Dating constraints on the last British-Irish Ice Sheet: a map and database

ANNA L.C. HUGHES¹, SARAH L. GREENWOOD² and CHRIS D. CLARK³

¹ Department of Geography, College of Science, Swansea University, Swansea, SA2 8PP, UK; a.hughes@swansea.ac.uk
² Department of Geological Sciences, Stockholm University, 10691 Stockholm, Sweden.
³ Department of Geography, University of Sheffield, Sheffield, S10 2TN, UK.

Abstract

We present a collation of 975 published dates relevant to the timing of build-up and retreat of ice over the British Isles during the most recent glacial stage. The spatial distribution of dates is essential to interpreting the evolution of the ice sheet over time and space. For this reason the dates are presented as a map showing the spatial distribution across the UK and Ireland. Full documentation for each date, attributed to its source publication and detailing geographic location, the material dated, its stratigraphic position or setting, the dating technique, the dating result, errors and calibration, and comments pertinent to its interpretation, are included in the accompanying table. It is anticipated that this dataset will be a useful resource for Quaternary research in the UK and Ireland and is therefore available to download as a shapefile and/or PDF file. The map is presented at a scale of 1: 2,700,000, designed to be printed at A2 size.
1. Introduction

Geochronology is an essential tool for ice sheet reconstruction. It enables us to connect spatially fragmented evidence, relate glacial events to dated climatic changes and consider the phasing of glacial events. Substantial effort has gone into establishing a chronology of the last British-Irish Ice Sheet (BIIS) (e.g. Andersen, 1981; Ballantyne, 2010; Bowen et al., 2002; Chiverrell and Thomas, 2010). Yet for a long time the chronology has been insufficient for assessing phasing with other ice sheets such as the Laurentide and Scandinavian, or the timing of regional/global climate signals such as Heinrich Events. For example, until very recently, the extent at the Last Glacial Maximum (LGM) was constrained by only five dates (Bowen et al., 2002). Often, and probably for good reasons such as cost and time, much geochronological work has been conducted on a local scale. The local-regional focus of the majority of work fails to produce a robust picture of the general form of the ice sheet and the relative timing of different sectors. In the absence of a good spatial density of dates there is a temptation to extrapolate local interpretations to the whole ice sheet. However, due to the geographic situation of the BIIS on the edge of the North Atlantic and its sensitivity to multiple transitions in the location of the Polar Front, it is probable that different sectors of the multi-domed ice sheet operated differently (Scourse et al., 2009; Clark et al., in press). Recent work has reflected a desire to produce ice sheet scale syntheses (e.g. Clark et al., 2004a; Evans et al., 2005; Bradwell et al., 2008b) but this has been largely pattern-based rather than on timing. Recent attempts at compiling dating information are welcome contributions, though have thus far focussed on a single time period (e.g. the LGM; Chiverrell and Thomas, 2010), dating method (e.g. terrestrial cosmogenic nuclides; Ballantyne, 2010) or data type (e.g. the offshore record of ice-rafted debris; Scourse et al., 2009). A full and insightful reconstruction of the last BIIS requires a synthesis of all available geochronological information across the whole of the former bed of the ice sheet, and beyond (e.g. Gyllencreutz et al., 2007), to tie point and spatial-pattern evidence, from sediments and geomorphology, together with data on timing.

This paper presents a database and map of published absolute dates that constrain the timing of the ice sheet. Our aim was to produce an easily accessible reference database of all published chronological evidence along the lines of the BRITICE database and map of geomorphological evidence (Clark et al., 2004a; Evans et al., 2005). This was motivated by the need to combine evidence from spatially distant parts of the ice sheet margin in order to reconstruct the retreat of the last BIIS (Clark et al., in press). The total volume of information gathered from systematic inspection of the literature (975 dates) was found to be reassuringly large. A considerable volume of information has amassed in the last decade, partially due to the advent of new dating methods such as in situ terrestrial cosmogenic isotope dating and a renewed interest in the last BIIS (e.g. Vincent et al., 2010; Ballantyne, 2010). In addition to reporting here the ‘raw’ summary of existing information, dates have been interpreted in terms of their significance for ice
sheet glacial history. All ages referred to in this paper are calendar ages unless documented with the suffix $^{14}\text{C}$ yr BP. The database follows a similar and more ambitious project to produce isochrones of build-up and deglaciation from a collation of dates and margin positions for all Eurasian ice sheets during the last glacial cycle conducted by the DATED-group at University of Bergen (Gyllencreutz et al., 2007) and the earlier compilation for the Laurentide Ice Sheet by Dyke et al. (2003).

2. Methods

2.1 Data collation

We conducted a thorough (but probably not exhaustive) search of the published literature for dates pertaining to the growth, development and decay of the last BIIS. Review articles and previous collations of chronological information were consulted in the first instance, including the online Oxford Radiocarbon Laboratory Datelist (Oxford Radiocarbon Accelerator Unit, 2008) and review articles (Sissons, 1967; Andersen, 1981; Sutherland, 1984; Jones and Keen, 1993; Bowen, 1999; Knight, 2001; Bowen et al., 2002; Evans et al., 2005). For Ireland the journal archives of *Archaeometry* (which publishes Oxford radiocarbon laboratory results) and *Radiocarbon* (Cambridge, Dublin, Belfast, Birmingham, SRR) were systematically searched. The search was extended beyond the Quaternary glaciological literature in order to capture a larger number of relevant dates. For example, the online date list of the Council for British Archaeology (CBA) ‘Archaeological Site Index to Radiocarbon Dates for Great Britain and Ireland’ was obtained in full from The Archaeology Data Service (Council for British Archaeology, 2000, (updated 2008)). The census date for inclusion of material was 31 October 2009. In press articles were included if available to us by this date. The dataset therefore is an update to that referred to in Greenwood and Clark (2009) for the Irish Ice Sheet which had a census date of February 2008. A full bibliography for the table is included at the end of this paper.

All sites from the continental shelf relating to the ice sheet and thought to be within the maximum extent limits portrayed in Sejrup et al. (2005) are included (Figure 1). Dates from beyond the maximum limits are excluded from the main database with the exception of dates on or close to the accepted maximum southern extension of ice across England and Wales. Offshore dates with implications for the timing of glacial events, such as the flux of ice-rafted detritus (IRD) (e.g. Scourse et al., 2009), are not included but instead are presented in Figure 1, together with a summary of the chronology of the adjacent Fennoscandian Ice Sheet.
Figure 1. Summary of distal geochronological information (from beyond maximum limits of the last British-Irish Ice Sheet). Information derived from a number of sources (Kroon et al., 2000; Auffret et al., 2002; Wilson et al., 2002; Carr, 2004; Houmark-Nielsen, 2004; Laban and van der Meer, 2004; Mangerud, 2004). Dashed line marks presently accepted maximum extent of ice during the last glacial. This is simplified after Sejrup et al. (2005) and Bradwell et al. (2008b). Only dates that fall within this maximum extent, as defined here, are included in the database in this paper.
Information we report for each date broadly follows that included by Dyke et al. (2003) in their database of radiocarbon dates for the Laurentide Ice Sheet. Location is given as reported in the original source; either latitude/longitude or national grid reference as appropriate. For completeness, where only one piece of location information was reported in the original source this was used to calculate the absent coordinates. In some cases precise geographic and projected coordinates were unspecified. To obtain coordinate information the location figure from the particular paper was scanned and geocorrected to obtain latitude/longitude and national grid reference (see Clark et al., 2004a, for description of the geocorrection procedure). Due to the potential for introducing location errors by this technique, if the site in question was considered a ‘classic’ or one reported in other papers, these references were checked prior, and in preference, to scanning. It is estimated that the error due to misplacement of dated sites is on the order of 1 km and therefore unlikely to be problematic for reconstruction at the scale of the ice sheet. Locations are given as 12 figure UK Ordnance Survey or Irish grid references and decimal degrees to three decimal places.

We report all dates and errors (to 1 standard deviation) as given in the original reference. Dates are from a variety of dating methods, but primarily radiocarbon analysis. In the case of radiocarbon dates the original radiocarbon age excluding any correction for marine reservoir effect is reported. All radiocarbon dates require calibration to calendar ages before they can be considered alongside absolute dates derived by other methods (Reimer et al., 2004; 2009; Guilderson et al., 2005). Detailed discussion of the differences between the available calibration curves is documented in (van der Plicht et al., 2004). The BIIS retreat pattern chronology presented in Clark et al. (in press) is based on the database presented here with the Fairbanks 0107 curve and online calculation tool (http://radiocarbon.ldeo.columbia.edu/) used to calibrate all radiocarbon dates (Fairbanks et al., 2005). Use of the Fairbanks calibration curve was largely a pragmatic choice. An alternative would have been to calibrate using the internationally agreed calibration curves INTCAL04 (Reimer et al., 2004) and MARINE04 (Hughen et al., 2004), as appropriate for each date, to the limit of these curves at c. 26 ka BP and continued with the Fairbanks curve for the remainder, noting the offset at the point of change. However, it was decided that the advantages of such an approach were outweighed by the benefits of using the same calibration curve for all dates, thus creating an internally consistent database from which to reconstruct the retreat pattern and timing of the last BIIS. Whilst this manuscript was in review, the INTCAL09 and MARINE09 curves extending back to 50 ka BP were released (Reimer et al., 2009). We therefore updated the database and calibrated ages listed in the Table are derived using the CALIB Radiocarbon Calibration Program (Version 6.0.2; http://calib.qub.ac.uk/calib/) using INTCAL09 and MARINE09 calibration curves as appropriate for each date. The calibrated dates therefore deviate slightly from calibrated ages listed in the database exert in Clark et al. (in press) and in Greenwood and Clark (2009). Twenty-eight dates were unable to be calibrated as they were either out of range of the calibration curve or no error margins
Both calibrated ages and original radiocarbon ages are presented in the accompanying Table.

Dates from in situ terrestrial cosmogenic nuclide dating are reported assuming zero erosion where different estimates are given in the original source, or as per original source where only one case is given. However, it is acknowledged that this is likely to be an unreasonable assumption in the context of a history of glacial erosion and deposition. Where there are multiple dates at a single location, it is common in cosmogenic exposure dating, though not always preferred, to take the oldest date as the most reliable (Phillips et al., 2008). This considers the possibility of inheritance and/or postglacial shielding and interprets the oldest date as a minimum limiting age (Heyman et al., 2011). However, some studies use a weighted average of the ages especially where ages occur in a cluster (e.g. Everest et al., 2006; Clark et al., 2009a;b). The most appropriate treatment of multiple dates from a single site is still under debate so combined/averaged ages should be treated with caution especially in consideration of differences arising due to various production rate models and significant error margins (e.g. ± 1000 years) (Heyman et al., 2011; Ballantyne, 2010). Each individual sample date is presented in the Table. No ‘recalibration’ of cosmogenic nuclide dates using different production rate estimate models has been conducted (e.g. Balco et al., 2009; Ballantyne, 2010). We report cosmogenic exposure ages derived using the production rate estimates and scaling as chosen in the original publication and do not report isotope determinations or associated sample information necessary to recalculate ages (Dunai and Stuart, 2009; Balco et al., 2008). We suggest reference to original sources for full details of laboratory calculations and measurements, and strongly recommend recalculating dates using the same production rates and scaling for precise comparisons with new information.

Where available, the following additional information is reproduced from the source material. Laboratory codes and/or sample numbers or source reference codes are given when listed in original source. Material dated, method of dating, and stratigraphic or setting information, including elevation, is reported as described in the original source. Interpretation of ice sheet context (see below) is based on this information and therefore is dependent on the original quality of description/interpretation. Additional pertinent comments made by the original authors and/or subsequent researchers are also recorded, for example, if a date was believed to be unreliable due to contamination. Many of the dates derived from the CBA date list contain little or no information on the stratigraphic position of the sampled material. Most of these dates are from archaeological artefacts and bone found in caves, and therefore constrain the approximate date that the cave was occupied. So, although they do not have complete stratigraphical information, where the sites lie within or close to the limit of the glaciated area, they can still provide minimum dates for when an area became deglaciated enough to allow human or animal occupation, and maximum dates for the onset of glacial conditions that prevented settlement.
During compilation of the database, no discrimination was made on the quality or reliability of dates. All dates encountered are reported here; any comments made by authors on the likely reliability of their dates are noted.

### 2.2 Interpretation

To the compilation of all reported chronological data, we add one element of interpretation. The purpose of data compilation was to provide a resource with which we can constrain ice sheet position in time (see Clark et al., in press). To achieve this, it is necessary to take an interpretative step in terms of each date’s context or setting. We assign each reported date an interpreted ‘ice sheet context’ based on its stratigraphic position or local setting (c.f. Bryson et al., 1969). Note that no new data or analysis is introduced in assigning a context to dates; we merely use the setting information provided in the source publication, and as documented in the Table (stratigraphic position/setting and comments columns). The contextual classes into which we organise the dates are as follows:

1. **Advance**: we recognise two types of stratigraphy that provide information on timing of ice sheet build up. Dated material incorporated within till; ice cover must postdate the given age, but is likely close to it, e.g. organics within till deposit. Dated material from a unit stratigraphically below a till unit; ice cover must postdate the given age, e.g. peat underlying till.

2. **Retreat**: dated material records ice free conditions subsequent to ice cover. The site possesses stratigraphic information specifically indicating ice free conditions postdate ice cover, e.g. dated organic material lies stratigraphically above a till, dated material infilling a kettle hole, or exposure age from within/below limit of glacial erosion.

3. **Ice free**: dated material records ice free conditions but its connection to evidence of ice cover is lacking. The site possesses no stratigraphic information which indicates prior ice cover, e.g. animal bones in caves, or organic sediments not explicitly described as overlying a till or subglacial landforms such as drumlins.

4. **Margin**: retreat, with evidence of immediate proximity to an ice margin, e.g. boulder from a moraine crest.

5. **Exposure time (cumulative)**: length of exposure at site that does not possess evidence of glacial erosion, or no setting or ‘stratigraphic’ information has been provided, e.g. sample above glacial erosion limit or trimline. The age may reflect actual length of time since the site last became exposed, or multiple phases of exposure.
and burial beneath non-erosive ice. Applies exclusively to ages derived from in situ cosmogenic isotope analysis.

We take the most conservative approach to contextualising the dates from the stratigraphic details provided in the original source material; if ‘stratigraphic’ position with respect to ice cover cannot be explicitly demonstrated, the date is assigned one of the more open classes (e.g. ice free). Dates which have been deemed unreliable are assigned as ‘unclassified’; common reasons for their exclusion include contamination of radiocarbon dates, incomplete resetting of luminescence dates, signal inheritance of cosmogenic surface exposure dates, or unreasonably large error margins. Where a single date can constrain more than one event (for example, organic material between two tills), it is given two classifications (e.g. advance; retreat). We note that there may be uncertainty in some classifications because of the lack of stratigraphic information or confidence in an in situ assemblage. For example, dates from bones within caves are classified as ice free, although they may have amassed in a variety of ways (active use of the cave vs. ice/meltwater transport) which may render the ice free date spatially erroneous. There may be conflicts between our interpretations and those of subsequent users of the database due to reinterpretations of the sedimentological and stratigraphic descriptions made in the original sources.

3. Database and map

From over 200 papers and the databases examined, 975 dates from a total of 378 locations were found and are enclosed in the database. We present the data in the accompanying Table and Map. The dataset is downloadable as a .shp and/or .pdf. The Map shows all dated sites with corresponding site numbers for cross-referencing with the database; additional .pdf layers illustrate ice sheet context information with labelled calibrated ages. We recommend printing with only one or two layers displayed for clarity.

Included in the database are 626 radiocarbon dates, 260 in situ terrestrial cosmogenic isotope dates, 80 luminescence, and 9 U- and Th-series dates. Largely as a result of the nature of the dating methods currently available to us (all based on exposure or lack thereof), the majority of absolute dates relate to ice free conditions, i.e. they are minimum dates for ice sheet retreat or maximum dates for ice sheet advance, and thus bracket the time period that the ice sheet existed in any particular area. Minimum dates for deglaciation of ice in (and maximum dates for advance of ice over) a particular area are most commonly derived from radiocarbon dating of organic sediments overlying (or underlying) till or moraines. Such dates define a relatively crude bracket for glaciation due
to the lag time involved between ice melt and vegetation succession. *In situ* terrestrial cosmogenic isotope exposure dating has been used on occasion to date moraine surfaces and luminescence dating has been attempted for glaciofluvial outwash sediments and loess. These dates provide a more direct means of dating specific ice sheet margin positions but tend to have high associated errors, often of the order of 1000s of years.

Out of the 975 dates, 816 are interpreted for their ice sheet context. Of these, 115 are *advance*, 24 are both *retreat* and *advance* dates, 150 are *retreat*, 84 are *margin*, and 337 are *ice free*. There are 106 *exposure time (cumulative)* dates. *Unclassified* dates include those that could not be calibrated or are considered unreliable by the original or subsequent authors (159). It is unsurprising that the majority of dates relate to ice free conditions and retreat, since an ice sheet will tend to erase or remould pre-existing material rather than preserve it. There are, however, a significant number of *advance* dates which is encouraging for efforts to constrain ice sheet build-up as well as deglaciation. The spatial distribution of dates is similarly encouraging and more ‘complete’ than one might have imagined. The number and distribution of sites, and the range of ages and ice sheet contexts, put us in a significantly better position for interpreting an ice sheet wide chronology for the BIIS than has hitherto been possible. The database has already been used, along with landform data on retreat patterns to reconstruct the demise of the BIIS (Clark et al., in press).

 Nonetheless, there are significant gaps in southern Scotland (notably the Southern Uplands), the Cheviots, the Dales, Lake District, central Wales, and central Ireland. Many of these data gaps lie in mountain areas, perhaps historically reflecting an absence of organic material suitable for radiocarbon dating in such locations, though this disparity is beginning to be overcome through application of cosmogenic exposure techniques (e.g. Ballantyne et al., 2009a). In Ireland, there is predominance of coastal or near coastal sites relative to inland locations, which may help efforts to pinpoint a time-window for ice sheet retreat back onto present-day land, but hinder attempts to document ice sheet retreat more fully back to its final sites of demise. The most notable gaps, however, remain the marine sectors of the ice sheet with very little information on the timing and rapidity of ice retreat across the continental shelf and from the North Sea. Our synthesis of geochronological knowledge, particularly the gaps, identifies targets for future dating programmes. We recognise there may be omissions and potential errors in the database which require revision; we appeal to the community to notify the corresponding author(s) of any such information, and new information post-dating the census for the database. It is anticipated that this database will be maintained and a new version released alongside an updated BRITICE database that is currently undergoing compilation.
4. Summary

Overall the number and spread of dates in time and space is impressive. The last 10 years has seen a dramatic increase in the number of dates, partly facilitated by the development and application of new dating techniques such as terrestrial cosmogenic nuclides and improvements to radiocarbon dating. However, it is evident from the map that the geographical spread is uneven. There are both significant gaps and areas of over-sampling. The Southern Uplands and Scottish-English border region extending down into northeast England, and central Wales and central Ireland stand out as the largest ‘holes’ in the distribution. Upland areas in general are under-sampled. Offshore, the southern North Sea is devoid of dates as are the seas between the Outer Hebrides and Northern Ireland. All of these regions should be targets for future dating campaigns. Areas that are currently adequately dated, at least from an ice sheet scale view, are the Irish coastline, the maximum southern limit in England (although recently published and existing dates from eastern England are in conflict and so this region requires careful consideration and possible reassessment of existing dates (Clark et al., in press), the Scilly Isles, the southern limit of the Loch Lomond Stadial ice cap, and the western coastline of mainland Scotland (especially in the vicinity of the Wester Ross Moraine). This reflects the long established aim of identifying the maximum extent of ice and the hunt for re-advances.

The temporal spread of dates is presented in Figure 2. The greatest frequency of dates is around 15 ka BP. This reflects the increased likelihood for preservation of dates constraining the margin positions and retreat of the ice. After 45 ka BP there are fewer than 10 dates for each 1000 year time interval. The large number of dates older than 56 ka BP reflects maximum ages for advance and exposure times where there has been insufficient erosion to give a true age for the most recent exposure (e.g. under cold based ice, Stroeven et al., 2002; Hättestrand and Stroeven, 2002; Fabel et al., 2002). It is interesting that there is near complete overlap of advance and deglacial dates in time. This demonstrates that different sectors of the ice sheet were advancing while other margins were retreating. We interpret this as support for a model of a dynamic multi-source last BIIS, possibly never in steady-state with climate (Clark et al., in press). It should be restated that we made no attempt to assess the quality of dates and that the database content reflects the existing published literature. In the light of new radiocarbon methods leading to revisions of previously accepted dates, it would be beneficial if all the dates contained in this database were scrutinised for quality and reliability. It is beyond the scope of our collective expertise (and a significant task in its own right) and we call on the dating community to address this, so as to avoid drawing incorrect interpretations.

We hope that the map and database will be a useful piece of reference information for the Quaternary community and stimulate new research and continued interest in the last BIIS, as was experienced following publication of the Glacial Map of Britain.
Figure 2. To complement the spatial distribution of dates presented in the map, this frequency histogram shows the temporal distribution of dates through the last glacial cycle. The final class includes all dates >55 ka BP (exposure dates with insufficient erosion and maximum bounding dates for ice advance). Dates are calibrated ages. The frequency of dates in each 1000 year class is coloured by the contextual class. Radiocarbon dates that could not be calibrated are excluded. Retreat and advance dates overlap. For example, there are dates constraining advance as late as 17 ka BP (followed by a later group of advance dates between 10-14 ka BP) and retreat dates as early as 42 ka BP. We suggest that this reflects the geographical spread of dates and asynchronous behaviour of different sectors of the ice sheet (Clark et al., in press). It is interesting that for most of the time (50 to 10 ka BP) there are recorded dates indicative of ice advances (at least in some sectors) and that this is even so during the global period of ice recession. It is only between 15 and 17 ka BP that no such advance dates exist.

(Clark et al., 2004a; Evans et al., 2005). We will periodically update the database and call upon the community to notify the authors of new information. Updated versions will be released through the BRITICE webpages (http://www.sheffield.ac.uk/geography/staff/clark_chris/britice.html); please check here for the latest version.

Software

Date information was recorded in Excel worksheets. Where location information was not given, maps were scanned and geocorrected in Erdas Imagine and ENVI. Shapefiles and the map were produced using ArcGIS 9.3. Final map was produced using Adobe Acrobat and Illustrator.
Data

The author has supplied data (as an ESRI Shapefile) used in the production of the accompanying map. This PDF has a ZIP archive embedded within it (see the attachment tab) containing the data; you will need to save the file and edit the file extension to .ZIP. Whilst the contents of the ZIP file are the sole responsibility of the author, the journal has screened them for appropriateness.

The shapefile is of date locations and is accompanied by a PDF of the tabular data. The table is published as supplementary downloadable material as it is too large to fit within the constraints of an A4 page. The table is designed to be readable when printed on A3 landscape paper. Site 108 is absent from the shapefile due to insufficient location information in the original source.

Acknowledgements

The majority of this work was undertaken as part of the PhD theses of ALCH and SLG who gratefully acknowledge studentship support from British Geological Survey (NER/S/A/2004/12102) and the University of Sheffield, respectively. ALCH is now supported by the GLIMPSE project funded by the Leverhulme Trust. We would also like to thank Colm Jordan (British Geological Survey) for supervisory support, Mark Bateman (University of Sheffield) for advice on radiocarbon calibration and supplying several unpublished dates, and the Centre for British Archaeology who kindly provided a copy of their existing online date list ‘Archaeological Site Index to Radiocarbon Dates from Great Britain and Ireland’ accessible through the Archaeology Data Service Catalogue (http://ads.ahds.ac.uk/catalogue/specColl/c14_cba/). This paper is a contribution to the BRITICE project. Due to the volume of information contained within the database it is unlikely to be completely free of typographical errors. We thank the reviewers for careful reviews that improved the manuscript and presentation of the database and map, but as authors take full responsibility for any data reporting inaccuracies.

References


surements XV, Radiocarbon, 24, 262–290.


CASELDINE, C. J. and EDWARDS, K. J. (1982) Interstadial and last interglacial deposits covered by till


CHIVERRELL, R. C. and THOMAS, G. S. P. (2010) Extent and timing of the Last Glacial Maxi-
mum (LGM) in Britain and Ireland: a review, Quaternary Science Reviews, 25, 535–549, doi:
10.1002/jqs.1404.

CLARK, C. D., EVANS, D. J., KHATWA, A., BRADWELL, T., JORDAN, C. J., MARSH, S. H., MIT-
CHELL, W. A. and BATEMAN, M. D. (2004a) Map and GIS database of glacial landforms and features
related to the last British Ice Sheet, Boreas, 33, 359–375, doi: 10.1080/03009480410001983.

CLARK, C. D., HUGHES, A. L. C., GREENWOOD, S. L., JORDAN, C. J. and SEJRUP, H. P. (in
press) Pattern and timing of retreat of the last British-Irish Ice Sheet, Quaternary Science Reviews, doi:
10.1016/j.quascirev.2010.07.019.

CLARK, J., MCCABE, A. M., SCHNABEL, C., CLARK, P. U., FREEMAN, S., MADEN, C. and XU,
S. (2009a) ¹⁰Be chronology of the last deglaciation of County Donegal, northwestern Ireland, Boreas,

CLARK, J., MCCABE, A. M., SCHNABEL, C., CLARK, P. U., MCCARRON, S., FREEMAN, S.,
MADEN, C. and XU, S. (2009b) Cosmogenic ¹⁰Be chronology of the last deglaciation of western Ire-
land, and implications for sensitivity of the Irish Ice Sheet to climate change, Geological Society of
America, Bulletin, 121, 3–16.

CLARK, P. U., MCCABE, A. M., MIX, A. C. and WEAVE, A. J. (2004b) Paleoclimate: Ra-
pid Rise of Sea Level 19,000 Years Ago and Its Global Implications, Science, 304, 1141–1143, doi:
10.1126/science.1094449.

COLHOUN, E. A., DICKSON, J. H., MCCABE, A. M. and SHOTTON, F. W. (1972) A Middle Mid-
landian freshwater series at Derryvree, Maguiresbridge, County Fermanagh, Northern Ireland, Pro-

COLHOUN, E. A. and SYNGE, F. M. (1980) The cirque moraines at Lough Nahanagan, County Wick-
low, Ireland, Proceedings of the Royal Irish Academy, 80B, 25–45.

COOPE, G. R. (1977) Fossil Coleopteran Assemblages as Sensitive Indicators of Climatic Changes dur-
ing Devensian (Last) Cold Stage, Philosophical Transactions of the Royal Society of London Series

COOPE, G. R. and BROPHY, J. A. (1972) Late glacial environmental changes indicated by a coleopteran

COOPE, G. R. and JOACHIM, M. J. (1980) Lateglacial environmental changes interpreted from fossil
Coleoptera from St Bees, Cumbria, England, Studies in the Lateglacial of North-West Europe, Perga-
mon, Oxford, pp. 55–68.


GRAY, J. M. (1975) Lateglacial, in situ barnacles from Glen Cruitten quarry, Oban, Quaternary Newsletter, 15, 1–2.


PEACOCK, J. D. and LONG, D. (1994) Late Devensian glaciation and deglaciation of Shetland, Quaternary Newsletter, 16–21.


