset evaluation (at BGS); submarine landform mapping; evaluation of field sites in NW and N Scotland.

Spring-Summer: assessment and sub-sampling of marine cores collected during 2015 Britice-Chrono cruise; first field season (NW Scotland); laboratory analyses of core material; C-14 application submission; PhD progression paper presentation (May 2016).

Year 2:

Lab analyses of core material; selection of further material for C-14 dating; second field season (Orkney & Shetland); continued analysis of bathymetric data; develop GIS shoreline model; collection of seabed geophysical data, and possible offshore coastal coring campaign (with BGS); presentation of results at national conference (e.g. QRA Annual Discussion Meeting, Jan 2017).

Year 3:

Final field season; lab analyses of core material and selection of material for C-14 dating; completion of GIS palaeo-shoreline model and interfacing with GIA; lead authorship of key manuscript(s); presentation at international meeting or workshop (e.g. AGU 2017, EGU or PALSEA2); thesis preparation, write-up and final submission.

Training & Skills

Training in specialist and complementary skills is the most important aspect of a PhD programme. Specialist training will be provided in: Quaternary geology field techniques, including 2D and 3D (terrestrial and submarine) geomorphological mapping; marine geophysical data interpretation; DEM generation, 3D visualisation and interrogation in ArcGIS, Fledermaus, etc.; field site selection; a range of (terrestrial, lacustrine, and shallow marine) sediment coring methods; sediment analysis: e.g. LOI, X-ray, MSCL, ITRAX (XRF); ^{14}C dating and construction of age-depth models using Bayesian methods (with NERC RCL and SUERC, East Kilbride); stratigraphic correlation techniques; micropalaeontological analysis.

The student will take the Geography Department training course which covers research skills and techniques; research environment; research management; personal effectiveness; communication skills; networking and team-working; career management. The student will join a vibrant community of staff and students with interests in ice sheet history and sea-level changes at Durham and BGS. The supervisors will also provide tailored training: e.g. fieldwork, data analysis, oral and poster presentations, paper writing, thesis writing, compiling bibliographies, troubleshooting, interview preparation.

References & Further Reading

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Further Information

This NERC-funded (CASE) Doctoral Training Partnership project is timed to run in parallel and scientifically complement with the £3.7M Britice-Chrono NERC Consortium (2012-2017) (PI: C.Clark, Sheffield) Bradwell is a senior Co-I and leads the Shetland & NW Scotland work packages.

For further information contact Prof Ian Shennan, ian.shennan@durham.ac.uk or Dr Tom Bradwell, tbrad@bgs.ac.uk