Quaternary Science Reviews 111 (2015) 107–112

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Short communication

Ice sheet extension to the Celtic Sea shelf edge at the Last Glacial Maximum

Daniel Praeg [a,*], Stephen McCarron [b], Dayton Dove [c], Colm Ó Cofaigh [d], Gill Scott [b], Xavier Monteys [e], Lorenzo Facchin [a], Roberto Romeo [a], Peter Coxon [f]

[a] OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), Borgo Grotta Gigante 42C, Trieste, 34010, Italy
[b] Maynooth University Department of Geography, Maynooth, Co. Kildare, Ireland
[c] British Geological Survey, Murchison House, West Mains Road, Edinburgh, Scotland, EH9 3LA, UK
[d] Department of Geography, Durham University, Durham, DH1 3LE, UK
[e] Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin, Ireland
[f] Department of Geography, Trinity College Dublin, Ireland

ARTICLE INFO

Article history:
Received 4 September 2014
Received in revised form
10 December 2014
Accepted 11 December 2014
Available online 4 February 2015

Keywords:
British–Irish Ice Sheet
Last Glacial Maximum
Celtic Sea
Cockburn Bank
Glacigenic sediments
Heinrich Event 2

ABSTRACT

Previous reconstructions of the British–Irish Ice Sheet (BIIS) envisage ice streaming from the Irish Sea to the Celtic Sea at the Last Glacial Maximum, to a limit on the mid-shelf of the Irish-UK sectors. We present evidence from sediment cores and geophysical profiles that the BIIS extended 150 km farther seaward to reach the continental shelf edge. Three cores recently acquired from the flank of outer Cockburn Bank, a shelf-crossing sediment ridge, terminated in an eroded glacigenic layer including two facies: over-consolidated stratified diamicts; and finely-bedded muddy sand containing micro- and macrofossil species of cold water affinities. We interpret these facies to result from subglacial deformation and glacimarine deposition from turbid meltwater plumes. A date of 24,265 ± 195 cal BP on a chipped but unabraded mollusc valve in the glacimarine sediments indicates withdrawal of a tidewater ice sheet margin from the shelf edge by this time, consistent with evidence from deep-sea cores for ice-rafted debris peaks of Celtic Sea provenance between 25.5 and 23.4 ka BP. Together with terrestrial evidence, this supports rapid (ca 2 ka) purging of the BIIS by an ice stream that advanced from the Irish Sea to the shelf edge and collapsed back during Heinrich event 2.

1. Introduction

The maximum extents attained by former ice sheets provide a basic constraint on reconstructions of their thickness and dynamics. The southernmost extent of the last British–Irish Ice Sheet (BIIS) has long been disputed (e.g. Mitchell et al., 1973; Scourse, 1991; Scourse and Furze, 2001; Bowen et al., 2002), but it is now agreed that onshore glacigenic deposits in Ireland and southern Britain provide evidence of an advance of the Irish Sea Ice Stream into the Celtic Sea during the Last Glacial Maximum (LGM), around 25–23 ka BP[1] (Scourse, 1991; Ó Cofaigh and Evans, 2001, 2007; Greenwood and Clark, 2009; Chiverrell and Thomas, 2010; Clark et al., 2010; McCarroll et al., 2010; Ó Cofaigh et al., 2012; Chiverrell et al., 2013). The extent of this advance across the continental shelf has been constrained by a dozen vibrocores acquired in the late 1970s that penetrated surficial sand and gravel to reach sediments of glacial character (Fig. 1; Pantin and Evans, 1984). These undated sediments were interpreted to include subglacial till and glacimarine mud, their distributions used to propose a grounding line on the mid-shelf, correlated to an LGM limit across the Isles of Scilly (Fig. 1; Scourse et al., 1990, 1991; Scourse and Furze, 2001; Scourse et al., 2009b). Till-like sediments at the base of two cores near the shelf edge were suggested to represent residual ice-rafted deposits (Fig. 1; Scourse et al., 1990, 1991). The proposed grounding line has been noted to represent a minimum extent of glacial ice, given that glacimarine sediment at the base of several cores could be underlain by (un-cored) subglacial till (Sejrup et al., 2005). Ice-marginal landforms have not been recognized in the Celtic Sea, which is dominated by a system of shelf-crossing ridges interpreted as palaeo-tidal sand banks (Stride,

* Corresponding author. Tel.: +39 040 214 0395.
E-mail address: dpraeg@ogs.trieste.it (D. Praeg).
[1] All ages in calendar years before present (BP).

http://dx.doi.org/10.1016/j.quascirev.2014.12.010

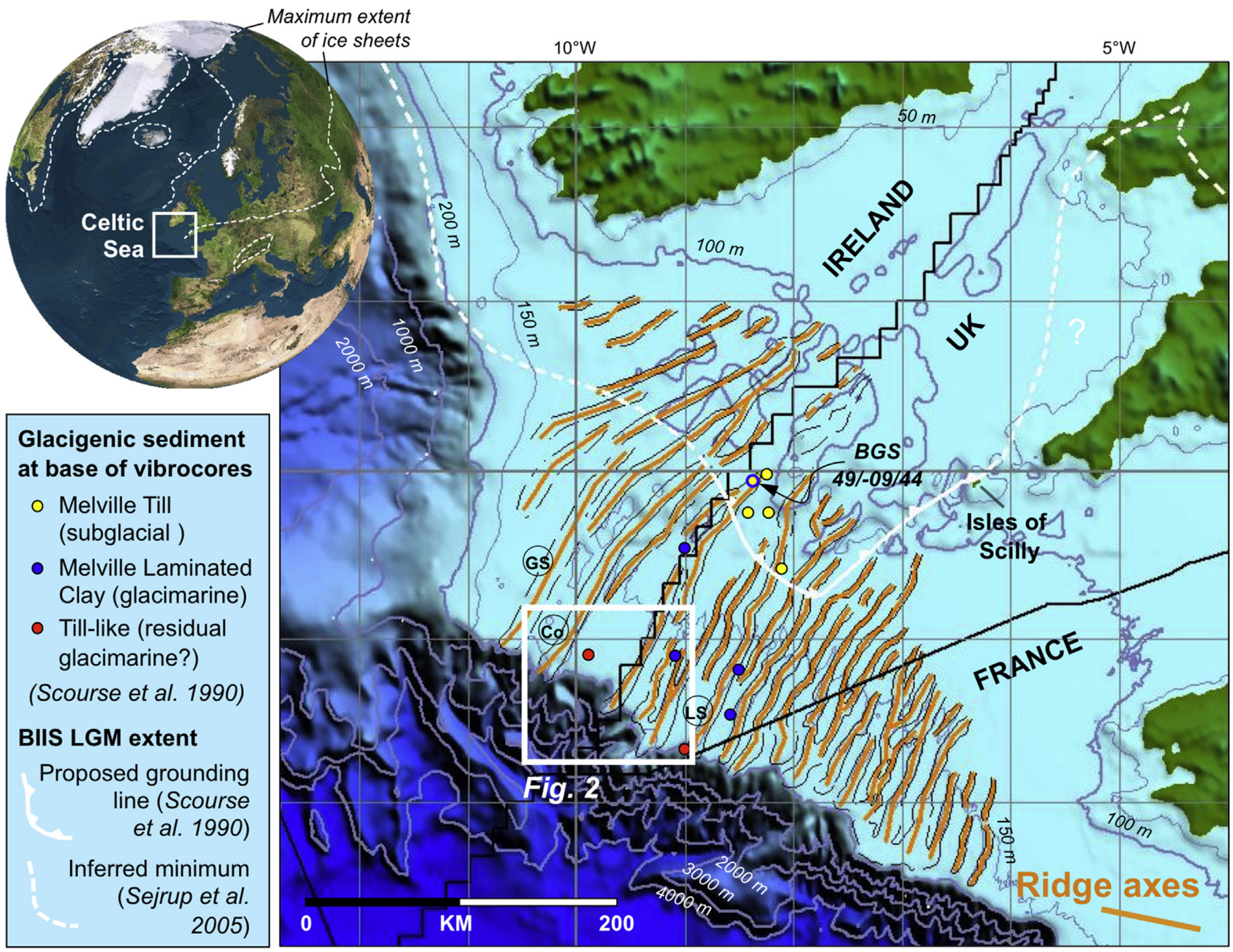

Fig. 1. The Celtic Sea relative to ice sheet limits. Top left: Quaternary ice sheet extents after Svendsen et al. (2004). Main figure: minimum extent of the last British–Irish Ice Sheet (BIIS) from Sejrup et al. (2005), anchored on a proposed grounding line on the Celtic Sea mid-shelf argued to record an advance of the Irish Sea Ice Stream (ISIS) to the northern Isles of Scilly (based on similar heavy mineral assemblages in the Scilly and Melville Tills; Scourse et al., 1990, 1991). The grounding line was drawn from the distribution of glacigenic facies (Scourse et al., 1990, 1991) at the base of the indicated vibrocores, acquired in the late 1970s by the then Institute of Geological Sciences, now British Geological Survey (BGS). System of seabed ridges up to 60 m high and 10 km wide mapped from Olex data (Gebco08). GS = Great Sole Bank, Co = Cockburn Bank, LS = Little Sole Bank.

1963; Bouysse et al., 1976; Stride et al., 1982), overlain at one site (core 49/-09/44, Fig. 1) by both subglacial till and glacimarine mud (Pantin and Evans, 1984; Evans, 1990; Scourse et al., 1990, 1991, 2009b).

Here we present new field evidence of glacigenic sediments on the Celtic Sea shelf, the first obtained in over three decades, and including the first direct determination of their age. The results are based on sediment cores (obtained with a 6 m vibrocorer) and subbottom profiles (2–5 kHz pinger) acquired in 2014 by the R/V *Celtic Explorer* near the edge of the Irish continental shelf (Fig. 1). Our aim is to rapidly communicate findings that have broad significance for on-going investigations of the seaward extent and dynamics of the last advance of the BIIS across the Celtic Sea. The implications of the results for the origin of the Celtic Sea ridges will be considered in a separate publication.

2. Results

The study area includes outer Cockburn Bank, a shelf-crossing ridge over 10 km wide that rises up to 50 m above the inter-ridge area to the SE (Figs. 1 and 2a). Pinger profiles show the ridge to be composed of weakly stratified sediments that thin across the inter-ridge area (Fig. 2b,c). Previous studies of the Irish-UK shelf by the British Geological Survey (BGS) assign upper Pleistocene sediments to a single unit, the Melville Formation, stratigraphically overlain by surficial sands and gravels 0–3 m thick that are only locally seismically resolved (e.g. Fig. 2c; Pantin and Evans, 1984; Evans, 1990).

2.1. Cored sediment facies

Three cores (≤1 m) from the lower flank of Cockburn Bank, located 1.1 km apart in water depths of 164–168 m (Fig. 2), penetrated brownish sand with gravel and shells up to 0.8 m thick, to terminate in up to 0.4 m of stiff to sticky greyish sediment (Fig. 3). The latter includes two facies, referred to as stratified diamict and bedded muddy sand, truncated by the surficial sandy layer (Fig. 3).

Stratified diamict: cores CE14003-VC-60 and VC-63 terminated in 0.21 m and 0.35 m respectively of stiff grey poorly-sorted and heterogeneous sediment, including contorted laminae of mud and fine sand with scattered granules, and lenses or beds of muddy sand with gravel and small shells, commonly aligned (Fig. 3). Shear strengths in the range of 3.6–5.8 kg/cm^2 indicate overconsolidation (Fig. 3; e.g. Anderson et al., 1991). In VC-60, a prominent shear plane truncates a lower interval with subhorizontal laminae, beneath an upper interval including coarser lenses. In VC-63, a lower laminated

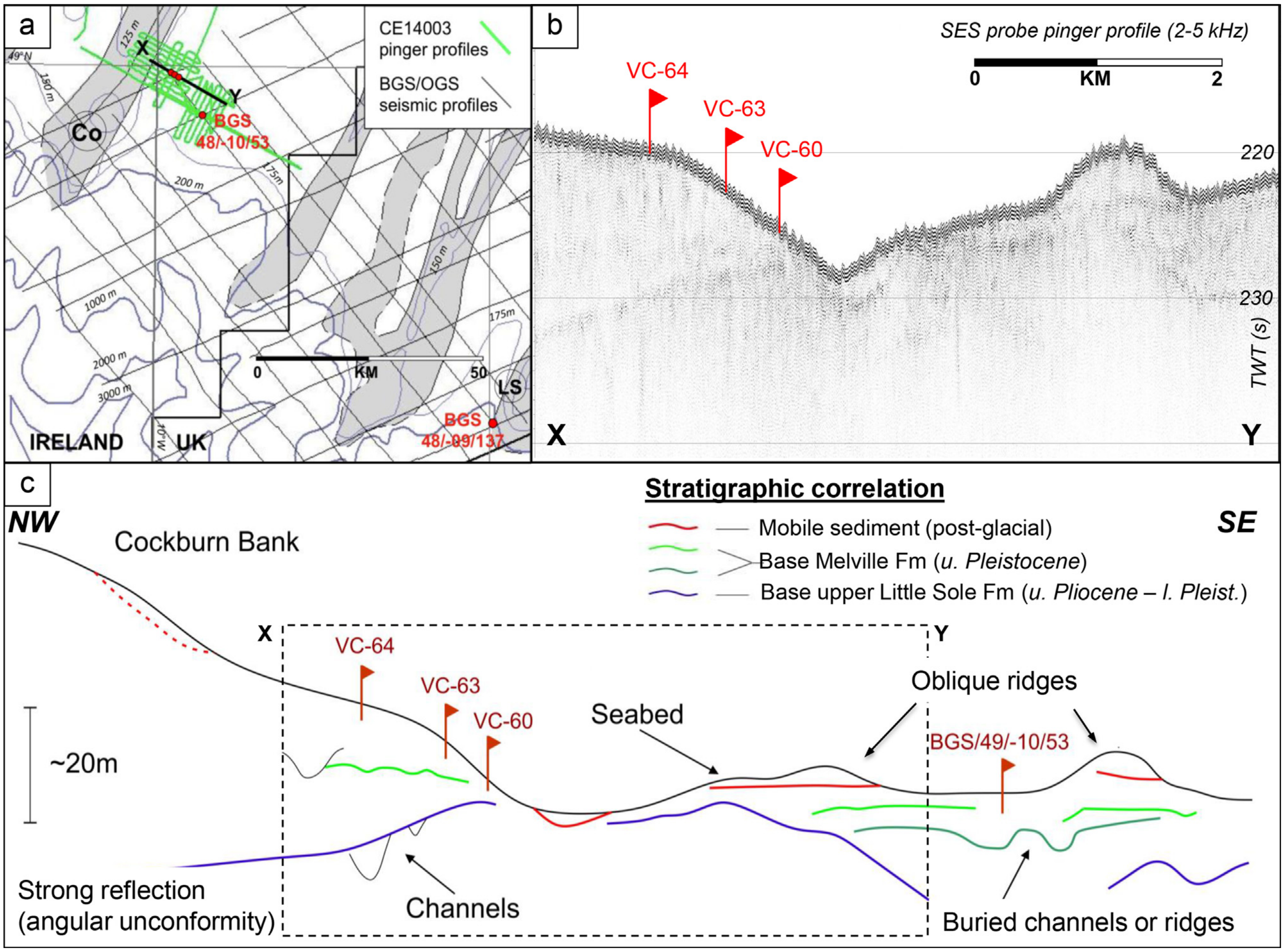

Fig. 2. Study area at the shelf edge of the Irish-UK Celtic Sea: a) Location of data acquired on and adjacent to Cockburn Bank during the CE14003 campaign of the Celtic Explorer, relative to existing data held by BGS and OGS (seabed ridges drawn from Olex data, edges approximate; Co = Cockburn Bank, LS = Little Sole Bank); b) 2–5 kHz pinger profile across the lower flank of Cockburn Bank, showing locations of three acquired cores; c) composite interpreted profile across Cockburn Bank and the inter-ridge area to the SE, showing correlation to stratigraphic units of Pantin and Evans (1984) as well as the projected locations of the three acquired cores and of BGS vibrocore 49/-10/53.

interval is truncated beneath an inclined series of sheared layers, or clasts, of stiff laminated diamict alternating with muddy sand with small aligned shells.

Bedded muddy sand: core VC-64 terminated in 0.4 m of sticky grey finely-bedded to laminated sediment, consisting primarily of silty fine sand but with both finer and coarser layers, and some evidence of bioturbation (Fig. 3). The facies is denser than that in cores VC-60 and VC-63, but normally consolidated with shear strengths <3 kg/cm^2 (Fig. 3). The sediment contains a diverse microfossil assemblage, with reworked (broken/damaged) and *in situ* species; the latter include benthic foraminifera indicative of cold (boreal) waters (e.g. *Cassidulina reniforme*, *Islandiella norcrossi* and *Elphidium clavatum*), as well as different-sized growth series of ostracod instars suggesting a quiescent depositional environment. The basal 2 cm of the core contained a chipped but unabraded valve of *Macoma cf. moesta* (Fig. 3d), a bivalve of Arctic distribution, that returned an AMS ^{14}C age of 24,460–24,070 cal BP (BETA #377772).

2.2. Seismic-scale sediment geometries

The three cores are comparable in length to the seabed return of the pinger (1–2 ms) and do not coincide with any reflection within the ridge (Fig. 2b,c). Thus the sediments at the base of the cores could correspond either to a thin layer at the top of the Melville Formation, or to its entire thickness (Fig. 2). Previous seismic profiles across the Celtic Sea ridges, including Cockburn Bank, show large-scale cross-beds consistent with a mainly sandy composition (Stride, 1963; Bouysse et al., 1976; Stride et al., 1982; Pantin and Evans, 1984; Evans, 1990; Marsset et al., 1999). Assuming Cockburn Bank to be a sand ridge, we infer its lower flank, over a distance of at least 1.1 km, to be capped by a thin (<1.5 m) layer of stratified diamict and bedded muddy sand, unconformably overlain by surficial sand and gravel (Fig. 3).

Across the inter-ridge area, the Melville Formation thins (<10 m) and is locally discontinuous (Fig. 2b,c). A diamict comparable to those in VC-60 and VC-63 was previously recovered 10 km to the SE in core 48/-10/53 (Fig. 2); the 2.2 m long core terminated in 6 cm of stiff grey sandy mud (>50% silt) with fine gravel (Scourse et al., 1990 and BGS field log). The core location is imprecise (≤1 km, Decca), but the depth of the diamict corresponds with the top of the Melville Formation (Fig. 2c). We infer that the eroded layer of stratified diamict and muddy sand at the top of the Melville Fm on the flank of Cockburn Bank extends at least 10 km across the inter-ridge area, as a layer of uncertain (0–10 m) thickness (Fig. 2c). A similar but sandier (>50%) stiff diamict was recovered at the shelf edge 75 km to the SE, adjacent to Little Sole Bank, in the lower 8 cm of 1.53 m long core 48/-09/137 (Fig. 2a; Scourse et al., 1990 and BGS field log), suggesting that such sediments may be discontinuously present beneath surficial sand and gravel along tens of kilometres of the outer Irish-UK shelf.

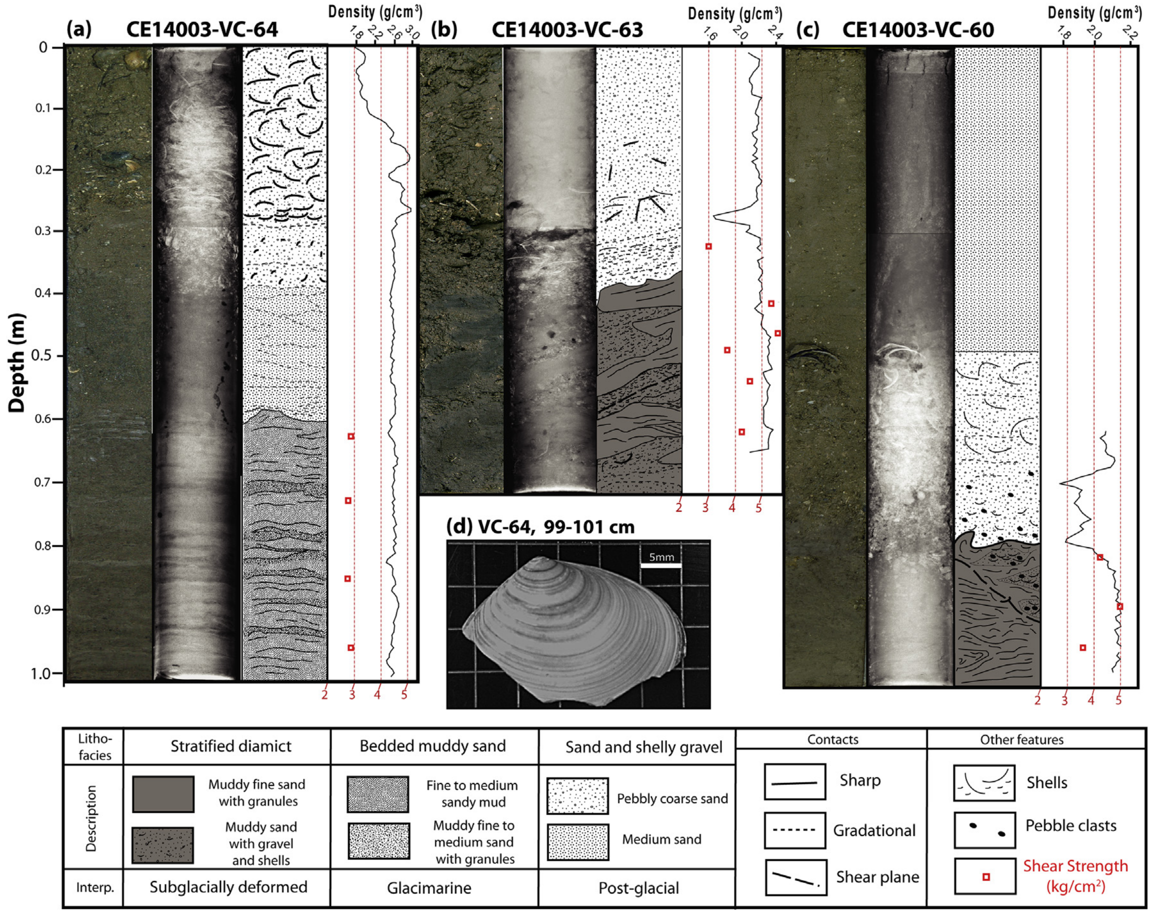

Fig. 3. Results from cores CE4003-VC-64, VC-63 and VC-60: a–c) photographs, X-radiographs, interpreted lithofacies and physical properties (density from GeoTek MSCL densiometer, shear strength from hand-held Torvane); d) photo of chipped but unabraded valve of *Macoma cf. moesta* washed from the lower 2 cm of VC-64, which yielded an AMS ^{14}C age of 24,460–24,070 Cal BP (BETA-377772).

3. Discussion – glacigenic sediments at the Celtic Sea shelf edge

The above results show that stiff diamicts are found both on and adjacent to seabed ridges along the Irish-UK shelf edge (Fig. 2), and occur in association with bedded glacimarine sediment dated to the LGM (Fig. 3). We interpret these sediments to come from an eroded sheet of glacigenic deposits that includes both subglacially deformed and ice-proximal glacimarine sediment.

The stratified diamicts in cores VC-60 and VC-63 are overconsolidated and contain shear planes and contorted layers (Fig. 3), consistent with loading and deformation beneath a grounded ice sheet (Evans et al., 2006). Alternatively, such sediment might result from iceberg rafting and turbation, in which poorly-sorted debris is deposited and reworked, with pre-existing material, by icebergs ploughing the seabed (Dowdeswell et al., 1994). However, this process does not account for the finely-bedded glacimarine muddy sands in VC-64 (Fig. 3), which record suspension settling of silt and fine sand in a quiescent environment, with pulsed input of coarser material. These deposits are difficult to explain by iceberg rafting at the edge of a high energy open Atlantic shelf; moreover, their turbation by icebergs would not in itself result in the stratified diamicts.

We argue that the simplest means to explain the presence of both glacigenic facies observed at the shelf edge is the advance and retreat of a tidewater ice sheet margin. Ice advance across a mid-latitude Atlantic shelf implies glacimarine deposition not only by ice rafting, but also by suspension settling from turbid and buoyant meltwater plumes, at rates that decrease seaward from the ice margin (Syvitski and Praeg, 1989; Syvitski, 1991). In our interpretation, the overconsolidated stratified diamicts on outer Cockburn Bank consist of sediments originally deposited beyond the ice margin that were subsequently overridden and subglacially deformed during its advance (cf. Ó Cofaigh et al., 2011); these are overlain by undeformed muddy sands deposited proximal to the retreating ice margin from meltwater plumes, at rates that diluted the input of gravel from iceberg rafting. Grounding line retreat resulted in the time-transgressive deposition across the shelf of a sheet of subglacial to glacimarine deposits, subsequently eroded and reworked by strong marine currents to contribute to the distribution of surficial sand and shelly gravel.

Our interpretation is compatible with evidence from glacigenic sediments previously cored across the Irish-UK shelf (Fig. 1), similarly inferred to form a discontinuous layer at the top of the Melville Formation on and between the seabed ridges (Pantin and Evans, 1984; Evans, 1990). Together with boulders found at seabed across the shelf, Pantin and Evans (1984) interpreted these sediments as ice-rafted material, but noted that they could also be interpreted as an eroded sheet of glacial deposits. The cored sediments were interpreted by Scourse et al. (1990, 1991) to include overconsolidated and homogeneous lodgment till deposited beneath an ice margin grounded on the mid-shelf, overlain in one core from a ridge flank (49/-09/44, Fig. 1) by glacimarine mud, consistent with landward retreat of a tidewater ice sheet margin; to seaward, ice rafting was argued to account for the deposition either of glacimarine mud or, near the shelf edge, of till-like sediments (Fig. 1). The latter comprise the stiff diamicts described above in cores 48/-10/53 and 48/-09/137 (Fig. 2), noted to have ice-proximal or lodgment till textural affinities also reflected in a poor microfossil content (Scourse et al., 1990, 1991). Based on our cores, we argue these to be subglacially deformed sediments, part of a sheet of overconsolidated diamicts likely to extend across the shelf, including beneath cored glacimarine muds as suggested by Sejrup et al. (2005).

The finely-bedded glacimarine muddy sand in VC-64 is comparable to the Melville Laminated Clay in cores farther landward on the shelf (Fig. 1), which grain size analyses show to consist of sandy silt to silty sand, almost entirely lacking in gravel, and containing an ostracod fauna indicating extremely low energy conditions of almost no currents (Scourse et al., 1990, 1991; Scourse and Furze, 2001). Scourse et al. (1990, 1991) acknowledged that the presence of such deposits across an open Atlantic shelf was difficult to explain by iceberg rafting, especially given modelling evidence that glacially lowered sea levels resulted in significantly increased tide and wave energies in the Celtic Sea (Belderson et al., 1986; Uehara et al., 2006; see Scourse et al., 2009b). We note that along tidewater ice sheet margins low energy seabed conditions are favoured by water column stratification, a result of the summer input of turbid and buoyant meltwater plumes and winter sea ice cover, which together may limit the action of tidal- and wave-induced currents (Syvitski and Praeg, 1989; Syvitski, 1991).

3.1. Implications for BIIS advance and retreat

On the above interpretation, the radiocarbon date of 24,265 ± 195 BP on a single mollusc valve from glacimarine sediment in VC-64 provides a maximum age on sedimentation along a tidewater ice margin, which was retreating from the shelf edge after 24.3 ka BP. This compares with evidence from deep-sea cores on the Celtic margin for increases in ice-rafted debris (IRD) of Irish-Celtic Sea provenance, with a smaller peak at c. 25.5–24.5 ka BP and a main peak at 23.6–23.4 ka BP encompassing Heinrich Event 2 (HE2; Scourse et al., 2001, 2009a; Auffret et al., 2002). These peaks are consistent with evidence from southern Ireland and the Isles of Scilly for the advance and retreat of the Irish Sea Ice Stream (ISIS) around 25–23 ka (Ó Cofaigh and Evans, 2007; Ó Cofaigh et al., 2012; McCarroll et al. 2010; see Chiverrell and Thomas, 2010; Chiverrell et al., 2013). Greenland ice cores record a northward migration of the polar front during this period, suggesting the IRD peaks could correspond to ISIS advance under cold conditions before 24.5 ka BP, followed by retreat under warmer conditions (Scourse et al., 2009a). This is supported by numerical modelling of increases in iceberg flux from the BIIS during rapid phases of ice stream advance and retreat, as part of binge–purge cycles that were phase-locked to regional climate variations with <1 ka delay (Hubbard et al., 2009).

Our results thus support previous interpretations linking IRD flux in deep-sea cores to a short-lived advance and retreat of the Irish Sea Ice Stream (Scourse and Furze, 2001; Scourse et al., 2009a,b). However, they further indicate that the BIIS extended across the Celtic Sea to the Irish-UK continental shelf edge, up to 150 km seaward of previously proposed limits (Fig. 1). We infer a rapid (2 ka) purging of the ice sheet, involving a cycle of ISIS advance and its collapse during HE2. Our results add to regional evidence of a highly dynamic BIIS drained by marine-based ice streams (Clark et al., 2010). Further field data and modelling studies are required to test our findings, which have linked implications for the maximum volume and thickness of the BIIS, for the dynamics of the ISIS in interaction with changing sea levels, as well as for the age and origin of the seabed ridges.

Acknowledgements

We warmly thank the Master and crew of the R/V *Celtic Explorer* during the GATEWAYS II campaign, with special thanks to John Barry and his deck crew. We are grateful for the generous support of the INFOMAR programme, a joint venture of the Marine Institute and the Geological Survey of Ireland. GATEWAYS II was funded by a ship-time award (CE14003) to Dr McCarron under the *Sea Change* strategy with the support of the Marine Institute and the Marine Research Sub-programme of the Irish National Development Plan 2007–2013. OGS participation was funded by the IPY GLAMAR project, awarded to Dr Praeg by the Italian polar research agency (PNRA 2009/A2.15). Access to original British Geological Survey core log and seismic data was arranged through a Digital Data License (IPR/126-9DR). We thank Mark Furze for his help in identifying the mollusc shell. We are grateful to James Scourse for many stimulating discussions and his helpful review of the manuscript, and we thank Dave Tappin for his thoughtful and constructive review.

References

Anderson, J.B., Kennedy, D.S., Smith, M.J., Domack, E.W., 1991. Sedimentary facies associated with Antarctica's floating ice masses. In: Anderson, J.B., Ashley, G.M. (Eds.), Glacial Marine Sedimentation: Paleoclimatic Significance, Boulder, Colorado, Geological Society of America Special Paper 261, pp. 1–25.
Auffret, G., Zaragosi, S., Dennielou, B., Cortijo, E., Van Rooij, D., Grousset, F., Pujol, C., Eynaud, F., Siegert, M., 2002. Terrigenous fluxes at the Celtic margin during the last glacial cycle. Mar. Geol. 188 (1–2), 79–108.
Belderson, R.H., Pingree, R.D., Griffiths, D.K., 1986. Low sea-level tidal origin of Celtic Sea sand banks – evidence from numerical modeling of M2 tidal streams. Mar. Geol. 73, 99–108.
Bouysse, P., Horn, R., Lapierre, F., Le Lann, F., 1976. Etude des grands bancs de sable du Sud-Est de la Mer Celtique. Mar. Geol. 20, 251–275.
Bowen, D.Q., Phillips, F.M., McCabe, A.M., Knutz, P.C., Sykes, G.A., 2002. New data on the Last Glacial Maximum in Great Britain and Ireland. Quat. Sci. Rev. 21, 89–101.
Chiverrell, R.C., Thomas, G.S.P., 2010. Extent and timing of the Last Glacial Maximum (LGM) in Britain and Ireland: a review. J. Quat. Sci. 25 (4), 535–549. http://dx.doi.org/10.1002/jgs.1404.
Chiverrell, R.C., Thrasher, I., Thomas, G.S.P., Lang, A., Scourse, J.D., Van Landeghem, K.J.J., Mccarroll, D., Clark, C., Ó Cofaigh, C., Evans, D.J.A., Ballantyne, C.K., 2013. Bayesian modelling the retreat of the Irish Sea Ice Stream. J. Quat. Sci. 28, 200–209.
Clark, C.D., Hughes, A.L.C., Greenwood, S.L., Jordan, C., Sejrup, H.P., 2010. Pattern and timing of retreat of the last British–Irish Ice Sheet. Quat. Sci. Rev. 35. http://dx.doi.org/10.1016/j.quascirev.2010.07.019.
Dowdeswell, J.A., Wittington, R.J., Marienfeld, P., 1994. The origin of massive diamicton facies by iceberg rafting and scouring, Scoresby Sund, East Greenland. Sedimentology 41, 21–35.
Evans, D.J.A., Phillips, E.R., Hiemstra, J.F., Auton, C.A., 2006. Subglacial till: formation, sedimentary characteristics and classification. Earth Sci. Rev. 78, 115–176.
Evans, C.D.R., 1990. The Geology of the Western English Channel and its Western Approaches. United Kingdom Offshore Regional Report. British Geological Survey; HMSO, London, p. 93.
Greenwood, S.L., Clark, C.D., 2009. Reconstructing the last Irish Ice Sheet 2: a geomorphologically-driven model of ice sheet growth, retreat and dynamics. Quat. Sci. Rev. 28, 3101–3123.
Hubbard, A., Bradwell, T., Golledge, N., Hall, A., Patton, H., Sugden, D., Cooper, R., Stoker, M., 2009. Dynamic cycles, ice streams and their impact on the extent, chronology and deglaciation of the British–Irish ice sheet. Quat. Sci. Rev. 28, 758–776.
McCarroll, D., Stone, S.O., Ballantyne, C.K., Scourse, J.D., Hiemstra, J.F., Evans, D.J.A., Fifield, L.K., Rhodes, E., 2010. Exposure-age constraints on the extent, timing and rate of retreat of the last Irish Sea ice stream. Quat. Sci. Rev. 29, 1844–1852.
Marsset, T., Tessier, B., Reynaud, J.-Y., De Batist, M., Plagnol, C., 1999. The Celtic Sea sand banks: sand body analysis from very high-resolution seismic data. Mar. Geol. 158, 89–109.
Mitchell, G.F., Penny, L.F., Shotten, F.W., West, R.G., 1973. A Correlation of the Quaternary Deposits in the British Isles. In: The Geological Society, London, Special Report 4, 99 pp.
Ó Cofaigh, C., Evans, D.J.A., 2001. Sedimentary evidence for deforming bed conditions associated with a grounded Irish Sea glacier, southern Ireland. J. Quat. Sci. 16 (5), 435–454.

Ó Cofaigh, C., Evans, D.J.A., 2007. Radiocarbon constraints on the age of the maximum advance of the British–Irish ice sheet in the Celtic Sea. Quat. Sci. Rev. 26, 1197–1203.
Ó Cofaigh, C., Evans, D.J.A., Hiemstra, J., 2011. Formation of a stratified subglacial "till" (glacitectonite) assemblage by ice-marginal thrusting and glacier overriding. Boreas 40, 1–14.
Ó Cofaigh, C., Telfer, M.W., Bailey, R.M., Evans, D.J.A., 2012. Late Pleistocene chronostratigraphy and ice sheet limits, southern Ireland. Quat. Sci. Rev. 44, 160–179. http://dx.doi.org/10.1016/j.quascirev.2010.01.011.
Pantin, H.M., Evans, C.D.R., 1984. The Quaternary history of the central and southwestern Celtic Sea. Mar. Geol. 57, 259–293.
Scourse, J.D., 1991. Late Pleistocene stratigraphy and palaeobotany of the Isles of Scilly. Philos. Trans. R. Soc. B334, 405–448.
Scourse, J.D., Austin, W.E.N., Bateman, R.M., Catt, J.A., Evans, C.D.R., Robinson, J.E., Young, J.R., 1990. Sedimentology and mircropalaeontology of glaciomarine sediments from the central and southwestern Celtic Sea. In: Dowdeswell, J.A., Scourse, J.D. (Eds.), Glacimarine Environments: Processes and Sedimentation, The Geological Society, London, Special Publications 53, pp. 329–347.
Scourse, J.D., Furze, M.F.A., 2001. A critical review of the glaciomarine model for Irish sea deglaciation: evidence from southern Britain, the Celtic shelf and adjacent continental slope. J. Quat. Sci. 16 (5), 419–434.
Scourse, J.D., Haapaniemi, A.I., Colmenero-Hidalgo, E., Peck, V.L., Hall, I.R., Austin, W.E.N., Knutz, P.C., Zahn, R., 2009a. Growth, dynamics and deglaciation of the last British–Irish Ice Sheet: the deep-sea ice-rafted detritus record. Quat. Sci. Rev. 28, 3066–3084.
Scourse, J.D., Robinson, J.E., Evans, C.D.R., 1991. Glaciation of the central and southwestern Celtic Sea. In: Ehlers, J., Gibbard, P.L., Rose, J. (Eds.), Glacial Deposits of Great Britain and Ireland. Balkema, Rotterdam, pp. 301–310.
Scourse, J., Uehara, K., Wainwright, A., 2009b. Celtic Sea linear tidal sand ridges, the Irish Sea Ice Stream and the Fleuve Manche: palaeotidal modelling of a transitional passive margin depositional system. Mar. Geol. 259, 102–111.
Sejrup, H.-P., Hjelstuen, B.O., Dahlgren, T., Haflidason, H., Kuijpers, A., Nygård, A., Praeg, D., Stoker, M.S., Vorren, T.O., 2005. Pleistocene glacial history of the NW European continental margin. Mar. Pet. Geol. 22, 1111–1129.
Stride, A.H., 1963. North-east trending ridges of the Celtic Sea. Proc. Ussher Soc. 1, 62–63.
Stride, A.H., Belderson, R.H., Kenyon, N.H., Johnson, M.A., 1982. Offshore tidal deposits: sand sheet and sand bank facies. In: Stride, A.H. (Ed.), Offshore Tidal Sands: Processes and Deposits. Chapman & Hall, New York, pp. 95–125.
Svendsen, J.I., , et al.29 Co-authors, 2004. Late Quaternary ice sheet history of northern Eurasia. Quat. Sci. Rev. 23 (11–13), 1229–1271.
Syvitski, J.P.M., 1991. Towards an understanding of sediment deposition on glaciated continental shelves. Cont. Shelf Res. 11 (8–10), 897–937.
Syvitski, J.P.M., Praeg, D., 1989. Quaternary sedimentation in the St. Lawrence estuary and adjoining areas, eastern Canada: an overview based on high-resolution seismo-stratigraphy. Géogr. Phys. Quat. 43 (3), 291–310.
Uehara, K., Scourse, J.D., Horsburgh, K.J., Lambeck, K., Purcell, A.P., 2006. Tidal evolution of the northwest European shelf seas from the Last Glacial Maximum to the present. J. Geophys. Res. 111, C09025. http://dx.doi.org/10.1029/2006JC003531.