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A stratigraphic investigation of the Celtic Sea megaridges based on seismic and core data from the Irish-UK sectors

Edward A. Lockhart[a, *], James D. Scourse[b], Daniel Praeg[c, d, 1], Katrien J.J. Van Landeghem[a], Claire Mellett[e], Margot Saher[a], Louise Callard[f], Richard C. Chiverrell[g], Sara Benetti[h], Colm Ó. Cofaigh[f], Chris D. Clark[i]

[a] *School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, LL59 5AB, UK*
[b] *College of Life and Environmental Sciences, University of Exeter, Penryn, Cornwall, TR10 9EZ, UK*
[c] *OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), Borgo Grotta Gigante, Trieste, Italy*
[d] *Géoazur (UMR 7329 CNRS), Rue Albert Einstein, 06560 Valbonne, France*
[e] *Wessex Archaeology, Portway House, Old Sarum Park, Salisbury, Wiltshire SP4 6EB, UK*
[f] *Department of Geography, Durham University, Lower Mountjoy, South Road, Durham, DH1 3LE, UK*
[g] *Department of Geography and Planning, University of Liverpool, Liverpool, L69 3BX, UK*
[h] *School of Geography and Environmental Sciences, Ulster University, Coleraine, Londonderry, BT52 1SA, UK*
[i] *Department of Geography, Sheffield University, Sheffield, S10 2TN, UK*

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ABSTRACT

The Celtic Sea contains the world's largest continental shelf sediment ridges. These megaridges were initially interpreted as tidal features formed during post-glacial marine transgression, but glacigenic sediments have been recovered from their flanks. We examine the stratigraphy of the megaridges using new decimetric-resolution geophysical data correlated to sediment cores to test hypothetical tidal vs glacial modes of formation. The megaridges comprise three main units, 1) a superficial fining-upward drape that extends across the shelf above an unconformity. Underlying this drape is 2), the Melville Formation (MFm) which comprises the upper bulk of the megaridges, sometimes displaying dipping internal acoustic reflections and consisting of medium to coarse sand and shell fragments; characteristics consistent with either a tidal or glacifluvial origin. The MFm unconformably overlies 3), the Upper Little Sole Formation (ULSFm), previously interpreted to be of late Pliocene to early Pleistocene age, but here shown to correlate to Late Pleistocene glacigenic sediments forming a precursor topography. The superficial drape is interpreted as a product of prolonged wave energy as tidal currents diminished during the final stages of post-glacial marine transgression. We argue that the stratigraphy constrains the age of the MFm to between 24.3 and 14 ka BP, based on published dates, coeval with deglaciation and a modelled period of megatidal conditions during post-glacial marine transgression. Stratigraphically and sedimentologically, the megaridges could represent preserved glacifluvial features, but we suggest that they comprise post-glacial tidal deposits (MFm) mantling a partially-eroded glacial topography (ULSFm). The observed stratigraphy suggests that ice extended to the continental shelf-edge.

1. Introduction and context

1.1. Celtic Sea megaridges

The Celtic Sea contains an extensive assemblage of shelf-crossing linear ridges, covering an area of ~65,000 km^2 across the Irish, UK and French sectors, with their long axes generally orientated north-east to south-west (Fig. 1; Stride et al., 1982). In the Irish-UK sectors, these are up to 200 km long, 15 km wide, 55 m

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* Corresponding author.
E-mail address: edward.lockhart@bangor.ac.uk (E.A. Lockhart).

[1] Currently: Laboratório de Geologia Marinha, Universidade Federal Fluminense, Av. Gen. Milton Tavares de Souza s.n., Gragoatá, Niterói, RJ, 242103–46, BR.

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high and 20 km apart, and represent the largest examples of such features in the world (Stride et al., 1982). These ‘megaridges’ are found between depths of −180 m and −100 m. In the French sector of the shelf, the ridges are smaller, existing up to 70 km long, 7.5 km wide, 50 m high and 16 km apart (Bouysse et al., 1976). Early workers argued that the ridges were tidal features, now moribund, formed during lower sea level (Belderson et al., 1986; Bouysse et al., 1976; Stride, 1963; Stride et al., 1982), and it has subsequently been shown that rising post-glacial sea levels were associated with a mega-tidal regime capable of reworking shelf deposits to form ridges (Belderson et al., 1986; Scourse et al., 2009; Uehara et al., 2006; Ward et al., 2016). Alternatively, a possible glacial origin of the ridges was considered by early workers (see Belderson et al., 1986), and has been reconsidered to account for the recovery of glacigenic sediments linked to seismic reflections within the flanks of the megaridges (Praeg et al., 2015a, 2015b).

The Celtic Sea shelf was glaciated by the Irish Sea Ice Stream (ISIS), the offshore extent of which has been constrained by glacigenic sediments on the Isles of Scilly (Scourse, 1991) and in a handful of vibrocores from the Irish and UK sectors (Pantin and Evans, 1984; Praeg et al., 2015b; Scourse et al., 1990). The minimum extent of the ISIS (Sejrup et al., 2005) was reconstructed from the distribution of over-consolidated diamict, Melville Till (MT), recovered at the base of cores on the inner to mid-shelf collected by the British Geological Survey (BGS) in the 1970s and 80s (Scourse et al., 1990). Below water depths of −135 m, the MT gave way to cores of laminated silty clay, Melville Laminated Clay (MLC; Scourse et al., 1990). Both sedimentary facies, MLC overlying MT, were retrieved in BGS vibrocore 49/-09/44 under 2 m of superficial sediment, acquired on the mid-shelf on the flank of a megaridge (Pantin and Evans, 1984), corresponding to Ridge 3 (Fig. 1). Additional glacigenic sediments were recovered from three vibrocores on a megaridge flank, Ridge 5 (Fig. 1), near the shelf-edge and have been interpreted to contain both subglacially deformed sediments and laminated proximal glacimarine sediments containing a bivalve shell dated to 24.3 ka BP, suggesting extension of the ISIS to the shelf-edge during the Last Glacial Maximum (Fig. 1; Praeg et al., 2015b). This shelf-edge age is consistent with dates from the south coast of Ireland, indicating that the initial ice advance occurred after 25–24 ka BP (Ó Cofaigh and Evans, 2007). This advance reached the Isles of Scilly by 25.4–24 ka BP (Smedley et al., 2017) before extending to the shelf-edge and subsequently retreating into St. George's Channel by 24.2 ka BP (Small et al., 2018; Scourse et al., submitted). This chronology suggests that the advance and subsequent retreat of the ISIS across the shelf was rapid (Chiverrell et al., 2013; Ó Cofaigh and Evans, 2007; Scourse et al., submitted; Small et al., 2018).

1.2. *Formation of the Celtic Sea megaridges: tidal sand banks vs glacifluvial eskers*

Tidal models of the Celtic Sea megaridges have been based on observations of their morphology and internal character, and modelling of shelf conditions during lower sea levels. Seismic profiles across the Celtic Sea ridges reveal dipping and truncated internal reflection surfaces (Pantin and Evans, 1984; Reynaud et al., 1999b), while short (mainly <5 m) sediment cores obtained from the megaridges across the Irish-UK sectors show that the primary unit comprising the ridges, the Melville Formation (MFm), mainly consists of medium to coarse sand and gravel (Evans, 1990; Pantin and Evans, 1984). Huthnance (1982a, 1982b) proposed a mechanism for ridge growth based upon the interaction between bottom friction over a mound and tidal currents, resulting in ridge growth through deposition on the crest and lateral migration. This is different to the mechanism of Houbolt (1968), who suggested that longitudinal helical vortices either side of a mound can result in axial ridge growth with little lateral migration. Tidal ridges generally consist of medium sand with some bedding planes (Davis and Balson, 1992) which transition to an underlying lag deposit at the base of the ridge (Houbolt, 1968), similar to observations of the MFm by Pantin and Evans (1984). Tidal modelling investigations support the interpretation that the Celtic Sea ridges are constructional features formed during rising sea level by strong tidal currents following deglaciation ca. 21 ka BP (Belderson et al., 1986; Scourse et al., 2009; Uehara et al., 2006; Ward et al., 2016), with the energy required to transport coarse sand (Ward et al., 2015). Palaeotidal model results presented in Scourse et al. (2009) suggest that the northern limit of the ridge field could represent the boundary where bed stresses weakened ~10 ka BP, resulting in the features becoming moribund with no additional axial growth.

However, a post-glacial tidal formation of the megaridges conflicts with the presence of glacigenic sediments on their flanks, including laminated and/or stiff fine-grained sediment, from the mid- and outer-shelf (Praeg et al., 2015b; Scourse et al., 1990, submitted). Additionally, gravel and bounders have been recovered from the flanks of ridges across the Irish-UK sectors, with the presence of the former being suggested to represent a mantle of ice-rafted debris (Pantin and Evans, 1984). The presence of glacigenic sediments overlying the ridges and the recovery of MT and MLC in core 49/-09/44 on a megaridge flank, was interpreted to indicate that the MFm existed prior to deglaciation (Evans, 1990; Pantin and Evans, 1984). The observation that glacigenic sediments appear to drape the megaridge flanks in the Irish-UK sectors has been attributed to either partial glacial overriding of the mid-shelf ridges (Scourse et al., 1990) or to tidal ridges forming syngenetically with deglaciation (Scourse et al., 2009). Alternatively, the entire internal bulk of the megaridges could represent large glacifluvial features or giant eskers (Praeg et al., 2015a). The large-scale internal cross-bedding and sandy composition of the MFm, as well as the presence of stiff glacigenic sediments, could be consistent with the characteristics of eskers (Praeg et al., 2015a). Eskers may also be hundreds of kilometers long and up to 80 m high, but commonly have widths <150 m that are consistent with a single subglacial meltwater conduits (e.g. Banerjee and McDonald, 1975; Rust and Romanelli, 1975; Storrar et al., 2015). However, eskerine ridges with widths of kilometres also occur (e.g. Banerjee and McDonald, 1975; Mäkinen, 2003; Rust and Romanelli, 1975), including features up to 10 km wide (Noormets and Flodén, 2002; Veillette, 1986). Large ridges have been attributed to deposition from multiple conduits supplying sediment to over- and backlapping outwash fans along a receding ice margin (Rust and Romanelli, 1975). A time-transgressive origin can account for esker networks >100 km long within a receding ice-marginal zone, producing linear ridge segments with spacings of up to 19 km (Storrar et al., 2014). Eskers are highly variable in structure and lithology, but generally contain several metres of plane- and cross-bedded sand and gravels (Banerjee and McDonald, 1975; Brennand and Shaw, 1996; Gorrell and Shaw, 1991; Hebrand and Åmark, 1989; Mäkinen, 2003). Additionally, eskers may contain a core of boulders and cobbles which fine upward and outward from the centre, representing the deposition of finer grained material due to decreasing meltwater pressures in the final stages of development (Gorrell and Shaw, 1991). As eskers develop in ice marginal zones that may also be subaqueous, glaciofluvial sands and gravels may be interlayered with subglacial diamicts and both give way laterally to lacustrine or marine muds (Rust and Romanelli, 1975).

1.3. *Aims and wider context*

The aim of this paper is to present new information on the Celtic