Radiocarbon constraints on readvances of the British–Irish Ice Sheet in the northern Irish Sea Basin during the last deglaciation

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Abstract

Moraines deposited by the Dundalk Bay ice lobe record two readvances of the Irish Ice Sheet into the northern Irish Sea Basin during the last deglaciation. These readvances overrode and incorporated fossiliferous marine muds from the floor of Dundalk Bay. AMS 14C dates from monospecific microfaunas obtained from these muds indicate that the earlier (Clogher Head) readvance occurred sometime between 15.0 and 14.2 14C ka BP, thus identifying a previously unrecognized ice-margin fluctuation in the Irish Sea Basin that is correlative with a readvance in northwest Ireland. The younger readvance occurred after 14.2 14C ka BP and is equivalent to the Killard Point readvance identified elsewhere in the Irish Sea Basin. These readvances occurred during the Oldest Dryas cold interval and bracket Heinrich event 1. Raised marine muds that were deposited between ice readvances require that a substantial ice sheet remained on Ireland throughout much of the last deglaciation, with attendant isostatic depression of at least 110 m.

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1. Introduction

In many areas of the Irish Sea Basin, the limits of readvances of the British–Irish Ice Sheet (BIIS) margin are marked by moraines comprised of sediments deposited from high-energy meltwater (Eyles and McCabe, 1988). These deposits often contain carbonate fossils derived by glacial reworking of marine sediments from the floor of the Irish Sea. Because the fossils are reworked from assemblages as old as the Pliocene, however, they are of limited use for radiocarbon dating of the ice readvances with which they are associated.

Glacial deposits along the northwestern coast of the Irish Sea, on the other hand, are commonly associated with raised marine muds containing in situ monospecific marine microfaunas dominated by the foraminifera Elphidium clavatum (85–95%). These faunas represent opportunistic biocoenoses recorded from arctic–subarctic areas recently vacated by glacier ice (Hald et al., 1994) and therefore provide a robust method to constrain the age of associated glacial events by AMS 14C (Haynes et al., 1995). Combined with reconstructions of large-scale depositional systems from drumlins and glaciomarine sediments, such dating of ice-margin fluctuations has demonstrated that the BIIS was sensitive to the millennial-scale climate changes that originated in the adjacent North Atlantic Ocean (McCabe et al., 1998, 2005). In particular, McCabe and Clark (1998) identified a readvance of the BIIS, defined as the Killard Point Stadial, which occurred ~14 14C ka BP, or shortly after, and perhaps in response to, Heinrich event 1. Here we present new AMS 14C ages from Dundalk Bay, Ireland, (Fig. 1) that, with published ages from the same region, constrain the timing of two readvances of the BIIS margin into the Irish Sea: one immediately before the Killard Point Stadial, and one that is correlative to the Killard Point readvance elsewhere in the Irish Sea Basin.

2. Glacial geology of Dundalk Bay

A prominent moraine occurs on the southern margin of Dundalk Bay between Keenan’s Cross and Clogher Head (Fig. 1). The moraine trends northwest to southeast, is up
to 25 m high, has steep slopes to the east, and thins to the west, where it terminates against bedrock slopes. The moraine is composed of poorly sorted and stratified coarse gravel that has been glaciotectonically deformed by ice advancing from the northwest (McCabe and Hoare, 1978). On the eastern side of the moraine at Togher, for example, 3 m of diamicton overlies at least 10 m of boulder gravel that exhibits westward-rising stacked shear planes (McCabe and Hoare, 1978). The location of the moraine and its internal structure indicates that it was deposited near the frontal margin of a large ice lobe that advanced into Dundalk Bay and extended into the Irish Sea beyond Clogher Head (Fig. 1). Immediately distal to the moraine at Clogher Head and extending as far south as the Boyne estuary, swash gullies and raised foreshore gravels indicate former high relative sea levels contemporaneous with the ice readvance (Fig. 1) (McCabe, 1973; Stephens and McCabe, 1977; Synge, 1977).

McCabe et al. (1987) also identified moraines on the south side of Dundalk Bay that record a more restricted position of an ice lobe than the Clogher Head moraines (Fig. 1). Northwest of Keenan’s Cross, McCabe (1973) mapped the southern limit of a gravelly moraine complex that continues southwestwards from Ardee as ice-marginal...
ridges that are <1 km across, corresponding to the maximum extent of Synge’s (1977) drumlin readvance. Along the southern shore of Dundalk Bay, correlative ridges occur between Linns and Dunany Point, but this moraine complex is composed mainly of muddy diamicton and fossiliferous marine muds associated with tidewater sedimentation (McCabe et al., 1987).

We associate the two northwest/southeast trending moraines on the north shore of Dundalk Bay with the same ice limit as recorded by the Dunany moraine complex (Fig. 1). The northeastern margin of the Dundalk Bay ice lobe terminated in a narrow arm of the sea and deposited a series of coalescing, ice proximal, coarse clastic deltas interbedded distally with subaqueous sand and diamicton. At Rathcor, these deposits have been ice pushed and overlie deformed fossiliferous marine muds (McCabe et al., 2005). Both moraines stratigraphically overlie marine muds along the northern margin of the bay, and at one location the outwash is interbedded with thick (<1 m) beds of marine mud, demonstrating contemporaneity (McCabe et al., 1987).

Coastal erosion a few kilometres north of the Clogher Head moraine near Port (Fig. 1) has exposed up to 3 m of diamicton overlain by 2.5 m of sand and gravel (Fig. 2). The diamicton is compact and matrix supported, with matrix texture ranging from mud to sand. About 60% of the clasts are glacially faceted, with most (~85%) derived from local Silurian siltstones, but a significant fraction is also comprised of igneous erratics derived from the north. We interpret the diamicton to be a basal till because the clast fabric is parallel to stacked subparallel shear planes that are 5–20 cm apart, rise southwards at 5–10°, and can be traced along the entire (40 m) exposure.

At one point along the section, a steeply inclined intrusion of grey mud 1.5 m high and up to 0.5 m across cuts across the tectonic stratification of the till (Fig. 2). The mud contains a microfossil assemblage dominated by E. clavatum, indicating a marine origin. These relationships suggest that ice overrode marine mud during its advance into Dundalk Bay, and the mud was injected into the till from below as a result of ice loading subsequent to shearing of the till.

The till at Port is overlain by a pronounced boulder lag (Fig. 2). Boulder length varies between 10 and 35 cm, or the same size range as those boulders found in the till below. We attribute the boulder lag to marine erosion of the till during a Lateglacial transgression after ice retreated from the site. This interpretation is supported by the overlying parallel-bedded pebble gravel and sand (Fig. 2) which have characteristics that are typical of raised foreshore deposits. These foreshore sediments cover an area of ~4 km² between the Clogher Head and Dunany Point moraines (Fig. 1). The presence of ice-wedge pseudomorphs in the beach gravel confirms that the transgression was Lateglacial and not post-glacial in age.

3. Chronology

McCabe et al. (2005) reported AMS 14C ages from marine muds at Linns (14, 160 ± 70 14C yr BP) and Rathcor Bay (14, 250 ± 130 14C yr BP) (Figs. 1, 3; Table 1) that constrain the age of the younger ice limit in Dundalk Bay.
Fig. 3. Schematic logs from critical sedimentary successions exposed around the margins of Dundalk Bay (see Fig. 1) together with the stratigraphic position of the nine AMS $^{14}$C dates used to constrain the age of ice sheet readvances. Detailed descriptions of the sedimentology of these sites are found in McCabe et al. (1987) and McCabe and Haynes (1996). The AMS $^{14}$C ages are from monospecific samples of *Elphidium clavatum* and are corrected for a 400 yr reservoir age. The AMS $^{14}$C ages for Rathcor and Linns are from McCabe et al. (2005) and those from Cooley Point are from McCabe and Haynes (1996).
to be $< 14.2 \text{ ^{14}C ka BP}$. The age of this readvance is in good agreement with dates from muds interbedded in terminal outwash associated with an ice margin at Killard Point (13,785 $\pm$ 115 $\text{^{14}C yr BP}$, 13,995 $\pm$ 105 $\text{^{14}C yr BP}$) (Fig. 1) (McCabe and Clark, 1998), suggesting that this Dundalk Bay readvance occurred during the Killard Point Stadial (Figs. 4, 5). Two AMS $\text{^{14}C}$ ages from marine muds at Rough Island (Table 1), north of Killard Point, indicate that deglaciation of the Killard Point readvance had begun before $\sim 13.0 \text{ ^{14}C ka BP}$ (Fig. 5).
Four new AMS $^{14}$C ages from monospecific samples of E. clavatum taken from different levels in the vertical mud dyke in the till at Port indicate open marine conditions in Dundalk Bay (McCabe and Haynes, 1996) (Table 1) (Fig. 3). Three AMS $^{14}$C ages from marine muds on the north side of Dundalk Bay at Cooley Point (Figs. 1, 3) provide additional evidence for open marine conditions at this time (McCabe and Clark, 1998), and Rough Island (orange) (McCabe and Clark, 1998; this paper). Note that although we assume a 400-yr reservoir age, the reservoir age may have varied during the last deglaciation in association with large changes in the Atlantic meridional overturning circulation (Bard et al., 1994; Waelbroeck et al., 2001; Bondvik et al., 2006; Peck et al., 2006). (c) Far-field records of relative sea level from Barbados (squares) (Bard et al., 1990), Sunda Shelf (Hanebuth et al., 2000), and Bonaparte Gulf (Yokoyama et al., 2000). (d) The Greenland GISP2 $\delta^{18}$O record (Grootes et al., 1993; Stuiver and Grootes, 2000).

Four new AMS $^{14}$C ages from monospecific samples of E. clavatum taken from different levels in the vertical mud dyke in the till at Port indicate open marine conditions in Dundalk Bay $\sim15.3$ $^{14}$C ka BP (Table 1) (Fig. 3). Three AMS $^{14}$C ages from marine muds on the north side of Dundalk Bay at Cooley Point (Figs. 1, 3) provide additional evidence for open marine conditions at this time (McCabe and Haynes, 1996) (Table 1). Incorporation of these muds into the till at Port thus occurred in association with an ice readvance to the Clogher Head ice limit $\leq15.0$ $^{14}$C ka BP. Because the $^{14}$C ages on marine muds at Linns and Rathcor Bay constrain a minimum age of deglaciation from this ice limit to be $\geq14.2$ $^{14}$C ka BP, the Clogher Head readvance occurred between 15.0 and 14.2 $^{14}$C ka BP, and is thus $\sim$1000 years older than the Killard Point readvance (Fig. 5).

4. Discussion

Our new dates from Dundalk Bay require a revision to the deglacial scenario for the Irish Sea Basin proposed by McCabe and Clark (1998) and McCabe et al. (1998). In this original scenario, McCabe et al. defined the Cooley Point Interstadial as a nonglacial interval that occurred between 16.7 and 14.7 $^{14}$C ka BP, and the Killard Point Stadial as a glacial readvance that began after 14.7 $^{14}$C ka BP. On the basis of the $^{14}$C ages that constrain the age of the Clogher Head readvance, we now define the Clogher Head Stadial as occurring $\leq15.0$ and $\geq14.2$ $^{14}$C ka BP (Fig. 5). The Cooley Point Interstadial was terminated by this readvance, rather than by the Killard Point readvance, and is thus redefined as occurring sometime $\geq16.7$ $^{14}$C ka BP and $\leq15.0$ $^{14}$C ka BP. We also define the Linns Interstadial as the nonglacial interval that separated the Clogher Head and Killard Point Stadials on the basis of the $^{14}$C ages on marine muds that were deposited in Dundalk Bay $\sim14.2$ $^{14}$C ka BP (Fig. 5). These $^{14}$C ages for the Linns Interstadial also narrow the start of the Killard Point Stadial as occurring after 14.2 $^{14}$C ka BP, while the $^{14}$C ages from terminal outwash at Killard Point date the time when the ice margin was at its maximum extent ($\sim13.8$ $^{14}$C ka BP). Finally, the $^{14}$C ages from Rough Island provide limiting ages for the end of the Killard Point Stadial ($\sim13.0$ $^{14}$C ka BP) (Fig. 5).

McCabe and Clark (2003) identified a readvance of the BIIS margin at Corvish, northwest Ireland, which they correlated with the Killard Point Stadial. However, we now recognize that the $^{14}$C ages that constrain the age of this event indicate instead that it is correlative with the Clogher Head Stadial (Fig. 5b). Accordingly, the evidence from Corvish and Dundalk Bay identifies the Clogher Head Stadial as a regional readvance of the BIIS margin.
The $^{14}$C ages on marine sediments that constrain the timing of the stadials and interstadials, as well as older $^{14}$C ages from Kilkeel north of Dundalk Bay (Figs. 1b, 5b) (Clark et al., 2004), also demonstrate that the northern part of the Irish Sea Basin was isostatically depressed below sea level throughout the last deglaciation until at least 12.7 $^{14}$C ka BP (youngest age from Rough Island). Sustained isostatic depression occurred when eustatic sea level was >100 m below present (Fig. 5c), thus suggesting isostatic depression of at least 110 m (>100 m sea level lowering plus the height at which raised marine sediments occur today). This amount of isostatic depression requires that a significant ice mass remained over Ireland during this time, with its margin experiencing two fluctuations that were likely on the order of 10s of km in length. Because ice-flow directional indicators and the Armoy moraine in NE Ireland show that the north channel of the Irish Sea was blocked by ice during H1 (McCabe et al., 1998), the marine flooding came from the south.

Records of ice-rafted debris (IRD) in marine cores off the coast of Ireland show a peak in IRD derived from the BIIS immediately prior to H1 (Fig. 5a) (Zaragosi et al., 2001; Peck et al., 2006), or at the same time as the Clogher Head Stadial. Because an IRD signal alone cannot distinguish among the many potential mechanisms that can produce such a signal (McCabe and Clark, 1998), this correlation is significant in identifying the IRD peak as representing a readvance of the BIIS margin into the Irish Sea, delivering debris-laden icebergs. Rather than associating the increase in IRD to an ice sheet instability (Zaragosi et al., 2001; Peck et al., 2006), however, we attribute the IRD signal to reflect an increase in the flux of icebergs associated with a steady-state readvance of the BIIS margin during the Clogher Head Stadial in response to a reduction in the Atlantic meridional overturning circulation (AMOC) (McManus et al., 2004) and attendant cooling of the North Atlantic region associated with the start of the Oldest Dryas cold interval (Fig. 5d).

Retreat of the BIIS margin during the Linns Interstadial apparently occurred at the same time as Heinrich 1 (Fig. 5a). We consider two possible scenarios that might explain this association. First, the AMOC nearly collapsed during H1 (McManus et al., 2004), with an attendant expansion of sea ice that may have weakened the hydrological cycle, causing a more negative mass balance over the BIIS in an otherwise cold climate. Alternatively, the retreat of the BIIS during the Linns Interstadial may represent a dynamic response of the ice sheet independent of H1 that was caused by isostatic loading with an attendant increase in calving-induced retreat of its marine margin.

Subsequent readvance of the BIIS into the northern Irish Sea Basin during the Killard Point Stadial may have occurred immediately after H1 in response to a warming climate suggested by the GISP2 $\delta^{18}$O record (Fig. 5d), resulting in a stronger hydrological cycle and more positive mass balance. On the other hand, if earlier retreat into the Linns Interstadial was a dynamical response to isostatic loading, subsequent readvance during the Killard Point Stadial may have similarly occurred when the ice margin stabilized on land and began to readvance again in response to the continued cold climate of the Oldest Dryas.

In either case, there is no corresponding IRD signal such as the one associated with the Clogher Head Stadial (Fig. 5a), even though the ice margin during the Killard Point Stadial also advanced into the Irish Sea Basin. This lack of a signal may reflect a flux of debris-poor icebergs or a different transport path than taken by those released during the Clogher Head Stadial. Irregardless of the cause, this relationship (ice readvance, no IRD signal) points to the complex processes that must contribute to the formation of an IRD signal, emphasizing caution in interpreting such a signal with respect to ice sheet behaviour and dynamics.

In summary, our $^{14}$C ages from raised marine sediments in the northern Irish Sea Basin require that a substantial ice sheet remain on Ireland throughout much of the last deglaciation, with isostatic depression of at least 110 m. During this time, there were two readvances of the BIIS, which define the Clogher Head and Killard Point Stadials (Fig. 5). These ice-margin fluctuations may have occurred in response to climate change associated with changes in the AMOC and attendant changes in sea ice and the hydrological cycle, or they may reflect dynamical responses of a marine-based ice margin to isostatic loading and unloading.

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References


