



# BRITICE Glacial Map, version 2: a map and GIS database of glacial landforms of the last British–Irish Ice Sheet

CHRIS D. CLARK , JEREMY C. ELY, SARAH L. GREENWOOD, ANNA L. C. HUGHES, ROBERT MEEHAN, IESTYN D. BARR, MARK D. BATEMAN , TOM BRADWELL, JENNY DOOLE, DAVID J. A. EVANS, COLM J. JORDAN, XAVIER MONTEYS, XAVIER M. PELLICER AND MICHAEL SHEEHY

**BOREAS**



Clark, C. D., Ely, J. C., Greenwood, S. L., Hughes, A. L. C., Meehan, R., Barr, I. D., Bateman, M. D., Bradwell, T., Doole, J., Evans, D. J. A., Jordan, C. J., Monteys, X., Pellicer, X. M. & Sheehy, M. 2018 (January): BRITICE Glacial Map, version 2: a map and GIS database of glacial landforms of the last British–Irish Ice Sheet. *Boreas*, Vol. 47, pp. 11–27. <https://doi.org/10.1111/bor.12273>. ISSN 0300-9483.

During the last glaciation, most of the British Isles and the surrounding continental shelf were covered by the British–Irish Ice Sheet (BIIS). An earlier compilation from the existing literature (BRITICE version 1) assembled the relevant glacial geomorphological evidence into a freely available GIS geodatabase and map (Clark *et al.* 2004: *Boreas* 33, 359). New high-resolution digital elevation models, of the land and seabed, have become available casting the glacial landform record of the British Isles in a new light and highlighting the shortcomings of the V.1 BRITICE compilation. Here we present a wholesale revision of the evidence, onshore and offshore, to produce BRITICE version 2, which now also includes Ireland. All published geomorphological evidence pertinent to the behaviour of the ice sheet is included, up to the census date of December 2015. The revised GIS database contains over 170 000 geospatially referenced and attributed elements – an eightfold increase in information from the previous version. The compiled data include: drumlins, ribbed moraine, crag-and-tails, mega-scale glacial lineations, glacially streamlined bedrock (grooves, roches moutonnées, whalebacks), glacial erratics, eskers, meltwater channels (subglacial, lateral, proglacial and tunnel valleys), moraines, trimlines, cirques, trough-mouth fans and evidence defining ice-dammed lakes. The increased volume of features necessitates different map/database products with varying levels of data generalization, namely: (i) an unfiltered GIS database containing all mapping; (ii) a filtered GIS database, resolving data conflicts and with edits to improve geo-local accuracy (available as GIS data and PDF maps); and (iii) a cartographically generalized map to provide an overview of the distribution and types of features at the ice-sheet scale that can be printed at A0 paper size at a 1:1 250 000 scale. All GIS data, the maps (as PDFs) and a bibliography of all published sources are available for download from: [https://www.sheffield.ac.uk/geography/staff/clark\\_chris/britice](https://www.sheffield.ac.uk/geography/staff/clark_chris/britice).

Chris D. Clark ([c.clark@sheffield.ac.uk](mailto:c.clark@sheffield.ac.uk)), Jeremy C. Ely, Mark D. Bateman and Jenny Doole, Department of Geography, University of Sheffield, Sheffield S10 2TN, UK; Sarah L. Greenwood, Department of Geological Sciences, Stockholm University, Stockholm 106 91, Sweden; Anna L. C. Hughes, Department of Earth Science, University of Bergen and Bjerknes Centre for Climate Research, Bergen 5020, Norway; Robert Meehan, Talamhíreland, 86 Athlumney Castle, Navan, Ireland; Iestyn D. Barr, School of Natural & Built Environment Queen's University, Belfast BT9 6AX, UK; Tom Bradwell, Biological and Environmental Sciences, University of Stirling, Stirling FK94LA, UK; David J. A. Evans, Department of Geography, Durham University, Durham DH1 3LE, UK; Colm J. Jordan, British Geological Survey, Nottingham NG12 5GG, UK; Xavier Monteys, Xavier M. Pellicer and Michael Sheehy, Geological Survey of Ireland, Dublin, Ireland; received 28th March 2017, accepted 28th June 2017.

Palaeo-ice sheets provide the opportunity to study ice-sheet behaviour over a longer time period (10 000s of years) than can be achieved by studying current ice sheets (10s of years) thereby permitting exploration of the long-term role of ice sheets in the climate system. The extent, geometry and dynamics of palaeo-ice sheets can be reconstructed from the geomorphological and geological evidence they leave behind, with the mapping, logging and description of such evidence being the vital ingredients. For many palaeo-ice sheets, such as the British–Irish Ice Sheet (BIIS), the accumulation of evidence at individual field-sites has been ongoing for well over 100 years (e.g. Geikie 1894) yielding thousands of publications. Using such work to build local to regional reconstructions of ice dynamics is feasible, but at the ice-sheet scale the volume of information becomes unmanageable. Often the information is spread across so many publications and across many decades of work, whereby interpretative modes often change; this is the *Compilation Issue*. Solving this problem assists in both illuminating the ‘big picture’ and in documenting and

pointing to key local-scale work that might otherwise be lost. If we now consider an ice-sheet modeller interested in knowing how well their model simulations match with empirical evidence, of say ice-sheet extent and flow, compilations certainly help, but the issue of data availability, ownership and format then arises; this is the *Open Data Issue* (cf. The Royal Society Science Policy Centre Report 2012). Ideally then, evidence of ice-sheet activity could be compiled and made freely available in easily accessible data formats and maps, and also in a manner that promotes (and cites) the value of the individual building blocks of evidence.

During the last glaciation, most of the British Isles and the surrounding continental shelf were covered by the BIIS (for overviews see Chiverrell & Thomas 2010; Clark *et al.* 2012). To assist investigation of the extent and geometry of the former ice sheet covering Britain, the BRITICE project tackled the compilation and open data issues by reading relevant publications and assessing, collating and digitizing the described evidence-base of glacial landforms to create a publication reporting the

methods (Clark *et al.* 2004), including a printed Glacial Map of Britain (at a scale of 1:625 000) and an accompanying freely available GIS geodatabase with >20 000 features (available from [https://www.sheffield.ac.uk/geography/staff/clark\\_chris/britice](https://www.sheffield.ac.uk/geography/staff/clark_chris/britice)). The compiled evidence was reviewed in Evans *et al.* (2005). The BRITICE V.1 map and these publications have been widely accessed and used by the scientific community, the education sector and the general public, with over 25 000 downloads from the website up to December 2016. The GIS files have been used to compare with results from numerical ice-sheet modelling (Hubbard *et al.* 2009; Patton *et al.* 2013).

A number of important developments, since the production of the original version, have highlighted its shortcomings and motivated us to fully revise the database to produce BRITICE version 2. Specifically, (i) much research has been published subsequent to the V.1 census date of 2002, along with various omissions and corrections; (ii) inclusion of data for Ireland (missing from BRITICE V.1) were required to better understand the entire ice-sheet footprint; (iii) the availability of high-resolution digital elevation models (DEMs) has permitted high-integrity mapping of the whole of the Irish and British landscapes (Greenwood & Clark 2008; Hughes *et al.* 2010) replicating patches of earlier field-mapping but considerably extending the coverage and improving the consistency; and (iv) mapping from newly available bathymetric data sets has revolutionized our information on submerged (offshore) glacial geomorphology (e.g. Graham *et al.* 2007; Bradwell *et al.* 2008; Benetti *et al.* 2010; Dunlop *et al.* 2010; Clark *et al.* 2012). Furthermore, the area covered by the last BIIS is now thought to have been considerably greater than previously envisioned, with glacial landforms and sediments recorded at many localities near the continental shelf break and across the North Sea Basin (Bradwell *et al.* 2008; Clark *et al.* 2012; Praeg *et al.* 2015; Thébaudeau *et al.* 2015; Sejrup *et al.* 2016). The purpose of this paper is to present an updated glacial map and geodatabase of glacial landforms relating to the BIIS, and to highlight the evidence gathered in the 15 years since the Clark *et al.* (2004) and Evans *et al.* (2005) syntheses. The aim of this compilation is the same as that of the original version: to present the geomorphological evidence pertinent to the behaviour of the whole ice sheet, and with emphasis on the primary observations rather than wider interpretations based upon them. The increased volume of features in V.2 (Fig. 1) necessitates different map and database products with varying levels of generalization and abstraction (see later).

### Method of database creation

During the last glacial the British–Irish Ice Sheet is considered to have reached its maximum areal coverage around 27 ka BP in the Dimlington Stadial of the Late

Devensian Substage (British chronostratigraphical unit) and its Irish equivalent the Late Midlandian Substage (Gibbard & Clark 2011). These are equivalent to the Late Weichselian and Late Wisconsinan elsewhere in the world (Europe and North America) and to Marine Isotope Stage 2 (MIS 2). We restrict inclusion of features in the database to those that are reasonably known to have formed in this last glaciation. Most glacial landforms in the British Isles, especially those that are depositional rather than erosional, undoubtedly relate to the last ice sheet that covered the area, but it is worth noting that this is a presumption on the basis of them being at the surface and that ice sheets are usually considered to be effective at destroying landforms from previous glaciations. We note that most landforms have not actually been geochronometrically dated as belonging to the last glacial; the task would be huge. Some of the landforms may belong to earlier glaciations, but we suspect this to be rare (e.g. Kleman 1994).

Figures and maps of glacial landforms published since 2002 were sought from journal articles, Ph.D. theses, British Geological Survey archives and Geological Survey of Ireland databases, including omissions that we were alerted to from prior to this date. Figure 2 outlines the procedure employed to compile these mapped features into the GIS database. The census date for the version we report here was 31/12/2015. The most recent data for Ireland can be accessed through the map viewers on <http://www.gsi.ie>. In Britain, studies relating solely to the Loch Lomond Stadial (LLS; equivalent to Greenland Stadial 1 and Younger Dryas) were not included, and we note that these are the focus of a similar map and GIS compilation produced by Bickerdike *et al.* (2016) and the main LLS ice limit is recorded on V.1 of the Glacial Map (Clark *et al.* 2004). However, some features within the LLS limit are included, as they are reported within regional studies, remain undated, and may actually relate to deglaciation of the main Dimlington Stadial (MIS 2) ice sheet. In cases where authors kindly provided us with their mapping in digital form (e.g. shapefiles) no further georeferencing was required and data entry was straightforward (Fig. 2). For the majority of cases however, data gathered from the literature were georeferenced using the annotated grid or tick marks in their figures and maps. Where such positional marks were absent or insufficient for georeferencing, the geomorphological data were visually transferred to a (Ordnance Survey) topographical map of the area using features such as coastlines, rivers or mountain summits, as a guide. Although probably rare, positional errors of 100s of metres could occur due to insufficient or inaccurate geographical referencing of maps in the source publications and due to our attempt to position features using the above method. When using the database we recommend the original sources are consulted whereupon such geo-locational issues can be readily appreciated. For consistency across the GIS

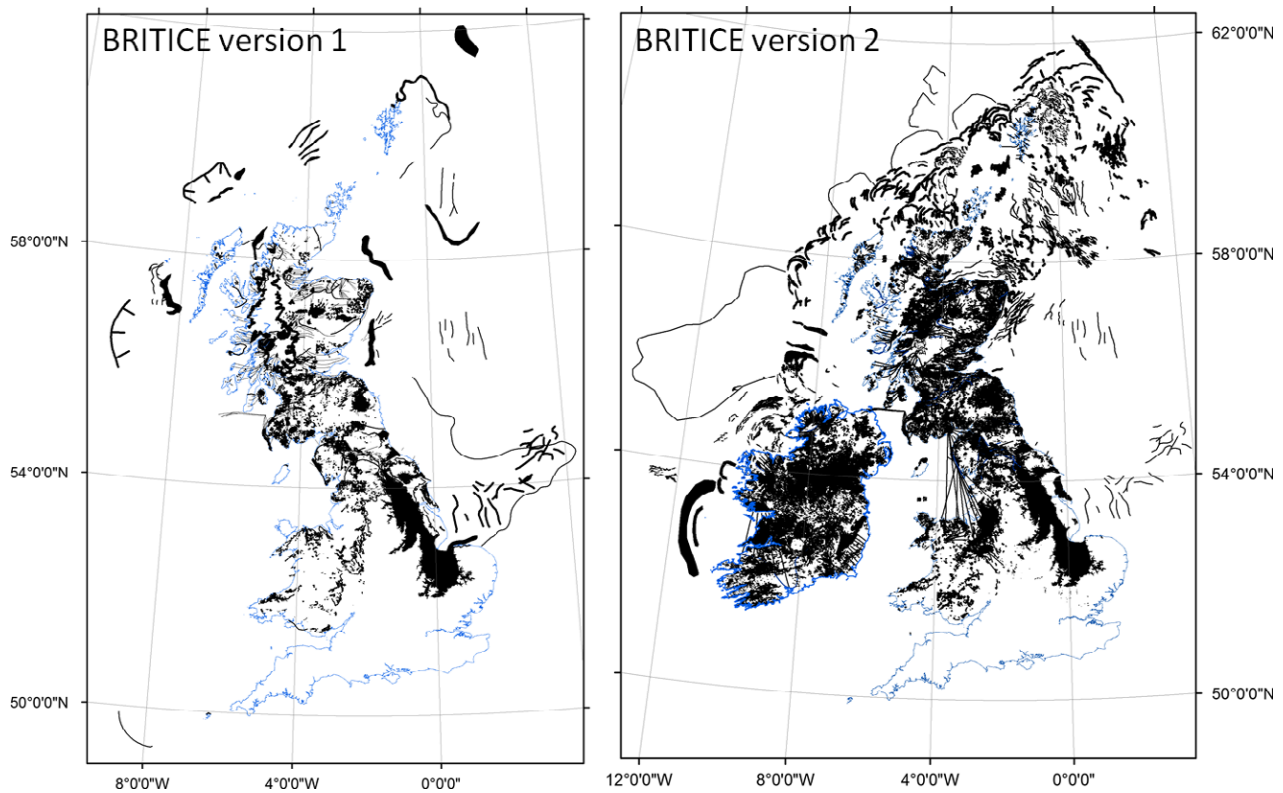


Fig. 1. Comparison of the density and distribution of mapped features (in black) in the previous version (V.1 >20 000 features) with the new version (V.2 >170 000 features). The main additions are coverage of Ireland, offshore ice-marginal features, subglacial bedforms are individually mapped rather than their pattern generalized, and the inclusion of many more meltwater channels. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

database all shapefiles are stored in a common projection (British National Grid).

Once the figures and maps had been georeferenced, the features were manually digitized into thematic layers and a citation to the published source and any additional comments were recorded in the GIS attribute table. The manner in which individual features are linked to their source citation varies, but always a source is noted, sometimes more than one. Many published figures and maps are inadequately drafted with respect to geographical coordinates, which can lead to them appearing in the wrong place once entered in the GIS. To improve the spatial accuracy of each feature, a further process of correction was undertaken by comparison to a high-resolution DEM (of 5 m grid-size; ©NEXTMAP GB, Intermap Technologies) whereby the true geographical location of a meltwater channel for example could be ascertained. Features were thus moved short distances (100s of metres) where deemed necessary (Fig. 3). This procedure was also applied to the V.1 data, thereby improving the positional accuracy of individual features. If landform features appeared to be absent from the DEM they were considered to be below the DEM resolution and so were not moved. Offshore, such adjustments were not possible, but the majority of offshore mapping appears to have low georeferencing errors (<5 m), due to the availability of grid references.

The Geological Survey of Ireland (GSI) conducted a similar procedure to that of the BRITICE V.1 above for Ireland with an objective to produce a spatially accurate geomorphology database. Features were mapped directly from Ordnance Survey Ireland (OSI) aerial imagery and DEMs and GSI LiDAR data. Reports in the literature (e.g. Flint 1930; Knight *et al.* 1999; McCabe *et al.* 1999; Greenwood 2008), where available, were consulted and considered. These features were amalgamated with that of BRITICE V.1 data and the updated features were digitized from the recent literature into an 'Unfiltered GIS Database' (Fig. 2). This unfiltered database is available for download, and retains all the features that were considered for the Glacial Map including conflicts and repetition where features have been mapped more than once, as well as citations to the original sources.

To avoid unnecessary confusion, duplications of mapped features were manually removed to build the filtered database. References and comments pertaining to the removed features were added to the attribute table of the remaining feature in order to retain traceability to the original workers and provide historically appropriate citations. In this reconciliation process the choice of feature to retain was based upon geo-locational accuracy, regional consistency with other features and the level of detail. Figure 4 illustrates an example of this reconciliation process (for an unusually popular area!)

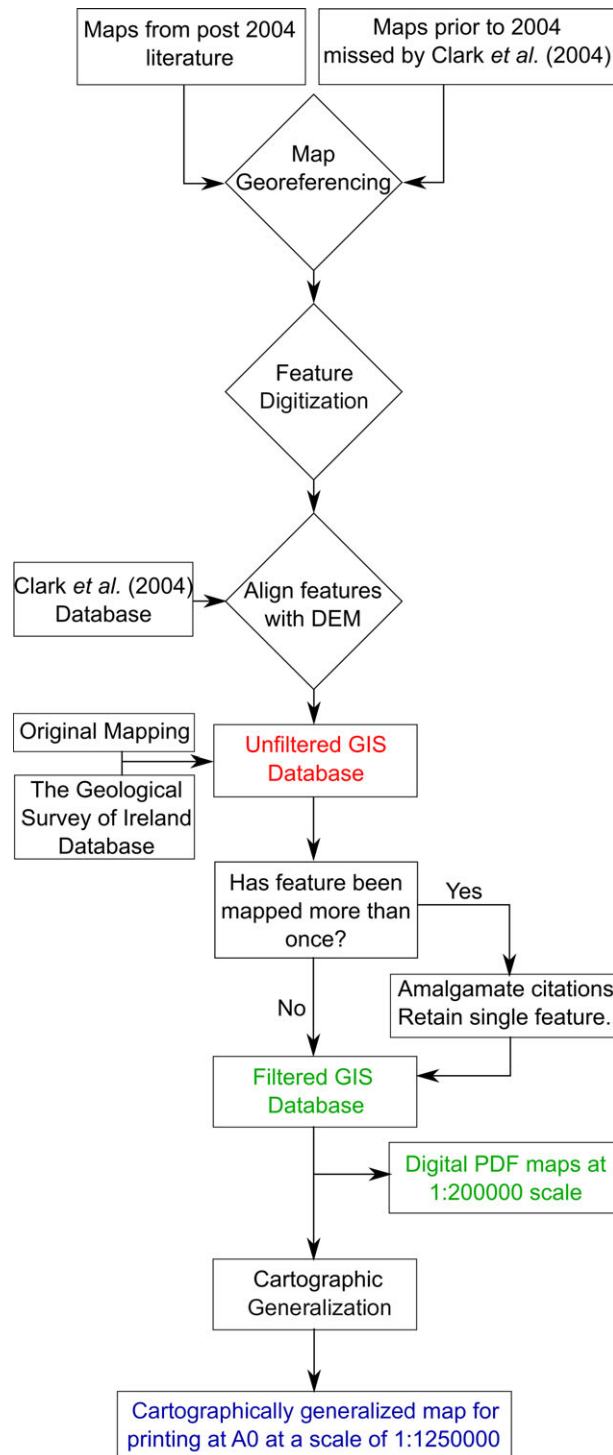


Fig. 2. Methodological overview of work-flow for database creation, and the three main products made available (highlighted in colour). See text for more details. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

and also shows a rare example of conflict resolution where the same geomorphological features have been interpreted as different glacial landforms. In such cases, for historical correctness, both interpretations

are retained in the attribute table of such features in the unfiltered data set.

Although conflicts of interpretation between feature types were rare, other examples of conflicts between the V.1 database and subsequent mapping (e.g. Hughes 2009; Hughes *et al.* 2010) were also resolved for the filtered database. This was mostly where the categorization of meltwater channels had been improved or changed (i.e. subglacial, lateral or proglacial types). In such cases the alternative interpretations are listed in the attribute table of those features.

Two landform types not recorded in BRITICE V.1 are included in this revised synthesis, namely glacially moulded bedrock and cirques (corries, coombes or cwms). For the inclusion of glacially moulded bedrock an extensive literature review was undertaken and the procedure outlined in Fig. 2 adopted. For the inclusion of cirques, we found that publications and maps did not sufficiently distinguish between arêtes, glacially moulded scarps and true cirques, and most mapping focussed on their distribution rather than their individual shape and size (e.g. Evans 2006). For these reasons, cirques were manually digitized from available high-resolution DEMs (NEXTMAP 5 m for Britain, SRTM 30 m for Ireland), using published distribution maps as a guide to their locations. Each cirque was given a confidence rating following Evans & Cox (1995), ranging from classic (1) to speculative (5). Publications covering cirques for each of the areas are referenced in the attribute table of the cirque shapefile. These two new landform types were added to the existing types from V.1 (subglacial lineations, crag-and-tails, eskers, subglacial ribs, meltwater channels, moraines, trimlines, trough-mouth fans, proglacial lakes and information regarding erratics) to yield our revised glacial geomorphological map of the BIIS.

Due to the high density and detail of the assembled features in the V.2 filtered database, two map products of differing scale, detail and purpose are presented. Three large maps, which contain all features in the filtered database (Fig. 5A) are made available as PDF files (Ireland, projected to Irish National Grid; North Scotland and offshore, British National Grid; and mainland Britain, British National Grid). These are designed to be viewed digitally at scales of around 1:200 000. Users can 'pan' across them or zoom and perhaps print off selected local regions of interest. However, the level of detail and scale prevent any sensible printing of the whole map (paper size would need to be around 5 by 5 metres). Therefore, we also present a cartographically generalized map of the whole ice-sheet domain (excerpt shown in Fig. 5C; and whole map in Fig. 10). Lengthy endeavours were required to produce this map with the density of features reduced via a process of cartographic generalization. Taking inspiration from the Glacial Map of Canada (Prest *et al.* 1968), multiple landforms were



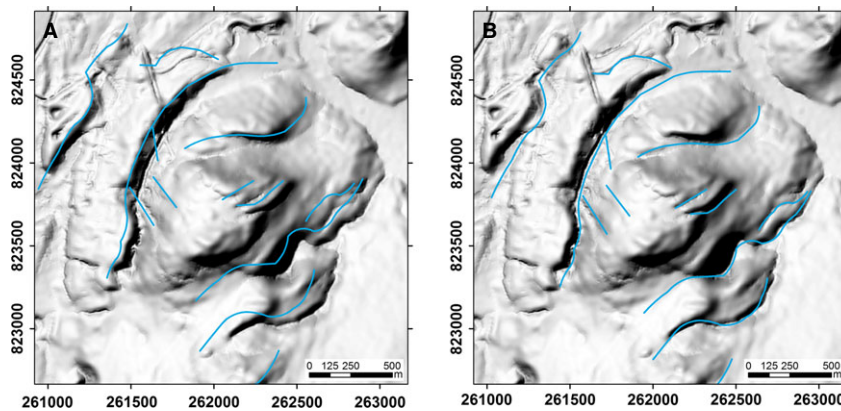


Fig. 3. Example of editing the position of mapped features to better fit the correct locations. A. Meltwater channels mapped by Turner *et al.* (2014), near the Great Glen region of Scotland, appear misaligned with their DEM representation due to georeferencing errors. B. These features were therefore moved to correspond to the DEM (which has a robust geocoding) in order to improve their positional accuracy. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

often grouped under the same symbol. Figure 5 shows an example of feature rationalization in this manner. The generalized map is projected to the British National Grid.

### Mapped features

Over 170 000 features exist in the filtered database as a series of thematic GIS shapefiles. Each feature class is

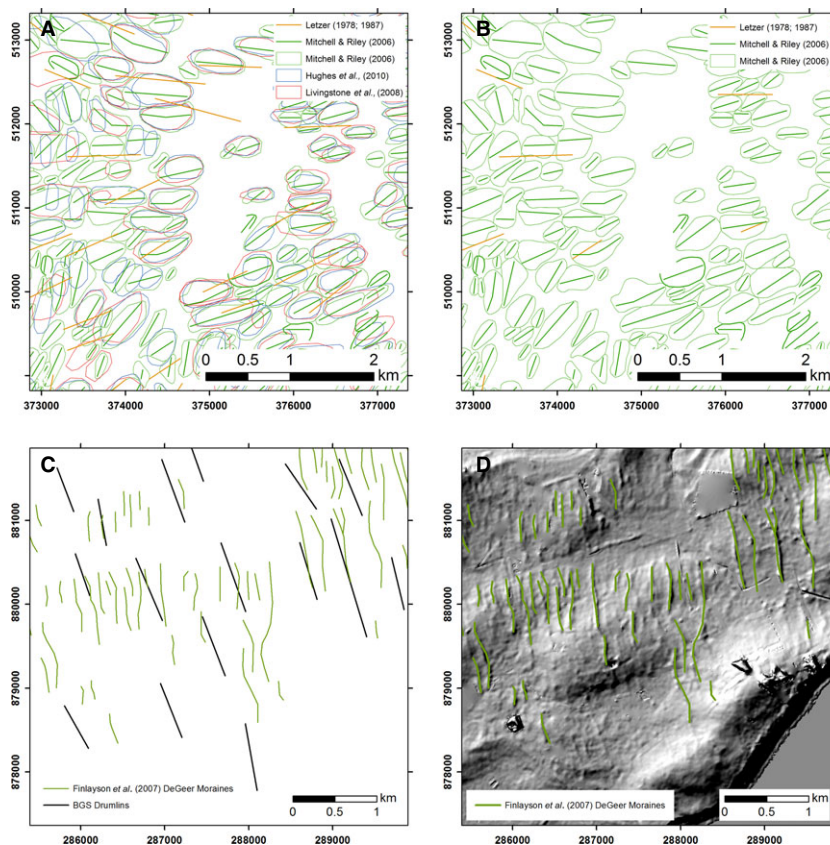


Fig. 4. Examples of landform reconciliation arising from conflict detection, duplication and resolution. A. Drumlins in the unfiltered database located in the Vale of Eden, England, illustrating up to fivefold duplication in their mapping. B. The filtered database used for map production. Note that in this case the majority of remaining features are from Mitchell & Riley (2006), due to the higher level of detail presented in that study. C. A rare example of a conflict in feature interpretation. In this location near between the Cromarty and Dornoch Firths, northeast Scotland, the same landforms have been mapped and interpreted as drumlins (British Geological Survey 1972) and as DeGeer moraines (Finlayson *et al.* 2007). D. Through consulting with the conflicting sources, the interpretation of DeGeer moraines is retained, based upon their scale, morphological appearance and supporting evidence in Finlayson *et al.* (2007). [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

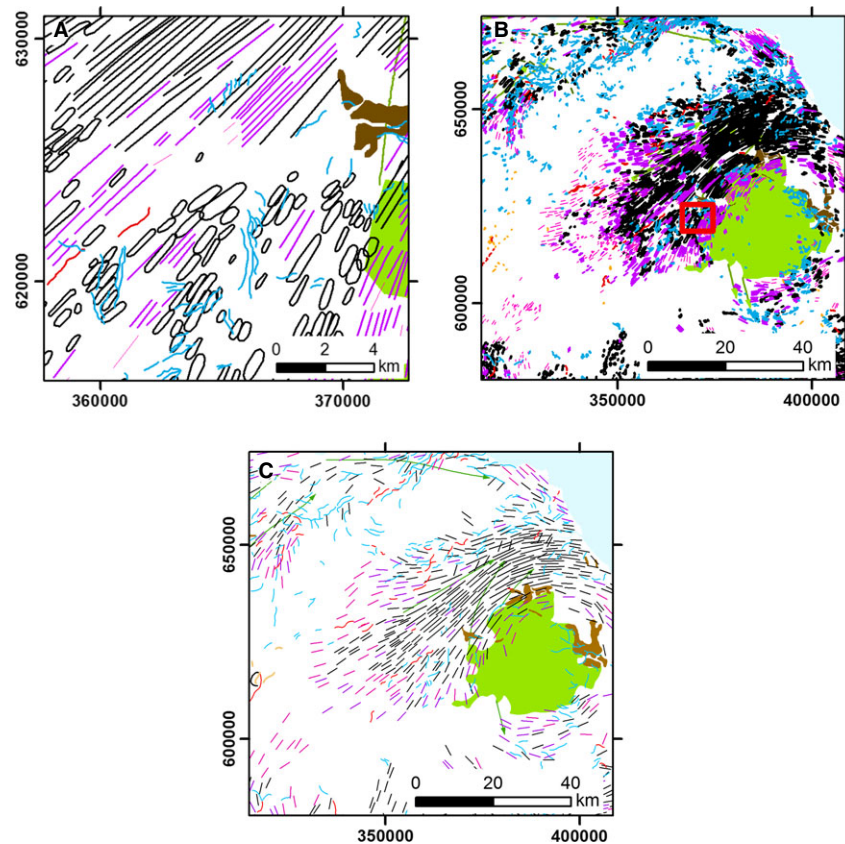


Fig. 5. An example of the generalization process, centred on the Tweed Palaeo-ice stream area, NE England. A. Small excerpt of the filtered database, showing the level of detail. B. Database over a broader area demonstrating that the density of features at this scale renders the map incomprehensible. Red box marks the position of excerpt in (A). C. Example of how data density were reduced, by cartographic generalization, to produce a map that is comprehensible at the scale of the whole ice sheet (AO at 1:1 125 000). [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

recorded as either polygons or lines appropriate to the size and nature of the landform. As illustrated in Fig. 6 each feature can be queried (via the attribute tables) to reveal the source publication from where the feature was taken, as well as further comments including sources within which the same feature was reported or mapped. Below we report on further details per theme.

#### *Subglacial bedforms and crag-and-tails*

Subglacial bedforms are the most common features in the database, totalling 106 367 polygons or lines (13 236 subglacial ribs; 85 824 subglacial lineations; and 7307 crag-and-tails). No subglacial ribs (i.e. Rogen or ribbed moraine) were included in the BRITICE V.1. Here we compile mapping of vast swathes of subglacial ribs in the 'Drumlin Belt' of Ireland (Knight & McCabe 1997; Clark & Meehan 2001; Greenwood & Clark 2008), which often display transitions into drumlins or are superimposed by drumlins (Fig. 7). Subglacial ribs occur less often in Britain, but noteworthy examples occur in northern Scotland (Finlayson & Bradwell 2008), west of Glasgow (Finlayson *et al.* 2010), in the

Solway lowlands (Livingstone *et al.* 2008; Hughes *et al.* 2010) and offshore of Anglesey (Van Landeghem *et al.* 2009).

Subglacial lineations are stored in polygon or line shapefiles according to how they were originally mapped by the authors. Whilst grouped here as 'subglacial lineations', reference to their reported landform 'type' (drumlin or mega-scale glacial lineation) is recorded in the attribute table. The majority of subglacial lineations are of a size and shape that would class them as drumlins (Clark *et al.* 2009). These drumlin fields form radial, often cross-cutting, patterns (Livingstone *et al.* 2008; Hughes *et al.* 2010, 2014). Irregular shaped drumlins occur south of Dumfries (Salt & Evans 2004; Hughes *et al.* 2010). These features are distinguished in the attribute table of the lineation shapefile as 'tadpole drumlins' after Hughes *et al.* (2010). The lineation record has also been extended offshore, with drumlin fields being found on the seabed in several studies (e.g. Van Landeghem *et al.* 2009; Benetti *et al.* 2010; Dunlop *et al.* 2010; Howe *et al.* 2012; Bradwell & Stoker 2015; Fig. 7B). Mega-scale glacial lineations (Clark 1993; Spagnolo *et al.* 2014; Ely *et al.* 2016) also occur near Berwick-upon-Tweed (Everest *et al.* 2005;

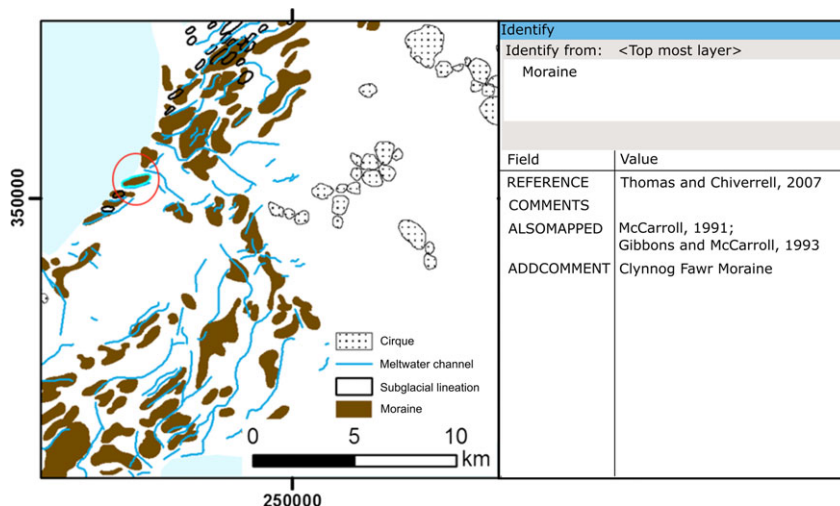


Fig. 6. All features within the GIS can be queried to reveal the source publication from which the feature was taken, and further comments including alternative sources that may have also reported or mapped it. In this example from the Llyn Peninsula in North Wales, clicking and highlighting (cyan) the moraine ridge near the top-left (see red circle), opens up data from the attribute table (on the right), which reports the reference from which the work was taken and citations to earlier work that also reported on the feature. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

Hughes *et al.* 2010), near Drogheda and Charlestown in Ireland (Greenwood & Clark 2008; Meehan 2013), and have been imaged beneath the seabed in the North Sea Basin (Graham *et al.* 2007).

Numerous studies subsequent to the V.1 database differentiate between subglacial lineations and crag-and-tails. Their identification and differentiation are aided by the use of high-resolution imagery, which better resolves the crag, or by additional detail being

provided on the surface materials and sediment thickness (e.g. Greenwood & Clark 2008; Hughes *et al.* 2010). Hence, crag-and-tails are now distinguished as a separate layer in the database, and we suggest they are displayed in GIS as arrows, because their flow direction is evident. There may of course be landforms in the subglacial lineation category that are in fact crag-and-tails but we had insufficient detail with which to observe the crag.

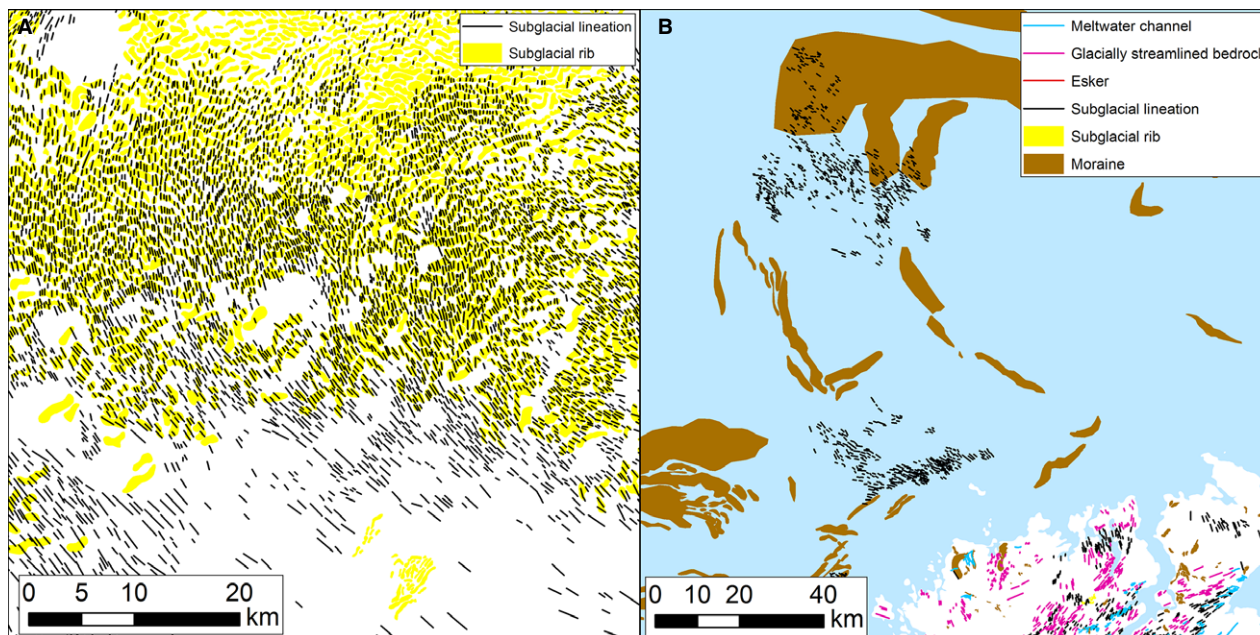


Fig. 7. Examples of subglacial bedforms and other landforms as portrayed on the Glacial Map. A. Subglacial ribs and drumlins across the 'Drumlin Belt', central Ireland. B. Drumlins and moraines mapped on the Malin shelf sea floor, northwest Ireland (see Benetti *et al.* 2010 and Dunlop *et al.* 2010), merged with onshore data. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]



Due to high-resolution geospatial data and continued extensive field mapping since 2002, we now have a comprehensive picture of the occurrence and distribution of subglacial bedforms onshore in Britain and Ireland. This could be improved by further field studies and the interpretation of improved resolution DEM and imagery. Our knowledge of offshore subglacial lineations has also improved since the V.1 database but higher resolution bathymetric data is required to complete the coverage and improve the detail. Especially useful may be 2D and 3D sub-bottom geophysical data, to reveal bedforms that have been buried by postglacial sediments (e.g. Stoker & Bradwell 2005; Graham *et al.* 2007).

#### *Glacially streamlined bedrock*

It is often possible to discern streamlining and former ice-flow direction from exposed bedrock surfaces (e.g. Bradwell 2005) expressed as lineated or grooved surfaces or as streamlining in the form of roches moutonnées or whalebacks. Such information drawn from publications yielded 14 529 features that we have recorded mostly as simple lines showing the sense of flow orientation and sometimes as polygons revealing the areal extent, for example, of roches moutonnées. Where authors have distinguished between the various forms of glacial streamlining comments to this effect are made in the attribute tables. These layers are best used to provide information on former ice-flow direction, and zones of glacial erosion on hard beds. The map should be regarded as a reconnaissance-level database in that it is far from complete or systematic in its categorizations between various landform types. We suggest that there is much further work that could be conducted on the distribution and form of these erosional subglacial landforms so that they can be more effectively used in palaeoglaciological reconstructions.

#### *Erratic transport*

For Britain not much new information has been uncovered for erratics since V.1 but we have now included such information for Ireland. The sources of erratics are depicted as either a polygon defining the source bedrock area or as a line defining a lithological boundary. The erratics are located at the downstream end of the shapefile lines (erratic paths; best displayed with an arrowhead) and the precise route of the path is merely inferred from other ice-flow directional indicators such as subglacial bedforms. We accept that the actual transport path could have been very different and the erratic may have moved in a number of discrete stages. Where authors noted the limits defining a line beyond which erratics were not found, these lines have been added (erratic limits). For Ireland, further information on how ice flow transported subglacial materials can be seen in the work of Greenwood & Clark (2009) where they relate and map till

lithologies to their upstream bedrock outcrops. For more information on the erratic layer refer to the V.1 paper (Clark *et al.* 2004).

#### *Eskers*

Our map now includes the extensive esker systems of Ireland, with a total of 4662 esker segments (i.e. individual mapped ridges that comprise an esker system) portrayed as polygons and lines in ESRI shapefile format. As the underlying data from which the esker systems were compiled came from surficial geological maps, academic publications (e.g. Warren & Ashley 1994) and close scrutiny of the entire terrestrial areas using DEMs, we consider that the database on esker distribution is nearly complete and is a comprehensive systematic record. Use of improved resolution DEMs and imagery coupled with analysis of field exposures and geophysical surveying should permit improved extraction of information in the future.

#### *Meltwater channels*

Meltwater channels ( $n = 27\,916$ ) are recorded for terrestrial and offshore areas and where authors have interpreted their various types this information is recorded in the attribute tables. Types include: subglacial meltwater channel; lateral meltwater channel; proglacial channel; tunnel valley; or as unspecified meltwater channel. Many of the channels have been systematically categorized into these types according to the criteria of Greenwood *et al.* (2007), and with levels of confidence in the interpretation annotated in the attribute tables. For the terrestrial part of Britain this layer is probably nearly complete because it was conducted by systematic mapping from a high-resolution (5 m) DEM, although it is likely that more channels could be found with analysis of higher resolution DEMs (e.g. from Lidar). Field checking could help because true meltwater channels can sometimes be difficult to distinguish from postglacial subaerial channels and because the latter sometimes occupy the former, further confusing the origins. Meltwater channels in Ireland were mapped from OSI elevation data and aerial imagery at a resolution of 10 m and further mapping at higher resolution would probably find many more examples than are shown here. Many meltwater channels remain to be discovered and mapped for the offshore areas, and most of the data reported here relate to the larger features (i.e. tunnel valleys) and hence this layer is far from complete. A difficulty is that multiple sets of tunnel valleys are often visible in sea-floor and sub-bottom geophysical data, only some of which will have been cut or occupied during the last glaciation. Using stratigraphical superposition and observations of sediment infilling to distinguish between valleys of different age is a large task that we have not undertaken and we merely report those already



deemed to be of last glacial in age. We suppose that in reality there will be many more such features, and consider that identifying them is an important future task (e.g. Jørgensen & Sandersen 2006; Kristensen *et al.* 2007).

### *Moraines*

The moraine layer has been significantly extended and fully revised in comparison to the V.1 edition. This is mostly due to improved offshore data coverage where extensive moraine systems have surprisingly been found since BRITICE V.1 (e.g. Bradwell *et al.* 2008; Dunlop *et al.* 2010; Clark *et al.* 2012) and by systematic survey of the whole terrestrial area using DEMs and satellite images (Greenwood 2008; Hughes 2009; Clark *et al.* 2012; Meehan 2013). The layer now contains 15 109 moraines, recorded as lines for the smaller features and polygons for larger features. It is probably the most useful layer in the database, because for the first time we now have an impressive continental-shelf-wide spatial spread of information that records the retreat pattern of the whole ice sheet. A cumbersome and internally conflicted nomenclature exists for categorizing moraines, one which we largely ignore in our database (although see comments in the attribute tables). For our purposes we take a broad view of the definition of a moraine as including any accumulation of sediment with a positive topographical expression forming a distinct landform and that has been interpreted to have accumulated ice-marginally. Moraines usually comprise glacial diamict but our broad definition includes ice-contact fans that may contain fluvially deposited sands and gravels. No distinction is made between terrestrial and offshore setting (e.g. moraines vs. morainal banks) and some of the latter features probably include grounding-zone wedges.

### *Trimlines*

Weathering limits, separating mountain summits with frost-weathered detritus from lower elevation ice-scoured slopes are frequently recognised in the uplands of Ireland and Britain; many have been called trimlines. We have now updated this layer to include trimlines in Ireland and with more examples from Britain from papers published since the census date for V.1. A total of 187 summits are now identified. Previously, in Clark *et al.* (2004) we noted that authors of papers usually interpreted trimlines as marking the maximum upper limit of the ice sheet – thereby defining nunataks – but that an alternative interpretation also existed; that trimlines marked subglacial boundaries between erosive warm-based ice and non-erosive cold-based ice. More recently, cosmogenic-nuclide dating of glacially deposited boulders on some Scottish and Irish summits above mapped trimlines has yielded exposure ages that falsify the interpretation of the trimline representing the maximum upper ice-sheet surface elevation (Fabel *et al.* 2012; Ballantyne & Stone 2015). These

authors suggest that these cosmogenic-nuclide data support the interpretation that British and Irish trimlines mark boundaries or zones between warm-based and cold-based ice. It remains an open question as to whether all trimlines in the database were produced at ice-sheet thermal boundaries or whether both types exist. Trimlines are retained in the database as important markers of ice-sheet activity and erosional evidence, and it will prove interesting to compare their location with ice-sheet modelling experiments that track such subglacial thermal boundaries and their evolution over time.

### *Cirques*

New to this version of the Glacial Map we include glacially produced part-open hollows cut into mountain flanks and variously called corries (Scottish), cwms (Welsh) or cirques (French and internationally used). Whilst much has been published on British and Irish cirques (e.g. Harker 1901; Sale 1970; Evans 2006) a complete map of their occurrence and distribution has until now been missing. The database contains 2208 examples. The cirques range in size from 47 to 965 m in depth (relief) and with mean elevations above sea level from 64 to 1188 m and they exist in all the main upland regions including some islands. The method of cirque mapping and analysis of their size and shape are to be reported elsewhere. In the attribute table we include data on cirque metrics including: length, width, a measure of circularity, minimum, maximum and mean elevations, directional aspect, mean slope, a measure of plan closure, distance to modern day coastline, information on their host rock lithology, and the cirque name (e.g. Cwm Idwal), and a grade indicative of its certainty and definition (Evans & Cox 1995). We suggest that within the limits of cirque definition that this is a complete record across the landscape.

### *Trough-mouth fans*

Major accumulations (or fans) of sediment deposited at the continental shelf edge interpreted to have been mostly fed by focussed ice-sheet flow, such as in ice streams, are included. Six large examples are portrayed, namely: the Foula Wedge; Sandoy Fan; Suduroy Fan; Rona Wedge; Sula Sgeir Fan; and the huge (300 × 200 km in size) Barra and Donegal Fan.

### *Ice-dammed lakes*

In common with the V.1 database we break with the restriction of only including glacial landforms by providing layers relating to ice-dammed lakes. We do so because they provide important information on the position of ice margins. Glacial lakes have mostly been reported in the literature from lake deposits found in positions that require an ice margin to dam the water body. A polygon layer defines the extent of ice-dammed lakes interpreted by authors of the cited publications. Caution is required in

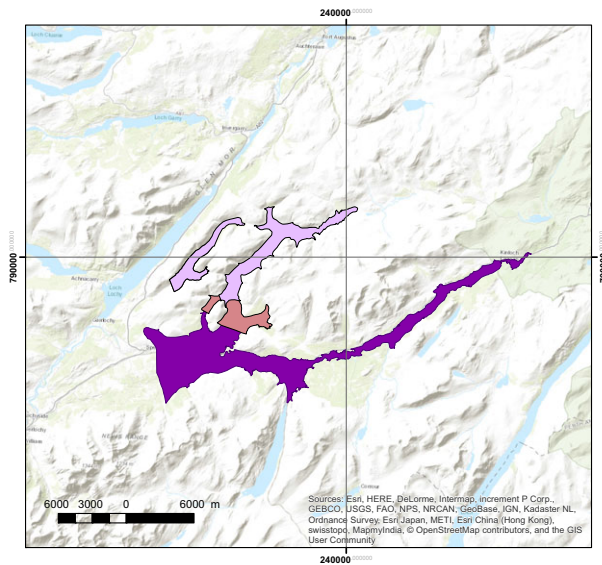


Fig. 8. Map representation of a series of ice-dammed lakes (in purple hues) in Glen Spean, Glen Roy and Glen Gloy, Scotland. Note that the ice-dam positions are to the south and west and that multiple water levels (355, 350, 325, 260 m a.s.l.) and lake extents are defined, from which the positions of impounding ice margins can be inferred. These lake extents are from Turner *et al.* (2014) and this paper and the wider literature of the area should be consulted for information on the relative and absolute timing of the lakes; the colouring and superposition shown here are merely to illustrate their extents. [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

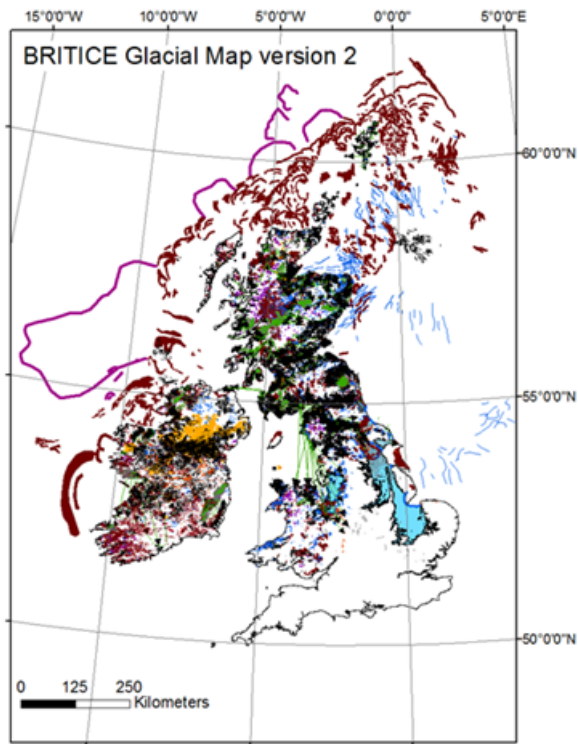
that the evidence is rarely complete enough to robustly define full lake extents. Furthermore, potential glacio-isostatic adjustments are at present unknown and hence we assume horizontal shorelines, an assumption that is almost certainly incorrect. Typically it is necessary to extrapolate far beyond patches of evidence with the aid of manual ‘contour-following’ or using GIS operations on DEMs. The evidence for ice-dammed lakes mostly comes from the elevation of sediments interpreted as being lacustrine found in sedimentary sections or from bore-holes, or in some cases by shorelines or spillways. One layer defines former lake extents, and in V.2 we have also included multiple water levels and concomitant lake extents where these have been defined in the literature (Fig. 8). The most notable examples of multiple lake levels are seen in the Scottish Glens of Spean, Roy, Gloy and Doe (from Turner *et al.* 2014) and the various levels of Lake Lapwoth and its nearby lakes in the Cheshire-Shropshire lowlands (Murton & Murton 2012). A thematic layer (Lake-dams) is used to define the approximate position and orientation of the inferred ice position required to hold back the lake body, and thereby provides an indication of the direction of ice retreat. Given that the existence of ice-dammed lakes is primarily defined by observations of lake sediments, a polygon layer is provided to show their distribution where authors have inferred they arise from ice-dammed rather than normal (non-ice-dammed) subaerial lakes. Over 50 British glacial lakes are

defined in the database, but no information is provided for Irish cases even though examples are reported in the literature. The information on ice-dammed lakes should be seen as a work-in-progress as there is much more that needs to be achieved with Irish and additional British lakes being defined and their extents and lake levels more robustly established. Murton & Murton (2012) do an excellent job reviewing the work on ice-dammed lakes and defining lake extents, levels and ages. We drew heavily from this work and readers are referred to it for lakes in our database and especially so for analysis of the weakly constrained, and not uncontroversial, large lake in eastern England (Glacial Lake Fenland and its possible connection to Lake Humber). Our database does not include the large ice-dammed (Dogger) lake that is thought to have existed in the southern North Sea Basin (e.g. Belt 1874; Valentin 1958; Woldstedt 1958), because substantive evidence for the lake has yet to be found and published even though it must surely have existed given the terrestrial emergence of this area, with a topographical depression and a complete ice dam across the North Sea preventing northwards escape of water (Sejrup *et al.* 2016).

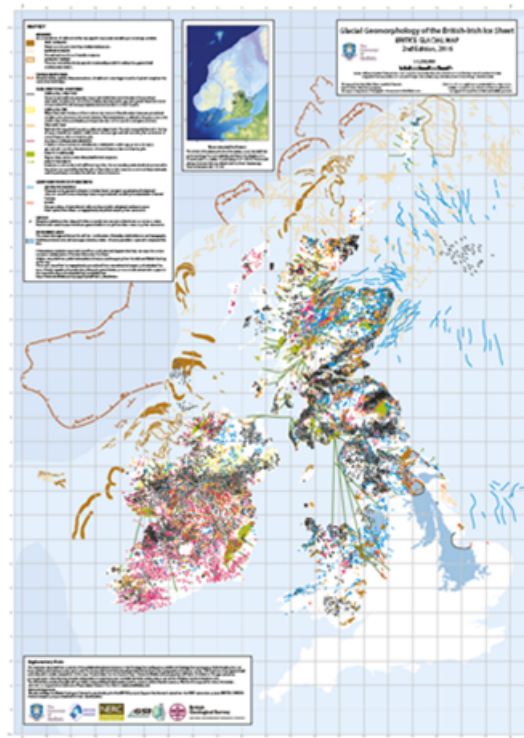
## Conclusions

We have undertaken a survey of the glacial geomorphological evidence of onshore and offshore Britain and Ireland to produce a new BRITICE map and GIS database (version 2). To our knowledge, all published geomorphological evidence in the themes that we targeted and relating to the extent and behaviour of the last ice sheet that covered much of the British Isles is now included (up to the census date of 31st December 2015). The fully revised GIS database contains over 170 000 geospatially referenced and attributed elements – an eightfold increase in information from the previous version (V.1; Clark *et al.* 2004). The spatial coverage has been increased (Ireland and continental shelf) and some new thematic layers added (cirques, crag-and-tails and glacially streamlined bedrock). The geolocation of many features has been improved. Data are stored in thematic layers including: drumlins, ribbed moraine, crag-and-tails, mega-scale glacial lineations, glacially streamlined bedrock (grooves, roches moutonnées and whalebacks); glacial erratics; eskers; meltwater channels (subglacial, lateral, proglacial and tunnel valleys); moraines; trimlines; cirques; trough-mouth fans and evidence defining ice-dammed lakes. Not included are themes such as raised shorelines, glacial striae, hummocky moraine, kame terraces, periglacial and aeolian landforms, alluvial and delta-fans, which if compiled in a future version, could help constrain aspects of ice cover, retreat and dynamics. Features thought to relate to previous glaciations (e.g. Anglian Stage) are also not included and could form the basis of future work. Features relating to the later and smaller Loch Lomond Stadial ice masses are excluded, but have already been compiled in Bickerdike *et al.* (2016). Comments or help to correct mistakes or add

## A GIS data layers (shapefiles)



## B Glacial Map (PDF) to print at A0



## c Full resolution maps (PDF) for digital viewing

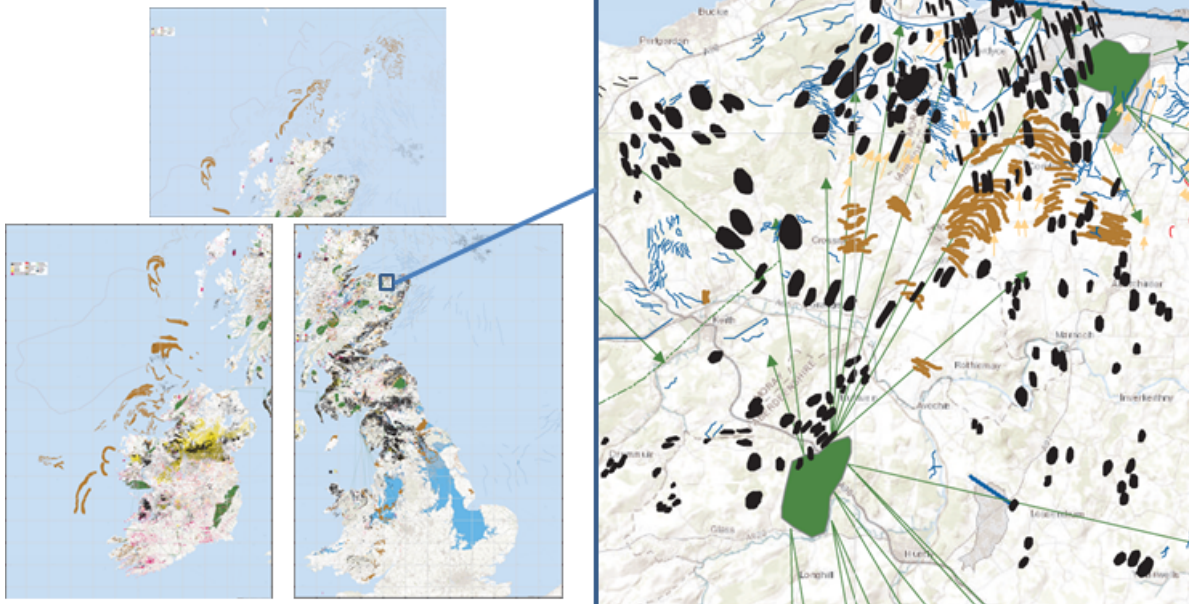
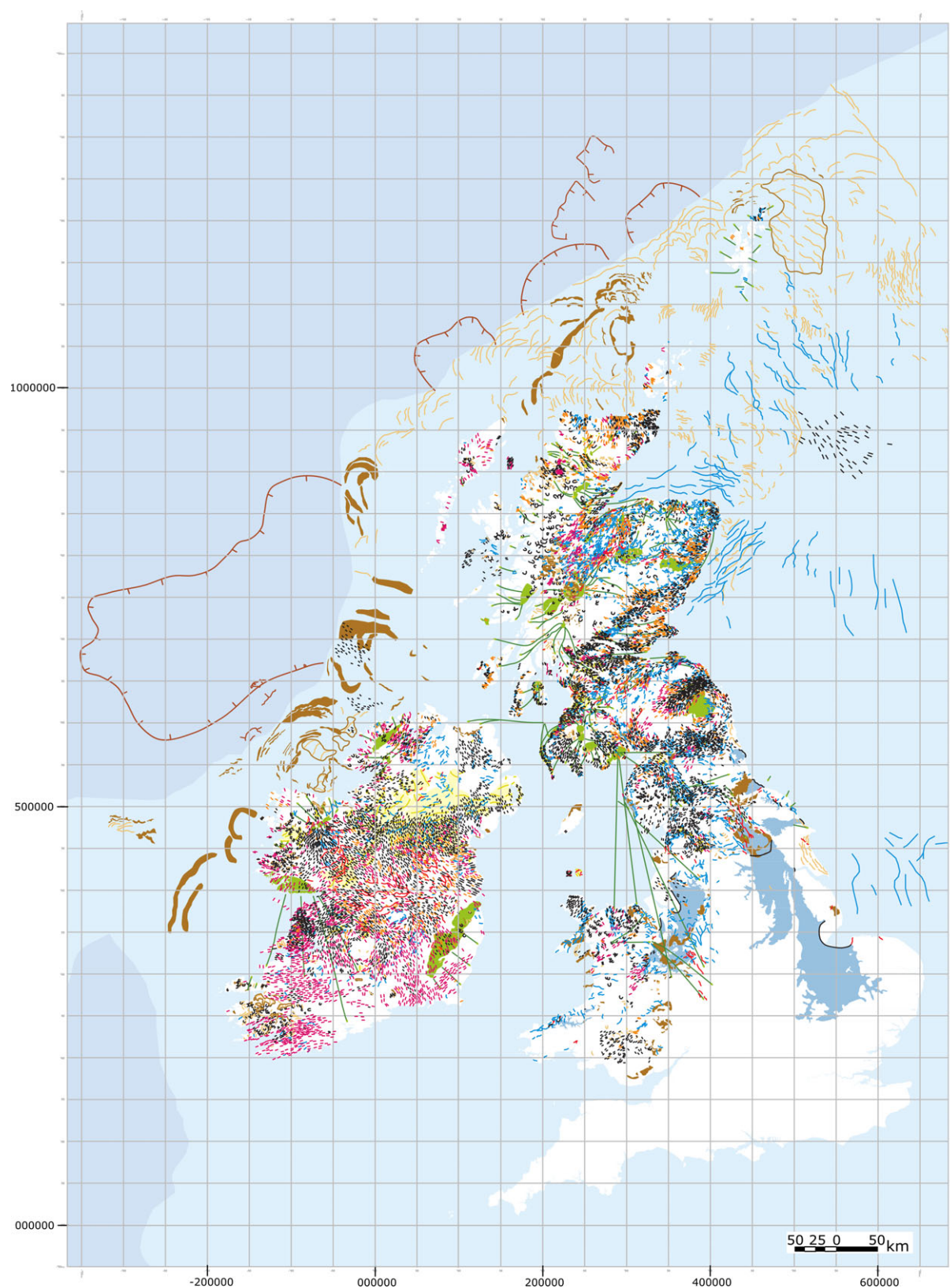


Fig. 9. BRITICE V.2 is available in varying scales and formats, with different levels of generalization and abstraction, which vary according to their anticipated use. A. Full-resolution GIS database (filtered or unfiltered), best used for maximum levels of information and for local to regional scale investigations. Data are provided as ESRI ArcMap shapefiles (Data S3). B. Cartographically generalized map (PDF) to provide an overview of the distribution and types of features at the ice-sheet scale (see Fig. 10, Data S2). C. Example of viewing the full-resolution database without using GIS. A series of three maps is available which are designed to be viewed as digital PDFs at scales of around 1:20 000 across which one can 'pan and scroll' to view areas of interest, or to print out selected areas (Data S2). [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]





*Fig. 10.* Overview of the cartographically generalized Glacial Map designed for viewing or printing at a paper size of A0 (84×119 cm) and scale of 1:1 250 000. The features are not properly visible at the scale reproduced here: refer to the PDF that can be downloaded (see note at end of the paper and Supporting Information). [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]



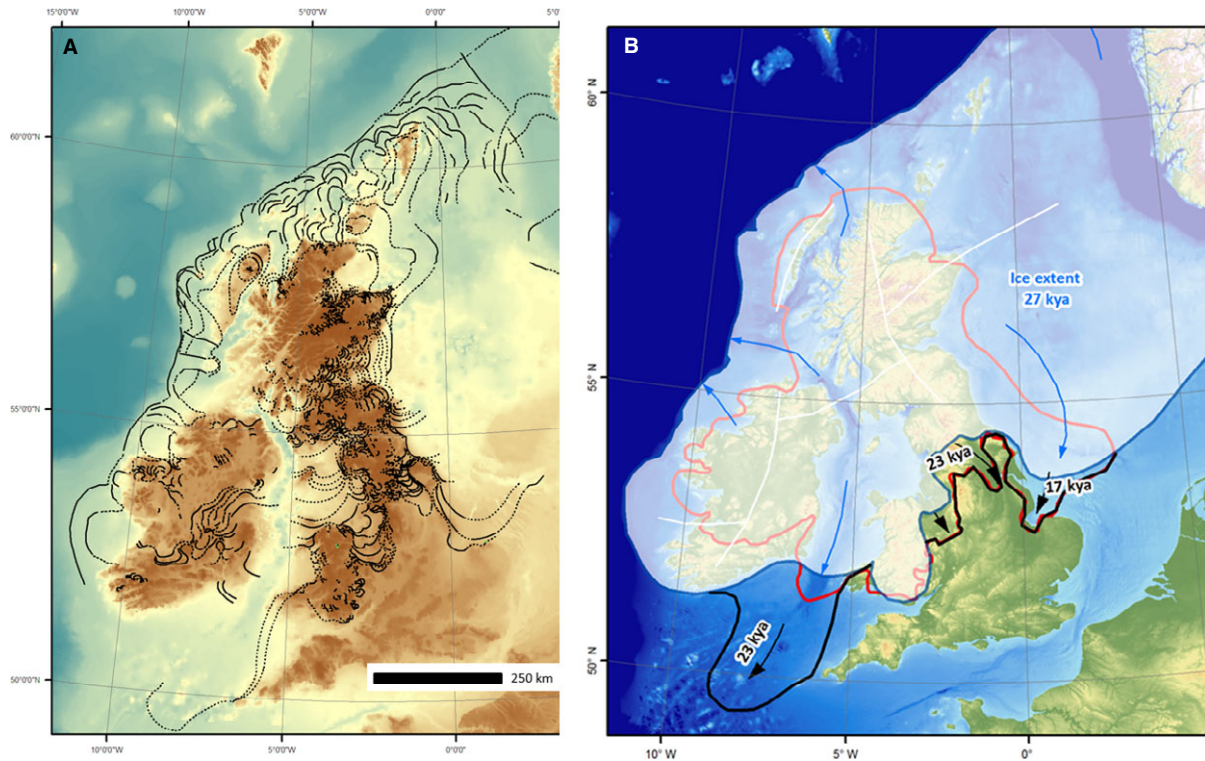


Fig. 11. A. Reconstruction of the pattern of retreat for the British–Irish Ice Sheet inferred from data in the BRITICE V.2 database, including moraines, meltwater channels, eskers and subglacial bedforms (adapted from Clark *et al.* 2012). B. Overview of the maximum ice-sheet extent, noting that it reached this at different times in various sectors. The red line depicts the earlier long-standing view of an ice sheet of more restricted extent as summarized in Bowen *et al.* (1986), and the white-shaded area shows ice extent at 27 ka BP with black lines depicting subsequent advances of the southern margin (from Clark *et al.* 2012). [Colour figure can be viewed at [www.boreas.dk](http://www.boreas.dk)]

new layers for a future version are welcome and should be directed to the lead author.

We encourage users of this BRITICE V.2 database to fully read this article and the V.1 publication so that they can appreciate and pay due regard to the caveats that we clearly set out regarding data quality and geographical spread. The revised database has some inconsistencies, most notably that some layers are nearly complete (e.g. subglacial bedforms) whilst some exist at a more reconnaissance-level (e.g. ice-dammed lakes). Consequently, the absence of features on the map in a specific place might merely reflect the failure of the research community to find them (or us to compile them) rather than a real absence. The V.1 map included ‘drift limits’, but this layer has been retired in this version. Meltwater features have been especially difficult to categorize into their subtypes (e.g. lateral meltwater channels; subglacial meltwater channels; tunnel valleys/channels) and we note that unlike most other layers that these have yet to be scientifically exploited, along with the eskers, to gain insight regarding subglacial hydrology. Given the high topographical variability across the British Isles, along with a mostly temperate former ice-sheet cover, we regard it likely that subglacial lakes existed. Some of the lake sediments reported in the database might actually relate to subglacial lakes (e.g. McCabe & Ó Cofaigh 1994) and

perhaps further examples will be discovered (e.g. in deep Scottish Lochs and fjords), but it remains difficult to robustly demonstrate a subglacial origin for lake sediments (Livingstone *et al.* 2012).

BRITICE V.2 is available in four map scales and formats, each with different levels of generalization and abstraction, which vary according to their anticipated use (Fig. 9). In the Supporting Information to this paper and on the BRITICE website ([https://www.sheffield.ac.uk/geography/staff/clark\\_chris/britice](https://www.sheffield.ac.uk/geography/staff/clark_chris/britice)) the following are available:

- An unfiltered GIS database containing all mapping, including overlaps and conflicts between mapping derived from different publications. This is highly detailed and best used in GIS for local to regional areas and where the maximum level of information is desired. Data are provided as ESRI ArcGIS shapefiles with notes and citations in the attribute tables (Data S3).
- A filtered GIS database, resolving data conflicts and with improved geo-locational accuracy to provide a consistent synthesis of highly detailed information. This is also best used in GIS for local to regional areas. Data are provided as shapefiles with notes and citations in the attribute tables (Data S3).

- To view the filtered database without using GIS, a series of three full-resolution PDF maps (Fig. 9C; Ireland; England, Scotland & Wales; Northern Scotland and offshore) are available that are designed to be viewed as digital PDFs at scales of around 1:200 000, across which one can 'pan and scroll' to view areas of interest, or to print out selected areas (Data S2). It would be impractical to attempt to print these as maps because at a scale sufficient to see the detail the paper would need to be 5 by 5 metres in size.
- A cartographically generalized map (Fig. 10) to provide an overview of the distribution and types of features of the whole ice sheet and which can be printed at a paper size of A0 (84 × 119 cm) and scale of 1:1 250 000 (Data S2). Although much detail is lost because of the generalization (e.g. extent of drumlin fields and flow orientations are shown rather than individual landforms) this map provides a holistic overview and could make an appropriate sized poster map to go on a wall.
- A bibliographic list of all sources used in this compilation is too long to include in this paper but the full citations are reported in the GIS shapefiles and a reference list is available for download (Data S1).

It should be clear from the above that there has been a large increase in the volume of glacial geomorphological evidence pertaining to the last ice sheet that covered much of the British Isles. The glacial maps and GIS database we present here help to celebrate this. They should assist those who wish to make sense of this rich information-base and hopefully will promote further work to discover more. Ongoing and new national mapping programmes and academic research can continue to make important contributions to these data sets. Most of the features have already been used to make a first-order map of the pattern of retreat of the ice sheet (Fig. 11A) and, together with published geochronometric dates, to build a reconstruction of the timing and pattern of retreat of the whole ice sheet (Clark *et al.* 2012). A major highlight of the new information base, especially offshore, is that the ice sheet was much more extensive than previously thought (e.g. Bowen *et al.* 1986), as shown in Fig. 11B. The ice-sheet retreat map is being used by the BRITICE-CHRONO project (2012–2018) to act as a spatial framework for collecting samples of organics, sand and boulders in a large dating programme (~800 new dates using OSL,  $^{14}\text{C}$  and cosmogenic-nuclide techniques) to better constrain the timing of ice retreat, explore the controls on retreat, and to improve ice-sheet modelling (<http://www.britice-chrono.group.shef.ac.uk/>). The project has undertaken a quality control exercise of all existing geochronometric dates (Small *et al.* 2017) and it is anticipated that these might be incorporated in future versions of the BRITICE map and database.

In addition to other thematic features noted earlier (e.g. glacial striae, raised shorelines) future versions of the BRITICE map may include the addition of layers

reporting chronology of ice retreat (from the BRITICE CHRONO project), including sample locations and meta-data for radiocarbon, cosmogenic and luminescence ages, and reconstructed margin positions at say 1000 year timesteps. Maps of ice-sheet thickness and elevation per timestep is another possibility for inclusion, derived from ice-sheet modelling experiments fitted to the landform and stratigraphically constrained chronological data.

The BRITICE V.2 GIS data (shapefiles), maps (as PDFs) and the full bibliography (PDF) can be downloaded from [https://www.sheffield.ac.uk/geography/staff/clark\\_chris/britice](https://www.sheffield.ac.uk/geography/staff/clark_chris/britice), and are also available as Data S1–S3. The V.1 data and maps are also available at the same website. Additionally, in collaboration with Esri UK, a BRITICE V.2 web application exists that allows users free access to view the landforms overlaid on a zoomable geographical base map with places names, and also to turn layers on and off and query individual features. It can be found by web searching for BRITICE Esri or using the link: <http://maps.arcgis.com/apps/webappviewer/index.html?id=70dd45e769534ff08cb41c9571ec5258>.

## References for BRITICE Glacial Map V.2

The database was compiled using the following sources referenced separately at the end of the online version of this article and in Data S1:

Agar (1954), Aitken (1990), Aitkenhead *et al.* (1991), Akhurst *et al.* (1997), Anderson *et al.* (1979), Andrews *et al.* (1990), Armstrong *et al.* (1985), Arthurton & Wadge (1981), Arthurton *et al.* (1988), Ballantyne (1988, 1990, 1999), Ballantyne & McCarroll (1995, 1997a,b), Ballantyne & Hallam (2001), Ballantyne & Stone (2012), Ballantyne *et al.* (1998, 2006, 2007a,b, 2008, 2009, 2011, 2013), Balson & Jeffery (1991), Bennett & Boulton (1993), Benetti *et al.* (2010), Boardman (1991), Boulton *et al.* (1977), Bowen (1970, 1982), Bradwell (2005, 2013), Bradwell & Stoker (2015), Bradwell *et al.* (2007, 2008a,b, c), Brandon (1989), Brandon *et al.* (1998), Brazier *et al.* (1996, 1998), Brooks *et al.* (2008), Brown & Cooke (1977), Brown (1993), Bryant (1977), Burgess & Holliday (1979, 1987), Cameron *et al.* (1998, 1992), Catt (1991a, b), Charlesworth (1924, 1926a, b, 1928a, b, 1929a, b, 1939, 1953, 1957), Clapperton (1970, 1971a, b), Clapperton *et al.* (1975), Clarhäll & Kleman (1999), Clark & Wilson (1994), Clark & Meehan (2001), Clark *et al.* (2004, 2009, 2012), Colhoun (1970, 1971), Colhoun *et al.* (1972), Connell *et al.* (1987), Cooper & Burgess (1993), Crimes *et al.* (1994), Crofts (2005), Cross & Hodgson (1975), Cullen (2012), Dahl *et al.* (1996), Davies *et al.* (1986), Davies (1997), Dawson (1982), Davison (2004), Day (1970), Delany (2001a, b, 2002), Delaney *et al.* (2010), Douglas (1991), Dunlop (2004), Dunlop *et al.* (2010), Earp *et al.* (1986), Eastwood *et al.* (1968), Edwards (1938), Edwards *et al.* (1950), Ehlers & Wingfield (1991), Ellis-Gruffydd (1977), Embleton (1964, 1970), Etienne *et al.* (2006), Evans (2003), Evans &

- Thomson (2010), Evans *et al.* (2001, 2003, 2005), Everest *et al.* (2005), Everest & Kubik (2006), Everest *et al.* (2006), Farrington (1936), Farrington & Mitchell (1951), Fairburn & Bateman (2016), Finch (1977), Finch & Walsh (1973), Finlayson (2012), Finlayson & Bradwell (2008), Finlayson *et al.* (2007, 2010, 2014), Fishwick (1977), Flinn (1978a, b, 1983), Flint (1930), Floyd (1999), Forsythe *et al.* (1996), Foster (1985), Foster (1970), Foster *et al.* (1999), Francis *et al.* (1970), Frost (1998), Frost & Holliday (1980), Fyfe *et al.* (1993), Gallagher *et al.* (1996), Gallagher *et al.* (2004), Garrard & Dobson (1974), Gaunt (1976, 1994), Gaunt *et al.* (1992), Geikie *et al.* (1869), Gemmell *et al.* (1972), George (1970), Gibbons & McCarroll (1993), Gibson (1993), Glasser & Smith (1999), Glasser *et al.* (2004), Golledge (2002, 2007), Golledge & Phillips (2008), Golledge & Hubbard (2005), Golledge & Stoker (2006), Golledge *et al.* (2008), Goodchild (1875), Gordon (1993a,b,c), Gordon & Auton (1993), Graham *et al.* (2001, 2007), Greenwood (2008), Greenwood & Clark (2008, 2009a, b, 2010), Gregory (1920), Gresswell (1952, 1967), Grieg *et al.* (1967), Hall (2013), Hall & Bent (1990), Hall *et al.* (1998, 2011), Hall & Glasser (2003), Hambrey *et al.* (2001), Harmer (1928), Harrod (1972), Hegarty (2002a, b), Hiemstra *et al.* (2006, 2015), Hill (1973), Holden (1977), Hollingworth (1931), Howarth (1908a, b, c, d), Howe *et al.* (2015), Huddart (1991, 1999), Huddart & Bennett (1997), Hughes (2009), Hughes *et al.* (2010), Jansson & Glasser (2008), Johnson (1965a, b) Johnson *et al.* (1993), Jordan (1997, 2002), Jowett (1914), Jowett & Charlesworth (1929), Kendall (1902, 1903), Kilfeather (2004), Kinahan (1883), King & Gage (1961), Knight (1997, 1999, 2002, 2003a, b, 2006), Knight *et al.* (1999), Knowles (1985), Lamb & Ballantyne (1998), Lawson (1995), Letzer (1978, 1987), Lewis (1970), Lewis & Richards (2005), Lintern (2001), Livingstone *et al.* (2008, 2015), Luckman (1970), Lunn (1980), Mackintosh (1880), Mathers (2014), McAdam *et al.* (1985), McCabe (1971, 1972, 1985, 1993, 1995, 2008), McCabe & Ó Cofaigh (1994, 1996), McCabe *et al.* (1999, 2007), McCarroll (1991, 1995), McCarroll & Ballantyne (2000), McLellan (1969), Meehan (1998, 1999a,b, 2013), Merritt *et al.* (1995), Miller *et al.* (2014), Mills & Hull (1976), Mitchell (1991, 1994, 2007), Mitchell & Buggie (1991), Mitchell & Riley (2006), Moseley & Walker (1952), Murdoch (1975), Murton & Murton (2012), NIREX (1997), Orme (1967), Palmer (1967), Parkes *et al.* (2012), Paterson *et al.* (1990, 1998), Patton *et al.* (2013a, b, c), Peacock (1968, 1984), Peacock *et al.* (1992), Peacock & Merritt (1997), Penny & Rawson (1969), Peters *et al.* (2015), Phillips *et al.* (2010), Pinson *et al.* (2013), Pocock (1940), Powell *et al.* (1992), Price (1960, 1963, 1983), Radge (1939), Rae *et al.* (2004), Raistrick (1926, 1931, 1933), Rees & Wilson (1998), Richards (2005), Roberts *et al.* (2007), Robinson & Ballantyne (1979), Rolfe *et al.* (2014), Rose (1980, 1981a, b, 1987), Rose & Letzer (1977), Rose & Smith (2008), Russell (1995), Salt (2001), Scourse & Furze (2001), Sejrup *et al.* (2005), Sissons (1958a, b, c, 1960, 1961a, b, 1963a, b, 1967, 1976, 1979a, b), Small *et al.* (2012), Smith (1932), Smith (1994), Smith & Francis (1967), Smith & Kimbell (1999), Stoker (1988), Stoker *et al.* (1993, 2006a, b, 2009), Straw (1960, 1961, 1969, 1979), Sugden (1968), Sugden *et al.* (1992), Sugden & Clapperton (1975), Sutherland (1981, 1984), Sutherland *et al.* (1984), Synge (1963, 1966, 1968, 1979), Taylor *et al.* (1971, 1963), Terwindt & Augustinus (1985), Thomas (1971, 1984, 1985, 1989, 1997), Thomas & Montague (1997), Thomas *et al.* (1998, 2004), Thomas & Chiverrell (2006, 2007), Thomson & Eden (1977), Thorp (1986, 1987, 1991), Trotter (1929), Turner *et al.* (2012, 2014), Van Landeghem *et al.* (2009), Vincent (1985), Warren (1977, 1988, 1991, 1992), Warren & Ashley (1994), West (1993), West *et al.* (1999), Whitehead *et al.* (1928), Whiteman (1981), Wills (1924), Wingfield (1990), Worsley (1991, 2005), Yates & Moseley (1958), Yorke *et al.* (2007), Young (1974, 1978).
- Acknowledgements.* – Co-authors from the V.1 map not listed on this paper (Anjana Khatwa, Stuart Marsh, Wishart Mitchell) are acknowledged for their support as V.1 clearly underpins the one presented here. The journal editor, Jan A. Piotrowski, is thanked for his adaptable approach at the time of V.1 publication, which permitted inclusion of a large fold-out map, and for his work on this paper. Phil Gibbard and John Lowe are thanked for their help in improving an earlier version of this manuscript. This work was supported by the Natural Environment Research Council consortium grant; BRITICE-CHRONO NE/J009768/1. David McCutcheon cartographer of [dvdmaps.co.uk](http://dvdmaps.co.uk) is thanked for his work. The authors wish to thank the Integrated Mapping for the sustainable development of Ireland's Marine Resources (INFOMAR) programme for supply of Irish offshore data sets (<http://www.infomar.ie/>). Rob Sharpe and Chris Barker of Esri UK are thanked for their support and the building of the web-based BRITICE application.
- ## References
- Note that this list only includes references cited in the main text – references for the database are listed separately at the end of the online version of this article and in the Supporting Information (Data S1).
- Ballantyne, C. K. & Stone, J. O. 2015: Trimlines, blockfields and the vertical extent of the last ice sheet in southern Ireland. *Boreas* 44, 277–287.
- Belt, T. 1874: The glacial period. *Nature* 10, 25–36.
- Benetti, S., Dunlop, P. & Ó Cofaigh, C. 2010: Glacial and glacially-related features on the continental margin of northwest Ireland mapped from marine geophysical data. *Journal of Maps* 6, 14–29.
- Bickerdike, H. L., Evans, D. J. A., Ó Cofaigh, C. & Stokes, C. R. 2016: The glacial geomorphology of the Loch Lomond Stadial in Britain: a map and geographic information system resource of published evidence. *Journal of Maps* 12, 1178–1186.
- Bowen, D. Q., Rose, J., McCabe, A. M. & Sutherland, D. G. 1986: Correlation of Quaternary glaciations in England, Ireland, Scotland and Wales. *Quaternary Science Reviews* 5, 299–340.
- Bradwell, T. 2005: Bedrock megagrooves in Assynt, NW Scotland. *Geomorphology* 65, 195–204.
- Bradwell, T. & Stoker, M. S. 2015: Submarine sediment and landform record of a palaeo-ice stream within the British–Irish Ice Sheet. *Boreas* 44, 255–276.
- Bradwell, T., Stoker, M. S., Golledge, N. R., Wilson, C. K., Merritt, J. W., Long, D., Everest, J. D., Hestvik, O. B., Stevenson, A. G., Hubbard, A., Finlayson, A. G. & Mathers, H. E. 2008: The northern

- sector of the last British Ice Sheet: maximum extent and demise. *Earth-Science Reviews* 88, 207–226.
- Chiverrell, R. C. & Thomas, G. S. P. 2010: Extent and timing of the Last Glacial Maximum (LGM) in Britain and Ireland: a review. *Journal of Quaternary Science* 25, 535–549.
- Clark, C. D. 1993: Mega-scale glacial lineations and cross-cutting ice-flow landforms. *Earth Surface Processes and Landforms* 18, 1–29.
- Clark, C. D. & Meehan, R. T. 2001: Subglacial bedform geomorphology of the Irish Ice Sheet reveals major configuration changes during growth and decay. *Journal of Quaternary Science* 16, 483–496.
- Clark, C. D., Evans, D. J. A., Khatwa, A., Bradwell, T., Jordan, C. J., Marsh, S. H., Mitchell, W. A. & Bateman, M. D. 2004: Map and GIS database of glacial landforms and features related to the last British Ice Sheet. *Boreas* 33, 359–375.
- Clark, C. D., Hughes, A. L. C., Greenwood, S. L., Jordan, C. & Sejrup, H. P. 2012: Pattern and timing of retreat of the last British-Irish Ice Sheet. *Quaternary Science Reviews* 44, 112–146.
- Clark, C. D., Hughes, A. L. C., Greenwood, S. L., Spagnolo, M. & Ng, F. S. L. 2009: Size and shape characteristics of drumlins, derived from a large sample, and associated scaling laws. *Quaternary Science Reviews* 28, 677–692.
- Dunlop, P., Shannon, R., McCabe, M., Quinn, R. & Doyle, E. 2010: Marine geophysical evidence for ice sheet extension and recession on the Malin Shelf: new evidence for the western limits of the British Irish Ice Sheet. *Marine Geology* 276, 86–99.
- Ely, J. C., Clark, C. D., Spagnolo, M., Stokes, C. R., Greenwood, S. L., Hughes, A. L. C., Dunlop, P. & Hess, D. 2016: Do subglacial bedforms comprise a size and shape continuum? *Geomorphology* 257, 108–119.
- Evans, I. S. 2006: Allometric development of glacial cirque form: geological, relief and regional effects on the cirques of Wales. *Geomorphology* 80, 245–266.
- Evans, D. J. A., Clark, C. D. & Mitchell, W. A. 2005: The last British Ice Sheet: a review of the evidence utilised in the compilation of the Glacial Map of Britain. *Earth-Science Reviews* 70, 253–312.
- Evans, I. S. & Cox, N. J. 1995: The form of glacial cirques in the English Lake District, Cumbria. *Zeitschrift für Geomorphologie* 39, 175–202.
- Everest, J., Bradwell, T. & Golledge, N. 2005: Subglacial landforms of the Tweed palaeo-Ice Stream. *Scottish Geographical Journal* 121, 163–173.
- Fabel, D., Ballantyne, C. K. & Xu, S. 2012: Trimlines, blockfields, mountain-top erratics and the vertical dimensions of the last British-Irish Ice Sheet in NW Scotland. *Quaternary Science Reviews* 55, 91–102.
- Finlayson, A. G. & Bradwell, T. 2008: Morphological characteristics, formation and glaciological significance of Rogen moraine in northern Scotland. *Geomorphology* 101, 607–617.
- Finlayson, A., Bradwell, T., Golledge, N. & Merritt, J. 2007: Morphology and significance of transverse ridges (De Geer Moraines) adjacent to the Moray Firth, NE Scotland. *Scottish Geographical Journal* 123, 257–270.
- Finlayson, A., Merritt, J., Browne, M., Merritt, J., McMillan, A. & Whitbread, K. 2010: Ice sheet advance, dynamics, and decay configurations: evidence from west central Scotland. *Quaternary Science Reviews* 29, 969–988.
- Flint, R. F. 1930: The origin of the Irish “eskers”. *Geographical Review* 20, 615–630.
- Geikie, J. 1894: *The Great Ice Age and its Relation to the Antiquity of Man*. 617 pp. Stanford, London.
- Gibbard, P. L. & Clark, C. D. 2011: Pleistocene glaciation limits in Great Britain. In Ehlers, J., Gibbard, P. L. & Hughes, P. D. (eds.): *Quaternary Glaciations: Extent and Chronology, A closer look, Part I, Europe*, 75–93. *Developments in Quaternary Science* 15. Elsevier, Amsterdam.
- Graham, A. G. C., Lonergan, L. & Stoker, M. S. 2007: Evidence for Late Pleistocene ice stream activity in the Witch Ground Basin, central North Sea, from 3D seismic reflection data. *Quaternary Science Reviews* 26, 627–643.
- Greenwood, S. L. 2008: *A palaeoglaciological reconstruction of the last Irish Ice Sheet*. Ph.D. thesis, University of Sheffield, 360 pp.
- Greenwood, S. L. & Clark, C. D. 2008: Subglacial bedforms of the Irish Ice Sheet. *Journal of Maps* 4, 332–357.
- 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. *Quaternary Science Reviews* 28, 3101–3123.
- Greenwood, S. L., Clark, C. D. & Hughes, A. L. C. 2007: Formalising an inversion methodology for reconstructing ice-sheet retreat patterns from meltwater channels: application to the British Ice Sheet. *Journal of Quaternary Science* 22, 637–645.
- Harker, A. 1901: Ice erosion in the Cuillin Hills, Skye. *Transactions of the Royal Society of Edinburgh* 40, 221–252.
- Howe, J. A., Dove, D., Bradwell, T. & Gaferia, J. 2012: Submarine geomorphology and glacial history of the Sea of the Hebrides, UK. *Marine Geology* 315, 64–76.
- 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. *Quaternary Science Reviews* 28, 758–776.
- Hughes, A. L. C. 2009: *The last British Ice Sheet; a reconstruction based on glacial landforms*. Ph.D. thesis, University of Sheffield, 297 pp.
- Hughes, A. L. C., Clark, C. D. & Jordan, C. J. 2010: Subglacial bedforms of the last British Ice Sheet. *Journal of Maps* 6, 543–563.
- Hughes, A. L. C., Clark, C. D. & Jordan, C. J. 2014: Flow-pattern evolution of the last British Ice Sheet. *Quaternary Science Reviews* 89, 148–168.
- Jørgensen, F. & Sandersen, P. B. 2006: Buried and open tunnel valleys in Denmark-erosion beneath multiple ice sheets. *Quaternary Science Reviews* 25, 1339–1363.
- Kleman, J. 1994: Preservation of landforms under ice sheets and ice caps. *Geomorphology* 9, 19–32.
- Knight, J. & McCabe, A. M. 1997: Identification and significance of ice-flow-transverse subglacial ridges (Rogen moraines) in northern central Ireland. *Journal of Quaternary Science* 12, 519–524.
- Knight, J., McCarron, S. G. & McCabe, A. M. 1999: Landform modification by palaeo-ice streams in east-central Ireland. *Annals of Glaciology* 28, 161–167.
- Kristensen, T. B., Huuse, M., Piotrowski, J. A. & Clausen, O. R. 2007: A morphometric analysis of tunnel valleys in the eastern North Sea based on 3D seismic data. *Journal of Quaternary Science* 22, 801–815.
- Livingstone, S. J., Clark, C. D., Piotrowski, J. A., Tranter, M., Bentley, M. J., Hodson, A., Swift, D. A. & Woodward, J. 2012: Theoretical framework and diagnostic criteria for the identification of palaeo-subglacial lakes. *Quaternary Science Reviews* 53, 88–110.
- Livingstone, S. J., Ó Cofaigh, C. & Evans, D. J. A. 2008: Glacial geomorphology of the central sector of the last British-Irish Ice Sheet. *Journal of Maps* 4, 358–377.
- McCabe, A. M. & Ó Cofaigh, C. 1994: Sedimentation in a subglacial lake, Enniskerry, eastern Ireland. *Sedimentary Geology* 91, 57–95.
- McCabe, A. M., Knight, J. & McCarron, S. G. 1999: Ice-flow stages and glacial bedforms in north central Ireland: a record of rapid environmental change during the last glacial termination. *Journal of the Geological Society, London* 156, 63–72.
- Meehan, R. T. 2013: *The merging of Quaternary map datasets: end of project report on project outputs*. 123 pp. Unpublished report, Geological Survey of Ireland, Dublin.
- Mitchell, W. A. & Riley, J. M. 2006: Drumlin map of the Western Pennines and southern Vale of Eden, Northern England, UK. *Journal of Maps* 2, 10–16.
- Murton, D. K. & Murton, J. B. 2012: Middle and Late Pleistocene glacial lakes of lowland Britain and the southern North Sea Basin. *Quaternary International* 260, 115–142.
- Patton, H., Hubbard, A., Glasser, N. F., Bradwell, T. & Golledge, N. R. 2013: The last Welsh Ice Cap: part 2 – Dynamics of a topographically controlled icecap. *Boreas* 42, 491–510.
- Praeg, D., McCarron, S., Dove, D., Ó Cofaigh, C., Scott, G., Monteys, X., Facchin, L., Romeo, R. & Coxon, P. 2015: Ice sheet extension to the Celtic Sea shelf edge at the Last Glacial Maximum. *Quaternary Science Reviews* 111, 107–112.
- Prest, V. K., Grant, D. R. & Rampton, V. N. 1968: *Glacial map of Canada*. Geological Survey of Canada, “A” Series Map 1253A.



- Sale, C. 1970: *Cirque distribution in Great Britain: a statistical analysis of variations in elevation, aspect and density*. M.Sc. dissertation, University College London, 123 pp.
- Salt, K. E. & Evans, D. J. A. 2004: Superimposed subglacially streamlined landforms of southwest Scotland. *Scottish Geographical Journal* 120, 133–147.
- Sejrup, H. P., Clark, C. D. & Hjelstuen, B. O. 2016: Rapid ice sheet retreat triggered by ice stream debuttressing: evidence from the North Sea. *Geology* 44, 355–358.
- Small, D., Clark, C. D., Chiverrell, R. C., Smedley, R. K., Bateman, M. D., Duller, G. A. T., Ely, J. C., Fabel, D., Medialdea, A. & Moreton, S. G. 2017: Devising quality assurance procedures for assessment of legacy geochronological data relating to deglaciation of the last British-Irish Ice Sheet. *Earth Science Reviews* 164, 232–250.
- Spagnolo, M., Clark, C. D., Ely, J. C., Stokes, C. R., Anderson, J. B., Andreassen, K., Graham, A. G. C. & King, E. C. 2014: Size, shape and spatial arrangement of mega-scale glacial lineations from a large and diverse dataset. *Earth Surface Processes and Landforms* 39, 1432–1448.
- Stoker, M. & Bradwell, T. 2005: The Minch palaeo-ice stream, NW sector of the British-Irish Ice Sheet. *Journal of the Geological Society of London* 162, 425–428.
- The Royal Society Science Policy Centre Report 2012: *Science as an open enterprise*. Issued: June 2012 DES24782. ISBN: 978-0-85403-962-3. © The Royal Society, 2012, 105 pp.
- Thébaudeau, B., Monteys, X., McCarron, S., O'Toole, R. & Caloca, S. 2015: Seabed geomorphology of the Porcupine Bank, West of Ireland. *Journal of Maps* 12, 1–11.
- Turner, A. J., Woodward, J., Stokes, C. R., Ó Cofaigh, C. & Dunning, S. 2014: Glacial geomorphology of the Great Glen Region of Scotland. *Journal of Maps* 10, 159–178.
- Valentin, H. 1958: Die Grenze der letzten Vereisung im Nordseeraum. *Deutscher Geographentag* 30, 359–366.
- Van Landeghem, K. J. J., Wheeler, A. J. & Mitchell, N. C. 2009: Seafloor evidence for palaeo-ice streaming and calving of the grounded Irish Sea Ice Stream: implications for the interpretation of its final deglaciation phase. *Boreas* 38, 119–131.
- Warren, W. P. & Ashley, G. M. 1994: Origins of the ice-contact stratified ridges (eskers) of Ireland. *Journal of Sedimentary Research* 64, 433–449.
- Woldstedt, P. 1958: *Das Eiszeitalter. Zweiter Band*. 438 pp. F. Enke Verlag, Stuttgart.

## Supporting Information

Additional Supporting Information may be found in the online version of this article at <http://www.boreas.dk>.

**Data S1.** Reference list for sources used to compile the database.

**Data S2.** Glacial Maps as PDFs: A. Cartographically generalized Glacial Map (poster) for viewing or printing at A0 paper size and scale of 1:1 250 000. B. Three full-resolution PDF maps: Ireland; England, Scotland & Wales; Northern Scotland and offshore.

**Data S3.** Esri GIS shapefiles of features stored as separate layers per theme (e.g. eskers).

## References in BRITICE V.2 database

- Agar, R. 1954: Glacial and post-glacial geology of Middlesbrough and the Tees estuary. *Proceedings of the Yorkshire Geological Society* 29, 237–253.
- Aitken, J. F. 1990: Glaciolacustrine deposits in Glen Nocht, Grampian Region, Scotland, UK. *Quaternary Newsletter* 60, 13–20.
- Aitkenhead, N., Bridge, D. M., Riley, N. J. & Kimbell, S. F. 1991: *Geology of the country around Garstang*. 120 pp. Memoir of the British Geological Survey. HMSO, London.
- Akhurst, M. C., Chadwick, R. A., Holliday, D. W., McCormac, M., McMillan, A. A., Millward, D. & Young, B. 1997. *Geology of the west Cumbria district*. 138 pp. British Geological Survey. HMSO, London.
- Anderson, J. G. C. & Owen, T. R. 1979: The late Quaternary history of the Neath and Afan Valleys, South Wales. *Proceedings of the Geologists' Association* 90, 203–211.
- Andrews, I. J., Long, D., Richards, P. C., Brown, S., Chester, J. A. & McCormac, M. 1990: *UK Offshore Regional Report: The Geology of the Moray Firth*. 96 pp. British Geological Survey. HMSO, London.
- Armstrong, M., Paterson, I. B., Browne, M. A. E., Brand, P. J., Chisholm, J. I., Harris, A. L. & Stephens, D. 1985: *Geology of the Perth and Dundee District*. 108 pp. Memoir of the British Geological Survey. HMSO, London.
- Arthurton, R. S. & Wadge, A. J. 1981: *Geology of the Country around Penrith*. 177 pp. Memoir of the British Geological Survey. HMSO, London.
- Arthurton, R. S., Johnson, E. W. & Mundy, D. J. C. 1988: *Geology of the Country around Settle*. 147 pp. Memoir of the British Geological Survey. HMSO, London.
- Ballantyne, C. K. 1988: Ice-Sheet Moraines in Southern Skye. *Scottish Journal of Geology* 24, 301–304.
- Ballantyne, C. K. 1990: The late Quaternary history of the Trotternish Escarpment, Isle of Skye Scotland and its implications for ice sheet reconstruction. *Proceedings of the Geologists' Association* 101, 171–186.
- Ballantyne, C. K. 1999: Maximum altitude of Late Devensian glaciation on the Isle of Mull and Isle of Jura. *Scottish Journal of Geology* 35, 97–106.
- Ballantyne, C. K. & Hall, A. M. 2008: The altitude of the last ice sheet in Caithness and east Sutherland, northern Scotland. *Scottish Journal of Geology* 44, 169–181.
- Ballantyne, C. K. & Hallam, G. E. 2001: Maximum altitude of Late Devensian glaciation on South Uist, Outer Hebrides, Scotland. *Proceedings of the Geologists' Association* 112, 155–167.
- Ballantyne, C. K. & McCarroll, D. 1995: The vertical dimensions of Late Devensian glaciation on the mountains of Harris and southeast Lewis, Outer Hebrides, Scotland. *Journal of Quaternary Science* 10, 211–223.
- Ballantyne, C. K. & McCarroll, D. 1997: Maximum altitude of the Late Devensian ice sheet on the Isle of Rum. *Scottish Journal of Geology* 33, 183–186.
- Ballantyne, C. K. & Stone, J. O. 2012: Did large ice caps persist on low ground in north-west Scotland during the Lateglacial Interstade? *Journal of Quaternary Science* 27, 297–306.
- Ballantyne, C. K., Hall, A. M., Phillips, W., Binnie, S. & Kubik, P. W. 2007a: Age and significance of former low-altitude corrie glaciers on Hoy, Orkney Islands. *Scottish Journal of Geology* 43, 107–114.
- Ballantyne, C. K., McCarroll, D., Nesje, A. & Dahl, S. O. 1997: Periglacial trimlines, former nunataks and the altitude of the last ice sheet in Wester Ross, northwest Scotland. *Journal of Quaternary Science* 12, 225–238.
- Ballantyne, C. K., McCarroll, D., Nesje, A., Dahl, S. O. & Stone, J. O. 1998: The last ice sheet in north-west Scotland: Reconstruction and implications. *Quaternary Science Reviews* 17, 1149–1184.
- Ballantyne, C. K., McCarroll, D. & Stone, J. O. 2006: Vertical dimensions and age of the Wicklow Mountains ice dome, Eastern Ireland, and implications for the extent of the last Irish ice sheet. *Quaternary Science Reviews* 25, 2048–2058.
- Ballantyne, C. K., McCarroll, D. & Stone, J. O. 2007b: The Donegal ice dome, northwest Ireland: Dimensions and chronology. *Journal of Quaternary Science* 22, 773–783.
- Ballantyne, C. K., McCarroll, D. & Stone, J. O. 2011: Periglacial trimlines and the extent of the Kerry-Cork Ice Cap, SW Ireland. *Quaternary Science Reviews* 30, 3834–3845.
- Ballantyne, C. K., Rinterknecht, V. & Gheorghiu, D. M. 2013: Deglaciation chronology of the Galloway Hills ice centre, southwest Scotland. *Journal of Quaternary Science* 28, 412–420.
- Ballantyne, C. K., Schnabel, C. & Xu, S. 2009: Readvance of the last British-Irish ice sheet during Greenland interstade 1 (GI-1): The Wester Ross readvance, NW Scotland. *Quaternary Science Reviews* 28, 783–789.
- Balson, S. & Jeffery, D. H. 1991: The glacial sequence of the southern North Sea. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 245–254. Balkema, Rotterdam.
- Benetti, S., Dunlop, P. & Ó Cofaigh, C. 2010: Glacial and glacially-related features on the continental margin of northwest Ireland mapped from marine geophysical data. *Journal of Maps* 6, 14–29.
- Bennett, M. R. & Boulton, G. S. B. 1993: Deglaciation of the Younger Dryas or Loch Lomond Stadial icefield in the northern Highlands, Scotland. *Journal of Quaternary Science* 8, 133–145.
- Boardman, J. 1991: Glacial deposits of the English Lake District. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 175–183. Balkema, Rotterdam.
- Boulton, G. S., Jones, A. S., Clayton, K. M. & Kenning, M. J. 1977: A British ice-sheet model and patterns of glacial erosion and deposition in Britain. In Shotton, F. W. (ed.): *British Quaternary Studies, Recent Advances*, 231–246. Clarendon Press, Oxford.
- Bowen, D. Q. 1970: South-east and central South Wales. In Lewis, C. A. (ed.): *The Glaciations of Wales and Adjoining Regions*, 197–227. Longman, London.
- Bowen, D. Q. 1982: Pleistocene deposits and fluvio-glacial landforms of north Preseli. In Bassett, M. G. (ed.): *Geological Excursions in Dyfed, South-West Wales*, 289–295. National Museum of Wales, Cardiff.
- Bradwell, T. 2005: Bedrock megagrooves in Assynt, NW Scotland. *Geomorphology* 65, 195–204.
- Bradwell, T. 2013: Identifying palaeo-ice-stream tributaries on hard beds: Mapping glacial bedforms and erosion zones in NW Scotland. *Geomorphology* 201, 397–414.
- Bradwell, T. & Stoker, M. S. 2015a: Submarine sediment and landform record of a palaeo-ice stream within the British–Irish Ice Sheet. *Boreas* 44, 255–276.
- Bradwell, T. & Stoker, M. 2015b: Asymmetric ice-sheet retreat pattern around northern Scotland revealed by marine geophysical surveys. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 105, 297–322.
- Bradwell, T., Fabel, D., Stoker, M., Mathers, H., McHargue, L. & Howe, J. 2008: Ice caps existed throughout the Lateglacial Interstade in northern Scotland. *Journal of Quaternary Science* 23, 401–407.
- Bradwell, T., Stoker, M. S., Golledge, N. R., Wilson, C. K., Merritt, J. W., Long, D., Everest, J. D., Hestvik, O. B., Stevenson, A. G., Hubbard, A. L. & Finlayson, A. G. 2008: The northern sector of the last British Ice Sheet: Maximum extent and demise. *Earth-Science Reviews* 88, 207–226.
- Bradwell, T., Stoker, M. & Krabbendam, M. 2008: Megagrooves and streamlined bedrock in NW Scotland: the role of ice streams in landscape evolution. *Geomorphology* 97, 135–156.
- Bradwell, T., Stoker, M. & Larter, R. 2007: Geomorphological signature and flow dynamics of The Minch palaeo-ice stream, northwest Scotland. *Journal of Quaternary Science* 22, 609–617.
- Brandon, A. 1989: *Geology of the Country between Hereford and Leominster*. 62 pp. Memoir of the British Geological Survey. HMSO, London.
- Brandon, A., Aitkenhead, N., Crofts, R. G., Ellison, R. A., Evans, D. J. & Riley, N. J. 1998: *Geology of the Country around Lancaster*. 181 pp. Memoir of the British Geological Survey. HMSO, London.
- Brazier, V., Gordon, J. E., Kirkbride, M. P. & Sugden, D. E. 1996: The late Devensian ice sheet and glaciers in the Cairngorm Mountains. In Glasser, N. F. & Bennett, M. R. (eds.): *The Quaternary of the Cairngorms, Field Guide*, 28–53. Quaternary Research Association, London.
- Brazier, V., Kirkbride, M. P. & Gordon, J. E. 1998: Active ice-sheet deglaciation and ice-dammed lakes in the northern Cairngorm Mountains, Scotland. *Boreas* 27, 297–310.

- Brooks, A. J., Bradley, S. L., Edwards, R. J., Milne, G. A., Horton, B. & Shennan, I. 2008: Postglacial relative sea-level observations from Ireland and their role in glacial rebound modelling. *Journal of Quaternary Science* 23, 175–192.
- Brown, I. M. 1993: Pattern of Deglaciation of the Last (Late Devensian) Scottish Ice-Sheet - Evidence From Ice-Marginal Deposits in the Dee Valley, Northeast Scotland. *Journal of Quaternary Science* 8, 235–250.
- Brown, E. H. & Cooke, R. U. 1977: Landforms and related glacial deposits in the Wheeler Valley area, Clwyd. *Cambria* 4, 32–45.
- Bryant, R. H. 1977: Bantry to Waterville. In Lewis, C. A. (ed.): *South and South West Ireland: INQUA 1977 Guidebook for Excursion A15*, 23–29. Geo Abstracts, Norwich, UK.
- Burgess, I. C. & Holliday, D. W. 1979: *Geology for the Country around Brough-under-Stainmore*. 131 pp. Memoir of the British Geological Survey. HMSO, London.
- Burgess, I. C. & Holliday, D. W. 1987: *Geology of the Country around Brough-under-Stainmore*. 131 pp. Memoir of the British Geological Survey. HMSO, London.
- Cameron, I. B., Aitken, A. M., Browne, M. A. E. & Stephenson, D. 1998: *Geology of the Falkirk District*. 106 pp. Memoir of the British Geological Survey. HMSO, London.
- Cameron, T. D. J., Crosby, A., Balson, P. S., Jeffrey, D. H., Lott, G. K., Bulat, J. & Harrison, D. J. 1992: *UK Offshore Regional Report: The Geology of the Southern North Sea*. 152 pp. British Geological Survey, HMSO, London.
- Catt, J. A. 1991a: Late Devensian glacial deposits and glaciations in eastern England and the adjoining offshore region. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 61–68. Balkema, Rotterdam.
- Catt, J. A. 1991b: The Quaternary history and glacial deposits of East Yorkshire. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 185–191. Balkema, Rotterdam.
- Charlesworth, J. K. 1924: The glacial geology of north-west Ireland. *Proceedings of the Royal Irish Academy* 36B, 174–314.
- Charlesworth, J. K. 1926a: The glacial geology of the Southern Uplands of Scotland, west of Annandale and upper Clydesdale. *Transactions of the Royal Society of Edinburgh* 60, 1–23.
- Charlesworth, J. K. 1926b: The readvance, marginal kame-moraine of the South of Scotland, and some later stages of retreat. *Transactions of the Royal Society of Edinburgh* 55, 25–50.
- Charlesworth, J. K. 1928a: The glacial geology of North Mayo and West Sligo. *Proceedings of the Royal Irish Academy* 38, 100–115.
- Charlesworth, J. K. 1928b: The glacial retreat from central and southern Ireland. *Quarterly Journal of the Geological Society* 84, 293–344.
- Charlesworth, J. K. 1929a: The South Wales end moraine. *Quarterly Journal of the Geological Society of London* 85, 335–355.
- Charlesworth, J. K. 1929b: The Glacial Retreat from Central and Southern Ireland. *Proceedings of the Royal Irish Academy* 39B, 95–106.
- Charlesworth, J. K. 1939: Some observations on the glaciation of north-east Ireland. *Proceedings of the Royal Irish Academy* 45B, 255–295.
- Charlesworth, J. K. 1953: *The Geology of Ireland*. 276 pp. Oliver and Boyd, Edinburgh.
- Charlesworth, J. K. 1957: *The Quaternary Era*. 1700 pp. Arnold, London.
- Clapperton, C. M. 1970: The evidence for a Cheviot ice cap. *Transactions of the Institute of British Geographers* 29, 31–45.
- Clapperton, C. M. 1971a: The location and origin of glacial meltwater phenomena in the eastern Cheviot Hills. *Proceedings of the Yorkshire Geological Society* 38, 361–380.
- Clapperton, C. M. 1971b: The pattern of deglaciation in part of north Northumberland. *Transactions of the Institute of British Geographers* 53, 67–78.
- Clapperton, C. M. & Sudgen, D. E. 1975: The glaciation of Buchan: a reappraisal. In Gemmell, A. M. D. (ed.): *Quaternary studies in North East Scotland*, 19–22. University of Aberdeen/Quaternary Research Association, Aberdeen.
- Clarhäll, A. & Kleman, J. 1999: Distribution and glaciological implications of relict surfaces on the Ultevis plateau, northwestern Sweden. *Annals of Glaciology* 28, 202–208.
- Clark, C. D. & Meehan, R. T. 2001: Subglacial bedform geomorphology of the Irish Ice Sheet reveals major configuration changes during growth and decay. *Journal of Quaternary Science* 16, 483–496.
- Clark, R. & Wilson, P. 1994: Valley moraines in Borrowdale. In Boardman, J. & Walden, J. (eds.): *The Quaternary of Cumbria*, 153–156. Quaternary Research Association, Oxford.
- Clark, C. D., Evans, D. J., Khatwa, A., Bradwell, T., Jordan, C. J., Marsh, S. H., Mitchell, W. A. & Bateman, M. D. 2004: Map and GIS database of glacial landforms and features related to the last British Ice Sheet. *Boreas* 33, 359–375.
- Clark, C. D., Hughes, A. L. C., Greenwood, S. L., Jordan, C. & Sejrup, H. P. 2012: Pattern and timing of retreat of the last British-Irish Ice Sheet. *Quaternary Science Reviews* 44, 112–146.
- Clark, C. D., Hughes, A. L. C., Greenwood, S. L., Spagnolo, M. & Ng, F. S. 2009: Size and shape characteristics of drumlins, derived from a large sample, and associated scaling laws. *Quaternary Science Reviews* 28, 677–692.
- Colhoun, E. A. 1970: On the nature of the glaciation and final deglaciation of the Sperrin Mountains and adjacent areas in the North of Ireland. *Irish Geography* 6, 162–185.
- Colhoun, E. A. 1971: The glacial stratigraphy of the Sperrin Mountains and its relation to the glacial stratigraphy of north-west Ireland. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science*, 71, 37–52.
- Colhoun, E. A., Dickson, J. H., McCabe, A. M. & Shotton, F. W. 1972: A Middle Midlandian freshwater series at Derryvree, Maguires-bridge, County Fermanagh, Northern Ireland. *Proceedings of the Royal Society of London B180*, 273–292.
- Connell, E. R. & Hall, A. M. 1987: The periglacial history of Buchan, north-east Scotland. In Boardman, J. (ed.): *Periglacial Processes and Landforms in Britain and Ireland*, 277–285. Cambridge University Press, Cambridge.
- Cooper, A. H. & Burgess, I. C. 1993: *Geology for the Country around Harrogate*. 105 pp. Memoir of the British Geological Survey. HMSO, London.
- Crimes, T. P., Chester, D. K., Hunt, N. C., Lucas, G. R., Mussett, A. E., Thomas, G. S. P. & Thompson, A. 1994: Techniques used in aggregate resource analyses of four areas in the UK. *Quarterly Journal of Engineering Geology* 27, 165–192.
- Crofts, R. G. 2005: *Quaternary of the Rossendale Forest and Greater Manchester Field Guide*. 70 pp. Quaternary Research Association, London.
- Cross, P. & Hodgson, J. M. 1975: New evidence for the glacial diversion of the River Teme near Ludlow, Salop. *Proceedings of the Geologists' Association* 86, 313–331.
- Cullen, C. 2012: *Deciphering the geomorphic and sedimentary record of the last Irish Ice Sheet in NW Donegal, Ireland: implications for glacial dynamics and decay configurations*. Ph.D. thesis, National University of Ireland, Galway, 434 pp.
- Dahl, S. O., Ballantyne, C. K., McCarroll, D. & Nesje, A. 1996: Maximum altitude of Devensian glaciation on the Isle of Skye. *Scottish Journal of Geology* 32, 107–115.
- Davies, J. R. 1997: *Geology of the Country around Llanilar and Rhayader*. 279 pp. Memoir of the British Geological Survey. HMSO, London.
- Davies, A., McAdam, A. D., Cameron, I. B., Elliot, R. W., Graham, D. K., Strachan, I. & Wilson, R. B. 1986: *Geology of the Dunbar District*. 69 pp. Memoir of the British Geological Survey. HMSO, London.
- Davison, S. 2004: *Reconstructing the Last Pleistocene (Late Devensian) Glaciation on the Continental Margin of Northwest Britain*. Ph.D. Thesis, University of Edinburgh, 311 pp.
- Dawson, A. G. 1982: Lateglacial Sea-Level Changes and Ice-Limits in Islay, Jura and Scarba, Scottish Inner Hebrides. *Scottish Journal of Geology* 18, 253–265.
- Day, J. B. W. 1970: *Geology of the Country around Bewcastle*. 357 pp. Memoir of the British Geological Survey. HMSO, London.
- Delaney, C., Crofts, R., Rhodes, E. & Jones, C. 2010: Evidence for former Glacial Lakes in the High Peaks and Rossendale Plateau areas, NW England. *EGU General Assembly Conference Abstracts* 12, 11084.
- Delany, C. 2001a: Esker formation and the nature of deglaciation: the Ballymahon Esker, Central Ireland. *North West Geography* 1, 23–33.

- Delany, C. 2001b: Morphology and sedimentology of the Rooskagh esker, Co. Roscommon. *Irish Journal of Earth Sciences* 19, 5–22.
- Delany, C. 2002: Sedimentology of a glaciofluvial landsystem, Lough Ree area, Central Ireland: implications of ice margin characteristics during Devensian deglaciation. *Sedimentary Geology* 149, 111–126.
- Douglas, T. 1991: Glacial deposits of Northumbria. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 169–174. Balkema, Rotterdam.
- Dunlop, P. 2004: *The characteristics of ribbed moraine and assessment of theories for their genesis*. Ph.D. thesis, University of Sheffield, 363 pp.
- Dunlop, P., Shannon, R., McCabe, A. M., Quinn, R. & Doyle, E. 2010: Marine geophysical evidence for ice sheet extension and recession on the Malin Shelf: New evidence for the western limits of the British Irish Ice Sheet. *Marine Geology* 276, 86–99.
- Earp, J. R. & Taylor, B. J. 1986: *Geology of the Country around Chester and Winsford*. 119 pp. Memoir of the British Geological Survey. HMSO, London.
- Eastwood, T., Hollingworth, S. E., Rose, W. C. C. & Trotter, F. M. 1968: *Geology of the Country around Cockermouth*. 326 pp. Memoir of the British Geological Survey. HMSO, London.
- Edwards, W. 1938: The glacial geology, in the geology of the country around Harrogate. *Proceedings of the Geologists' Association* 49, 333–343.
- Edwards, W., Mitchell, G. H. & Whitehead, T. H. 1950: *Geology of the District North and East of Leeds*. 93 pp. Memoirs of The British geological Survey. HMSO, London.
- Ehlers, J. & Wingfield, R. 1991: The extension of the Late Weichselian/Late Devensian ice sheets in the North Sea basin. *Journal of Quaternary Science* 6, 313–326.
- Ellis-Gruffydd, I. D. 1977: Late Devensian glaciation in the upper Usk basin. *Cambria* 4, 46–55.
- Embleton, C. 1964: Subglacial drainage and supposed ice-dammed lakes in north-east Wales. *Proceedings of the Geologists' Association* 75, 31–38.
- Embleton, C. 1970: North eastern Wales. In Lewis, C. A. (ed.): *The Glaciations of Wales and Adjoining Regions*, 59–82. Longman, London.
- Etienne, J. L., Jansson, K. N., Glasser, N. F., Hambrey, M. J., Davies, J. R., Waters, R. A., Maltman, A. J. & Wilby, P. R. 2006: Palaeoenvironmental interpretation of an ice-contact glacial lake succession: an example from the late Devensian of southwest Wales, UK. *Quaternary Science Reviews* 25, 739–762.
- Evans, D. J. A. (ed.) 2003: *The Quaternary of the Western Highland Boundary – Field Guide*. 227 pp. Quaternary Research Association, London.
- Evans, D. J. A. & Ó Cofaigh, C. 2003: Depositional evidence for marginal oscillations of the Irish Sea ice stream in southeast Ireland during the last glaciation. *Boreas* 32, 76–101.
- Evans, D. J. A. & Thomson, S. A. 2010: Glacial sediments and landforms of Holderness, eastern England: a glacial depositional model for the North Sea Lobe of the British-Irish Ice Sheet. *Earth-Science Reviews* 101, 47–189.
- Evans, D. J. A., Clark, C. D. & Mitchell, W. A. 2005: The last British Ice Sheet: A review of the evidence utilised in the compilation of the Glacial Map of Britain. *Earth-Science Reviews* 70, 253–312.
- Evans, D. J. A., Thomson, S. & Clark, C. D. 2001: The glacial history of east Yorkshire. In Bateman, M. D., Buckland, P. C., Frederick, C. D. & Whitehouse, N. J. (eds.): *The Quaternary of East Yorkshire and North Lincolnshire, Field Guide*, 1–12. Quaternary Research Association, London.
- Everest, J. & Kubik, P. 2006: The deglaciation of eastern Scotland: cosmogenic  $^{10}\text{Be}$  evidence for a Lateglacial stillstand. *Journal of Quaternary Science* 21, 95–104.
- Everest, J. D., Bradwell, T., Fogwill, C. J. & Kubik, P. W. 2006: Cosmogenic  $^{10}\text{Be}$  age constraints for the western Ross readvance moraine: insights into British Ice-Sheet behaviour. *Geografiska Annaler. Series A, Physical Geography* 88, 9–17.
- Everest, J., Bradwell, T. & Golledge, N. 2005: Subglacial landforms of the Tweed palaeo-ice stream. *The Scottish Geographical Magazine* 121, 163–173.
- Fairburn, W. A. & Bateman, M. D. 2016: A new multi-stage recession model for Proglacial Lake Humber during the retreat of the last British-Irish Ice Sheet. *Boreas* 45, 133–151.
- Farrington, A. 1936: The glaciation of the Bantry Bay district. *Scientific Proceedings of the Royal Dublin Society* 21, 345–361.
- Farrington, A. & Mitchell, G. F. 1951: The end moraine north of Flamborough Head. *Proceedings of the Geologists' Association* 62, 100–106.
- Finch, T. F. 1977: *Guidebook for Excursion C16: Western Ireland*. INQUA, Norwich.
- Finch, T. F. & Walsh, M. 1973: Drumlins of County Clare. *Proceedings of the Royal Irish Academy* 73B, 405–413.
- Finlayson, A. G. 2012: Ice dynamics and sediment movement: Last glacial cycle, Clyde basin, Scotland. *Journal of Glaciology* 58, 487–500.
- Finlayson, A. G. & Bradwell, T. 2008: Morphological characteristics, formation and glaciological significance of Rogen moraine in northern Scotland. *Geomorphology* 101, 607–617.
- Finlayson, A. G., Bradwell, T., Golledge, N. & Merritt, J. 2007: Morphology and significance of transverse ridges (De Geer Moraines) adjacent to the Moray Firth, NE Scotland. *Scottish Geographical Journal* 123, 257–270.
- Finlayson, A. G., Fabel, D., Bradwell, T. & Sugden, D. E. 2014: Growth and decay of a marine terminating sector of the last British-Irish Ice Sheet: a geomorphological reconstruction. *Quaternary Science Reviews* 83, 28–45.
- Finlayson, A. G., Merritt, J., Browne, M., McMillan, A. & Whitbread, K. 2010: Ice sheet advance, dynamics, and decay configurations: evidence from west central Scotland. *Quaternary Science Reviews* 29, 969–988.
- Fishwick, A. 1977: The Conway Basin. *Cambria* 4, 56–64.
- Flinn, D. 1978a: The glaciation of the Outer Hebrides. *Geological Journal* 13, 195–199.
- Flinn, D. 1978b: The most recent glaciation of the Orkney-Shetland Channel and adjacent areas. *Scottish Journal of Geology* 14, 109–123.
- Flinn, D. 1983: Glacial Meltwater Channels in the Northern Isles of Shetland. *Scottish Journal of Geology* 19, 311–320.
- Flint, R. F. 1930: The origin of the Irish “eskers”. *Geographical Review* 20, 615–630.
- Floyd, J. D. 1999: *Geology of the Carrick-Loch Doon District*. 122 pp. Memoir of the British Geological Survey. HMSO, London.
- Forsythe, I. H., Hall, I. H. S. & MacMillan, A. A. 1996: *Geology of the Airdrie District*. 94 pp. Memoir of the British Geological Survey. HMSO, London.
- Foster, H. D. 1970: Sarn Badrig, a sub-moraine in Cardigan Bay, north Wales. *Zeitschrift für Geomorphologie* 14, 475–486.
- Foster, S. W. 1985: *The Late Glacial and Post Glacial History of the Vale of Pickering and Northern Yorkshire Wolds*. Ph.D. thesis, University of Hull, 123 pp.
- Foster, S. D., Morigi, A. N. & Browne, M. A. E. 1999: *Quaternary Geology – Towards Meeting User Requirements*. 123 pp. British Geological Survey, Keyworth, Nottingham.
- Francis, E. H., Forsyth, I. H., Read, A., W. A., M., Dawson, J., Elliot, R. W., Harris, A. L., McQuillin, R., Taylor, J. & Wilson, R. B. 1970: *Geology of the Stirling District*. 357 pp. Memoir of the British Geological Survey. HMSO, London.
- Frost, D. V. 1998: *Geology of the Country around Northallerton*. 109 pp. Memoir of the British Geological Survey. HMSO, London.
- Frost, D. V. & Holliday, D. W. 1980: *The Geology of the Country around Bellingham*. 124 pp. Memoir of the British Geological Survey. HMSO, London.
- Fyfe, J. A., Long, D. & Evans, D. 1993: *UK Offshore Regional Report: The Geology of the Mulin-Hebrides Sea area*. 91 pp. British Geological Survey, London.
- Gallagher, C., Sutton, G. & Bell, T. 2004: Submerged ice marginal forms in the Celtic Sea off Waterford Harbour, Ireland. *Irish Geography* 37, 145–165.
- Gallagher, C., Thorp, M. & Steenson, P. 1996: Glacier dynamics around Slieve Bloom, central Ireland. *Irish Geography* 29, 67–82.
- Garrard, R. A. & Dobson, M. R. 1974: The nature and maximum extent of glacial sediments off the west coast of Wales. *Marine Geology* 16, 31–44.



- Gaunt, G. D. 1976: The Devensian maximum ice limit in the Vale of York. *Proceedings of the Yorkshire Geological Society* 40, 631–637.
- Gaunt, G. D. 1994: Geology of the Country around Goole, Doncaster and the Isle of Axholme 169 pp. Memoir of the British Geological Survey. HMSO, London.
- Gaunt, G. D., Fletcher, T. P. & Wood, C. J. 1992: *Geology of the Country around Kingston upon Hull and Brigg* 172 pp. Memoir of the British Geological Survey. HMSO, London.
- Geikie, A., Geikie, J. & Peach, B. N. 1869: *Explanation of Sheet 14: Ayrshire, Southern District* 27 pp. Memoir of the British Geological Survey. HMSO, Edinburgh.
- Gemmell, A. M. D. & George, P. K. 1972: The glaciation of the west Midlands: a review of recent research. *North Staffordshire Journal of Field Studies* 12, 1–20.
- George, T. N. 1970: *British Regional Geology. South Wales* (3rd edition). 100 pp. British Geological Survey. HMSO, London.
- Gibbons, W. & McCarroll, D. 1993: *Geology of the Country around Aberdaron and Bardsey Island*. 88 pp. Memoir of the British Geological Survey. HMSO, London.
- Gibson, P. J. 1993: Geological and Geomorphological Applications of Low-Angle Illumination Satellite Imagery in Northern Ireland. *Irish Geography* 26, 58–64.
- Glasser, N. F. & Smith, G. S. 1999: Glacial meltwater erosion of the Mid-Cheshire Ridge: implications for ice dynamics during the Late Devensian glaciation of northwest England. *Journal of Quaternary Science* 14, 703–710.
- Glasser, N. F., Etienne, J. L., Hambery, M. J., Davies, J. R., Waters, R. A. & Wilby, P. R. 2004: Glacial meltwater erosion and sedimentation as evidence for multiple glaciations in west Wales. *Boreas* 33, 224–237.
- Golledge, N. R. 2002: Glaci-tectonic deformation of proglacial lake sediments in the Cairngorm Mountains. *Scottish Journal of Geology* 38, 127–136.
- Golledge, N. R. 2007: An ice cap landsystem for palaeoglaciological reconstructions: characterizing the Younger Dryas in western Scotland. *Quaternary Science Reviews* 26, 213–229.
- Golledge, N. R. & Hubbard, A. 2005: Evaluating Younger Dryas glacier reconstructions in part of the western Scottish Highlands: a combined empirical and theoretical approach. *Boreas* 34, 274–286.
- Golledge, N. R. & Phillips, E. 2008: Sedimentology and architecture of De Geer moraines in the western Scottish Highlands, and implications for grounding-line glacier dynamics. *Sedimentary Geology* 208, 1–14.
- Golledge, N. R. & Stoker, M. S. 2006: A palaeo-ice stream of the British Ice Sheet in eastern Scotland. *Boreas* 35, 231–243.
- Golledge, N. R., Finlayson, A. G., Bradwell, T. & Everest, J. D. 2008: The last glaciation of Shetland, north Atlantic. *Geografiska Annaler. Series A, Physical Geography* 90, 37–53.
- Goodchild, J. C. 1875: The glacial phenomena of the Eden Valley and the Western part of the Yorkshire Dale district. *Quarterly Journal of the Geological Society of London* 31, 55–99.
- Gordon, J. E. 1993a: The glaciation of Caithness. In Gordon, J. E. & Sutherland, D. G. (eds.): *Quaternary of Scotland*, 87–91. Chapman and Hall, London.
- Gordon, J. E. 1993b: Littlemill. In Gordon, J. E. & Sutherland, D. G. (eds.): *Quaternary of Scotland*, 181–184. Chapman and Hall, London.
- Gordon, J. E. 1993c: Carstairs kames. In Gordon, J. E. & Sutherland, D. G. (eds.): *Quaternary of Scotland*, 544–549. Chapman and Hall, London.
- Gordon, J. E. & Auton, C. A. 1993: The Kildrummie kames. In Gordon, J. E. & Sutherland, D. G. (eds.): *Quaternary of Scotland*, 176–181. Chapman and Hall, London.
- Graham, A. G. C., Lonergan, L. & Stoker, M. S. 2007: Evidence for Late Pleistocene ice stream activity in the Witch Ground Basin, central North Sea, from 3D seismic reflection data. *Quaternary Science Reviews* 26, 627–643.
- Graham, C., Stewart, H. A., Poulton, C. V. L. & James, J. W. C. 2001: A description of offshore gravel areas around the UK. *British Geological Survey Commissioned Report CR01/259*, 30 pp.
- Greenwood, S. L. 2008: *A palaeo-glaciological reconstruction of the last Irish Ice Sheet*. Ph.D. thesis, University of Sheffield, 360 pp.
- Greenwood, S. L. & Clark, C. D. 2008: Subglacial bedforms of the Irish ice sheet. *Journal of Maps* 4, 332–357.
- Greenwood, S. L. & Clark, C. D. 2009a: Reconstructing the last Irish Ice Sheet 1: changing flow geometries and ice flow dynamics deciphered from the glacial landform record. *Quaternary Science Reviews* 28, 3085–3100.
- Greenwood, S. L. & Clark, C. D. 2009b: Reconstructing the last Irish Ice Sheet 2: a geomorphologically-driven model of ice sheet growth, retreat and dynamics. *Quaternary Science Reviews* 28, 3101–3123.
- Greenwood, S. L. & Clark, C. D. 2010: The sensitivity of subglacial bedform size and distribution to substrate lithological control. *Sedimentary Geology* 232, 130–144.
- Gregory, J. W. 1920: The Irish Eskers. *Philosophical Transactions of the Royal Society of London B* 210, 115–151.
- Gresswell, R. K. 1952: The glacial geomorphology of the southern part of the Lake District. *Liverpool and Manchester Geological Journal* 1, 57–70.
- Gresswell, R. K. 1967: The geomorphology of Fylde. In Steel, R. W. & Lawton, R. (eds.): *Liverpool Essays in Geography*, 25–42. University of Liverpool, London.
- Grieg, D. C., Wright, J. E., Hains, B. A. & Mitchell, G. H. 1967: *Geology of the Country around Church Stretton, Craven Arms, Wenlock Edge and Brown Clee*. 379 pp. Memoir of the British Geological Survey. HMSO, London.
- Hall, A. M. 2013: The last glaciation of Shetland: local ice cap or invasive ice sheet? *Norwegian Journal of Geology* 93, 229–242.
- Hall, A. M. & Bent, A. J. A. 1990: The limits of the last British ice sheet in northern Scotland and the adjacent shelf. *Quaternary Newsletter* 61, 2–12.
- Hall, A. M. & Glasser, N. F. 2003: Reconstructing the basal thermal regime of an ice stream in a landscape of selective linear erosion: Glen Avon, Cairngorm Mountains, Scotland. *Boreas* 32, 191–207.
- Hall, A. M., Auton, C. A., Michie, U. M., Pearson, S. G. & Riding, J. B. 2011: Switching flow patterns within the last ice sheet in northern Scotland. *Scottish Journal of Geology* 47, 157–167.
- Hall, I. H. S., Browne, M. A. E. & Forsyth, I. H. 1998: *Geology of the Glasgow District*. 117 pp. Memoir of the British Geological Survey. HMSO, London.
- Hambrey, M. J., Davies, J. R., Glasser, N. F., Waters, R. A., Dowdeswell, J. A., Wilby, P. R., Wilson, D. & Etienne, J. L. 2001: Devensian glacial sedimentation and landscape evolution in the Cardigan area of southwest Wales. *Journal of Quaternary Science* 16, 455–482.
- Harmer, F. W. 1928: The distribution of erratics and drift. *Proceedings of the Yorkshire Geological Society* 21, 79–150.
- Harrod, T. R. 1972: *An investigation of major events in the geomorphological evolution of south and central Kesteven*. Ph.D. thesis, University of Sheffield, 350 pp.
- Hegarty, S. 2002a: *Pathways and processes of Late Pleistocene subglacial meltwater flows, County Kilkenny*. Ph.D. thesis. University College Dublin, 377 pp.
- Hegarty, S. 2002b: The Quaternary of Kilkenny. *Irish Quaternary Association Field Guide No 24*, 52 pp. Irish Quaternary Association, Dublin.
- Hiemstra, J. F., Evans, D. J. A., Scourse, J. D., McCarroll, D., Furze, M. F. & Rhodes, E. 2006: New evidence for a grounded Irish Sea glaciation of the Isles of Scilly, UK. *Quaternary Science Reviews* 25, 299–309.
- Hiemstra, J. F., Shakesby, R. A. & Vieli, A. 2015: Late Quaternary glaciation in the Hebrides sector of the continental shelf: was St Kilda overrun by the British-Irish Ice Sheet? *Boreas* 44, 178–196.
- Hill, A. R. 1973: The distribution of drumlins in County Down, Ireland. *Annals of the Association of American Geographers* 63, 226–240.
- Holden, W. G. 1977: *The glaciation of central Ayrshire*. Ph.D. thesis, University of Glasgow, 486 pp.
- Hollingsworth, S. E. 1931: Glaciation of western Edenside and adjoining areas and the drumlins of the Edenside and Solway Basin. *Quarterly Journal of the Geological Society of London* 87, 281–359.
- Howarth, J. H. 1908a: The ice-borne boulders of Yorkshire. *The Naturalist March*, 97–109.
- Howarth, J. H. 1908b: The ice-borne boulders of Yorkshire. *The Naturalist April*, 143–146.

- Howarth, J. H. 1908c: The ice-borne boulders of Yorkshire. *The Naturalist June*, 219–224.
- Howarth, J. H. 1908d: The ice-borne boulders of Yorkshire. *The Naturalist July*, 245–252.
- Howe, J. A., Anderton, R., Arosio, R., Dove, D., Bradwell, T., Crump, P., Cooper, R. & Cocuccio, A. 2015: The seabed geomorphology and geological structure of the Firth of Lorn, western Scotland, UK, as revealed by multibeam echo-sounder survey. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 105, 273–284.
- Huddart, D. 1991: The glacial history and glacial deposits of the north and west Cumbrian lowlands. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial Deposits in Great Britain and Ireland*, 151–167. Balkema, Rotterdam.
- Huddart, D. 1999: Supraglacial trough fills, southern Scotland: origins and implications for deglacial processes. *Glacial Geology and Geomorphology*, electronic journal (<http://boris.qub.ac.uk/ggg>), Queens University, Belfast.
- Huddart, D. & Bennett, M. R. 1997: The Carstairs Kames (Lanarkshire, Scotland): morphology, sedimentology and formation. *Journal of Quaternary Science* 12, 467–484.
- Hughes, A. L. C. 2009: *The last British Ice Sheet: a reconstruction based on glacial landforms*. Ph.D. thesis, University of Sheffield, 297 pp.
- Hughes, A. L. C., Clark, C. D. & Jordan, C. J. 2010: Subglacial bedforms of the last British Ice Sheet. *Journal of Maps* 6, 543–563.
- Jansson, K. N. & Glasser, N. F. 2008: Modification of peripheral mountain ranges by former ice sheets: The Brecon Beacons, Southern UK. *Geomorphology* 97, 178–189.
- Johnson, R. H. 1965a: Glacial geomorphology of the west Pennine slopes between Cliviger and Congleton. In Whittow, J. B. & Wood, P. D. (eds.): *Essays in Geography for A.A. Miller*, 58–94. Reading University Press, Reading.
- Johnson, R. H. 1965b: The origin of the Churnet and Rudyard Valleys. *North Staffordshire Journal of Field Studies* 5, 95–105.
- Johnson, H., Richards, P. C., Long, D. & Graham, C. C. 1993: *UK Offshore Regional Report: The Geology of the Northern North Sea*. 110 pp. British Geological Survey, HMSO, London.
- Jordan, C. J. 1997: Quaternary geology mapping in the Republic of Ireland - how much can be achieved through satellite remote sensing? *Twelfth International Conference and Workshops on Applied Geologic Remote Sensing*, Vol. 2. Denver, Colorado, 33–44.
- Jordan, C. J. 2002: *An holistic approach to mapping the Quaternary Geology and reconstructing the last glaciation of West County Mayo, Ireland, using satellite remote sensing and 'conventional' mapping techniques*. Ph.D. thesis. Queen Mary, University of London, 311 pp.
- Jowett, A. 1914: The glacial geology of East Lancashire. *Quarterly Journal of the Geological Society of London* 70, 199–231.
- Jowett, A. & Charlesworth, J. K. 1929: The glacial geology of the Derbyshire Dome and western slopes of the southern Pennines. *Journal of the Geological Society of London* 85, 307–334.
- Kendall, P. F. 1902: Glacier-lakes in the Cleveland Hills. *Quarterly Journal of the Geological Society*, lviii, 471–571.
- Kendall, P. F. 1903: The glacier Lakes of Cleveland. *Proceedings of the Yorkshire Geological Society* 15, 1–40.
- Kilfeather, A. A. 2004: *Glaciation, deformation and till porosity: County Laois, Ireland*. Ph.D. thesis. Queen Mary, University of London, 123 pp.
- Kinahan, G. H. 1883: Notes on the Cervus Megaceros. *Transactions of the Edinburgh Geological Society* 4, 343–345.
- King, C. A. M. & Gage, M. 1961: Note on the extent of glaciation in part of West Kerry. *Irish Geography* 4, 202–208.
- Knight, J. 1997: Morphological and morphometric analyses of drumlin bedforms in the Omagh Basin, north central Ireland. *Geografiska Annaler* 79A, 255–266.
- Knight, J. 1999: Problems of Irish drumlins and Late Devensian ice sheet reconstructions. *Proceedings of the Geologists' Association* 110, 9–16.
- Knight, J. 2002: Bedform Patterns, subglacial meltwater events, and Late Devensian ice sheet dynamics in north-central Ireland. *Global Planetary Change* 35, 237–253.
- Knight, J. 2003a: Geomorphic and sedimentary evidence for patterns of late Midlandian ice retreat in the Tempo Valley, north-central Ireland. *Global and Planetary Change* 35, 237–253.
- Knight, J. 2003b: Geomorphic evidence for patterns of late Midlandian ice advance and retreat in the Omagh Basin. *Irish Geography* 36, 1–22.
- Knight, J. 2006: Geomorphic evidence for active and inactive phases of Late Devensian ice in north-central Ireland. *Geomorphology* 75, 4–19.
- Knight, J., McCarron, S. G. & McCabe, A. M. 1999: Landform modification by palaeo-ice streams in east-central Ireland. *Annals of Glaciology* 28, 161–167.
- Knowles, A. 1985: The Quaternary history of north Staffordshire. In Johnson, R. H. (ed.): *The Geomorphology of North West England*, 222–236. Manchester University Press, Manchester.
- Lamb, A. L. & Ballantyne, C. K. 1998: Paleonunataks and the altitude of the last ice sheet in the south-west Lake District, England. *Proceedings of the Geologists' Association* 109, 305–316.
- Lawson, T. J. 1995: Boulder trains as indicators of former ice flow in Assynt, NW Scotland. *Quaternary Newsletter* 75, 15–21.
- Letzer, J. M. 1978: *The Glacial Geomorphology of the region bounded by Shap Fells, Stainmore, and the Howgill Fells in East Cumbria*. M.Phil. thesis, University of London, 123 pp.
- Letzer, J. M. 1987: Drumlins of the southern Vale of Eden. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial deposits in Great Britain and Ireland*, 323–334. Balkema, Rotterdam.
- Lewis, C. A. 1970: The upper Wye and Usk regions. In Lewis, C. A. (ed.): *The Glaciations of Wales and Adjoining Regions*, 147–173. Longman, London.
- Lewis, C. A. & Richards, A. E. eds. 2005: *The glaciations of Wales and Adjacent Areas*. 228 pp. Logaston Press, Almeley, Herefordshire.
- Lintern, B. C. 2001: *Geology of the Kircudbright-Dalbeattie District*. 123 pp. Memoir of the British Geological Survey. HMSO, London.
- Livingstone, S. J., Ó Cofaigh, C. & Evans, D. J. A. 2008: Glacial geomorphology of the central sector of the last British-Irish Ice Sheet. *Journal of Maps* 4, 358–377.
- Livingstone, S. J., Roberts, D. H., Davies, B. J., Evans, D. J., Ó Cofaigh, C. & Gheorghiu, D. M. 2015: Late Devensian deglaciation of the Tyne Gap Palaeo Ice Stream, northern England. *Journal of Quaternary Science* 30, 790–804.
- Luckman, B. B. 1970: The Hereford basin. In Lewis, C. A. (ed.): *The Glaciations of Wales and Adjoining Regions*, 175–196. Longman, London.
- Lunn, A. G. 1980: Quaternary. In Robson, D. A. (ed.): *The Geology of North East England*, 48–60. Special Publication, Natural History Society of Northumberland.
- Mackintosh, F. G. S. circa 1880. Map: Showing the positions, Limits and Directions of Dispersion, and inter-crossing of the Courses of the Boulders of the W. of England and Eastern Part of N. Wales.
- Mathers, H. 2014: *The impact of the Minch palaeo-ice stream in NW Scotland: Constraining glacial erosion and landscape evolution through geomorphology and cosmogenic nuclide analysis*. Ph.D. thesis. University of Glasgow, 123 pp.
- McAdam, A. D., Tulloch, W., Elliot, R. W., Floyd, J. D., Wilson, R. B. & Graham, D. K. 1985: *Geology of the Haddington District*. 99 pp. Memoir of the British Geological Survey. HMSO, London.
- McCabe, A. M. 1971: *The glacial geomorphology of eastern counties Meath and Louth, eastern Ireland*. Ph.D. thesis, Trinity College Dublin, 123 pp.
- McCabe, A. M. 1972: Directions of late-Pleistocene ice-flows in eastern counties Meath and Louth, Ireland. *Irish Geography* 6, 443–461.
- McCabe, A. M. 1985: Glacial geomorphology. In Edwards, K. J. & Warren, W. P. (eds.): *The Quaternary History of Ireland*, 67–93. Academic Press, London.
- McCabe, A. M. 1993: The 1992 Farrington Lecture: Drumlin Bedforms and Related Ice-Marginal Depositional Systems in Ireland. *Irish Geography* 26, 22–44.
- McCabe, A. M. 1995: *North-West Donegal*. 96 pp. Irish Association for Quaternary Studies, Dublin.
- McCabe, A. M. 2008: *Glacial Geology and Geomorphology: The Landscapes of Ireland*. 288 pp. Dunedin Academic Press, Edinburgh.
- McCabe, A. M. & Ó Cofaigh, C. 1994: Sedimentation in a subglacial lake, Enniskerry, eastern Ireland. *Sedimentary Geology* 91, 57–95.
- McCabe, A. M. & Ó Cofaigh, C. 1996: Upper Pleistocene facies sequences and relative sea-level trends along the south coast of Ireland. *Journal of Sedimentary Research* 66, 376–390.

- McCabe, A. M., Clark, P. U., Clark, J. & Dunlop, P. 2007: Radiocarbon constraints on readvances of the British-Irish Ice Sheet in the northern Irish Sea Basin during the last deglaciation. *Quaternary Science Reviews* 26, 1204–1211.
- McCabe, A. M., Knight, J. & McCarron, S. G. 1999: Ice-flow stages and glacial bedforms in north central Ireland: a record of rapid environmental change during the last glacial termination. *Journal of the Geological Society, London* 156, 63–72.
- McCarroll, D. 1991: Ice directions in western Llyn and the status of the Gwynedd readvance of the last Irish Sea glacier. *Geological Journal* 26, 137–143.
- McCarroll, D. 1995: Geomorphological evidence from the Llyn Peninsula constraining models of the magnitude and rate of isostatic rebound during deglaciation of the Irish Sea Basin. *Geological Journal* 30, 157–163.
- McCarroll, D. & Ballantyne, C. K. 2000: The last ice sheet in Snowdonia. *Journal of Quaternary Science* 15, 765–778.
- McLellan, A. G. 1969: The last glaciation and deglaciation of central Lanarkshire. *Scottish Journal of Geology* 5, 248–268.
- Meehan, R. T. 1998: *The Quaternary Geology and last glaciation and deglaciation of northwest Meath and adjacent parts of Westmeath and Cavan*. Ph.D. thesis, National University of Ireland, 504 pp.
- Meehan, R. T. 1999a: Directions of ice flow during the last glaciation in counties Meath, Westmeath and Cavan, Ireland. *Irish Geography* 32, 26–51.
- Meehan, R. T. 1999b: Investigating the Irish Drumlin Readvance Theory. Poster presented to 'Extent and Chronology of Glaciation Symposium' at the XV INQUA Congress, Durban, South Africa. Abstracts Volume.
- Meehan, R. T. 2013: *The Merging of Quaternary Map Datasets*. 107 pp. Report for the Geological Survey of Ireland, Dublin.
- Merritt, J. W., Auton, C. A. & Firth, C. R. 1995: Ice-proximal glaciomarine sedimentation and sea-level change in the Inverness area, Scotland - a review of the deglaciation of a major ice stream of the British Late Devensian Ice-Sheet. *Quaternary Science Reviews* 14, 289–329.
- Miller, H., Cotterill, C. J. & Bradwell, T. 2014: Glacial and paraglacial history of the Troutbeck Valley, Cumbria, UK: Integrating airborne LiDAR, multibeam bathymetry, and geological field mapping. *Proceedings of the Geologists' Association* 125, 31–40.
- Mills, D. A. C. & Hull, J. H. 1976: *Geology of the Country around Barnard Castle*. 385 pp. Memoir of the British Geological Survey, HMSO, London.
- Mitchell, W. A. 1991: Dimlington Stadial ice sheet in the Western Pennines. In Mitchell, W. A. (ed.): *Western Pennines: Field Guide*, 25–42. Quaternary Research Association, London.
- Mitchell, W. A. 1994: Drumlins in ice-sheet reconstructions, with reference to the western Pennines, northern England. *Sedimentary Geology* 91, 313–331.
- Mitchell, W. A. 2007: Reconstructions of the Late Devensian (Dimlington Stadial) British-Irish Ice Sheet: the role of the upper Tees drumlin field, north Pennines, England. *Proceedings of the Yorkshire Geological Society* 56, 221–234.
- Mitchell, W. A. & Buggie, T. 1991: Bluecaster. In Mitchell, W. A. (ed.): *Western Pennines: Field Guide*, 91–93. Quaternary Research Association, London.
- Mitchell, W. A. & Riley, J. M. 2006: Drumlin map of the Western Pennines and southern Vale of Eden, northern England, UK. *Journal of Maps* 2, 10–16.
- Moseley, F. & Walker, D. 1952: Some aspects of the Quaternary period in north Lancashire. *The Naturalist*, 41–54.
- Murdoch, W. 1975: The geomorphology and the glacial deposits of the area around Aberdeen. In Gemmell, A. M. D. (ed.): *Quaternary Studies in North East Scotland*, 14–18. University of Aberdeen/Quaternary Research Association, Aberdeen.
- Murton, D. K. & Murton, J. B. 2012: Middle and Late Pleistocene glacial lakes of lowland Britain and the southern North Sea Basin. *Quaternary International* 260, 115–142.
- NIREX. 1997: *The Quaternary of the Sellafield area*. NIREX Report SA/97/027. NIREX Ltd
- Orme, A. R. 1967: Drumlins and the Weichsel Glaciation of Connemara. *Irish Geography* 5, 262–274.
- Palmer, J. 1967: Landforms. In Beresford, M. W. & Jones, G. R. J. (eds.): *Leeds and its Region*, 16–29. Arnold and Sons, Leeds.
- Parkes, M., Meehan, R. & Preteseille, S. 2012: *The Geological Heritage of Waterford*. 123 pp. Report for the Irish Geological Heritage Programme, Geological Survey of Ireland, Dublin.
- Paterson, I. B., Hall, I. H. S. & Stephenson, D. 1990: *Geology of the Greenock District*. 69 pp. Memoir of the British Geological Survey, HMSO, London.
- Paterson, I. B., McAdam, A. D. & MacPherson, K. A. T. 1998: *Geology of the Hamilton District*. 94 pp. Memoir of the British Geological Survey, HMSO, London.
- Patton, H., Hubbard, A., Bradwell, T., Glasser, N. F., Hambrey, M. J. & Clark, C. D. 2013c: Rapid marine deglaciation: asynchronous retreat dynamics between the Irish Sea Ice Stream and terrestrial outlet glaciers. *Earth Surface Dynamics* 1, 53–65.
- Patton, H., Hubbard, A., Glasser, N. F., Bradwell, T. & Golledge, N. R. 2013a: The last Welsh Ice Cap: Part 1—Modelling its evolution, sensitivity and associated climate. *Boreas* 42, 471–490.
- Patton, H., Hubbard, A., Glasser, N. F., Bradwell, T. & Golledge, N. R. 2013b: The last Welsh Ice Cap: Part 2—Dynamics of a topographically controlled icecap. *Boreas* 42, 491–510.
- Peacock, J. D. 1968: *Geology of the Elgin District*. 165 pp. Memoir of the British Geological Survey, HMSO, London.
- Peacock, J. D. 1984: *Quaternary Geology of the Outer Hebrides*. 26 pp. Memoir of the British Geological Survey, HMSO, London.
- Peacock, J. D. & Merritt, J. W. 1997: The Tynacolle-Blackrock ridge: a possible ice front position for the glacier ice occupying Loch Indaal. In Dawson, A. G. & Dawson, S. (eds.): *The Quaternary of Islay and Jura: Field Guide*, 66–77. Quaternary Research Association, Cambridge.
- Peacock, J. D., Austin, W. E. N., Selby, I., Graham, D. K., Harland, R. & Wilkinson, I. P. 1992: Late Devensian and Flandrian paleoenvironmental shelf west of the Outer Hebrides. *Journal of Quaternary Science* 7, 145–161.
- Penny, L. F. & Rawson, P. F. 1969: Field meeting in East Yorkshire and North Lincolnshire. *Proceedings of the Geologists' Association* 80, 193–218.
- Peters, J. L., Benetti, S., Dunlop, P. & Ó Cofaigh, C. 2015: Maximum extent and dynamic behaviour of the last British-Irish Ice Sheet west of Ireland. *Quaternary Science Reviews* 128, 48–68.
- Phillips, E., Everest, J. & Diaz-Doce, D. 2010: Bedrock controls on subglacial landform distribution and geomorphological processes: Evidence from the Late Devensian Irish Sea Ice Stream. *Sedimentary Geology* 232, 98–118.
- Pinson, L. J., Vardy, M. E., Dix, J. K., Henstock, T. J., Bull, J. M. & MacLachlan, S. E. 2013: Deglacial history of glacial lake Windermere, UK: implications for the central British and Irish Ice Sheet. *Journal of Quaternary Science* 28, 83–94.
- Pocock, T. I. 1940: Glacial drift and river terraces of the Herefordshire Wye. *Zeitschrift für Gletscherkunde* 27, 98–117.
- Powell, J. H., Cooper, A. H. & Benfield, A. C. 1992: *Geology of the country around Thirsk*. 129 pp. Memoir of the British Geological Survey, HMSO, London.
- Price, R. J. 1960: Glacial meltwater channels in the upper Tweed drainage basin. *Geographical Journal* 126, 485–489.
- Price, R. J. 1963: A glacial meltwater drainage system in Peebleshire, Scotland. *Scottish Geographical Magazine* 79, 133–141.
- Price, R. J. 1983: *Scotland's Environment during the Last 30,000 Years*. 224 pp. Scottish University Press, Glasgow.
- Radge, G. W. 1939: The glaciation of North Clevedon. *Proceedings of the Yorkshire Geological Society* 24, 180–205.
- Rae, A. C., Harrison, S., Mighall, T. & Dawson, A. G. 2004: Periglacial trimlines and nunataks of the Last Glacial Maximum: the Gap of Dunloe, southwest Ireland. *Journal of Quaternary Science* 19, 87–97.
- Raistrick, A. 1926: The glaciation of Wensleydale, Swaledale and the adjoining parts of the Pennines. *Proceedings of the Yorkshire Geological Society* 20, 366–410.
- Raistrick, A. 1931: The glaciation of Wharfedale, Yorkshire. *Proceedings of the Yorkshire Geological Society* 22, 9–30.
- Raistrick, A. 1933: The glacial and post-glacial periods in West Yorkshire. *Proceedings of the Geologists' Association* 44, 263–269.

- Rees, J. G. & Wilson, A. A. 1998: *Geology of the Country around Stoke-on-Trent*. 152 pp. Memoir of the British Geological Survey. HMSO, London.
- Richards, A. E. 2005: Herefordshire. In Lewis, C. A., & Richards, A. E. (eds.): *The Glaciations of Wales and Adjacent Areas*, 129–144. Logaston Press, Almeley, Herefordshire.
- Roberts, D. H., Dackombe, R. V. & Thomas, G. S. 2007: Palaeo-ice streaming in the central sector of the British–Irish Ice Sheet during the Last Glacial Maximum: evidence from the northern Irish Sea Basin. *Boreas* 36, 115–129.
- Robinson, M. & Ballantyne, C. K. 1979: Evidence for the glacial readvance pre-dating the Loch Lomond advance in Wester Ross. *Scottish Journal of Geology* 15, 271–277.
- Rolfe, C. J., Hughes, P. & Brown, A. G. 2014: Timing of the maximum extent of Late Pleistocene glaciation in NW Europe: Evidence from Lundy. *Journal of the Lundy Field Society* 4, 1–14.
- Rose, J. 1980: Landform development around Kidson, Upper Swaledale, Yorkshire. *Proceedings of the Yorkshire Geological Society* 43, 201–219.
- Rose, J. 1981a: Field guide to the Quaternary geology of the southeastern part of the Loch Lomond basin. *Proceedings of the Geological Society of Glasgow* 123, 12–28.
- Rose, J. 1981b: Field guide to the Quaternary geology of the southeastern part of the Loch Lomond basin. *Proceedings of the Geological Society of Glasgow* 123, 3–19.
- Rose, J. 1987: Drumlins as part of a glacier bedform continuum. In Menzies, J. & Rose, J. (eds.): *Drumlin Symposium*, 103–116. Balkema, Rotterdam.
- Rose, J. & Letzer, J. M. 1977: Superimposed drumlins. *Journal of Glaciology* 18, 471–480.
- Rose, J. & Smith, M. J. 2008: Glacial geomorphological maps of the Glasgow region, western central Scotland. *Journal of Maps* 4, 399–416.
- Russell, A. J. 1995: Late Devensian meltwater movement and storage within the Ochil Hills, Central Scotland. *Scottish Journal of Geology* 31, 65–78.
- Salt, K. E. 2001: *Palaeo ice sheet dynamics and depositional settings of the Late Devensian Ice Sheet in South West Scotland*. Ph.D. thesis, University of Glasgow, 331 pp.
- 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. *Journal of Quaternary Science* 16, 419–434.
- Sejrup, H. P., Hjelstuen, B. O., Dahlgren, K. T., Hafliðason, H., Kuijpers, A., Nygård, A., Praeg, D., Stoker, M. S. & Vorren, T. O. 2005: Pleistocene glacial history of the NW European continental margin. *Marine and Petroleum Geology* 22, 1111–1129.
- Sissons, J. B. 1958a: Supposed ice-dammed lakes in Britain, with particular reference to the Eddleston Valley, southern Scotland. *Geografiska Annaler* 40, 159–187.
- Sissons, J. B. 1958b: The deglaciation of part of East Lothian. *Publications of the Institute of British Geographers* 25, 59–77.
- Sissons, J. B. 1958c: Subglacial stream erosion in southern Northumberland. *Scottish Geographical Magazine* 74, 164–174.
- Sissons, J. B. 1960: Some aspects of glacial drainage channels in Britain, Part I. *Scottish Geographical Magazine* 76, 131–146.
- Sissons, J. B. 1961a: Some aspects of glacial drainage channels in Britain, Part II. *Scottish Geographical Magazine* 77, 15–36.
- Sissons, J. B. 1961b: A subglacial drainage system by the Tinto Hills, Lanarkshire. *Transactions of the Edinburgh Geological Society* 18, 175–193.
- Sissons, J. B. 1963a: The Perth readvance in central Scotland. Part I. *Scottish Geographical Magazine* 79, 151–163.
- Sissons, J. B. 1963b: The glacial drainage system around Carlops, Peeblesshire. *Publications of the Institute of British Geographers* 32, 95–111.
- Sissons, J. B. 1967: *The Evolution of Scotland's Scenery*. 259 pp. Oliver and Boyd, Edinburgh.
- Sissons, J. B. 1976: *The Geomorphology of the British Isles: Scotland*. 150 pp. Methuen, London.
- Sissons, J. B. 1979a: The limit of the Loch Lomond Advance in Glen Roy and vicinity. *Scottish Journal of Geology* 15, 31–42.
- Sissons, J. B. 1979b: The Loch Lomond Stadial in the British Isles. *Nature* 280, 198–203.
- Small, D., Rinterknecht, V., Austin, W., Fabel, D. & Miguens-Rodriguez, M. 2012: In situ cosmogenic exposure ages from the Isle of Skye, northwest Scotland: implications for the timing of deglaciation and readvance from 15 to 11 ka. *Journal of Quaternary Science* 27, 150–158.
- Smith, B. 1932: The glacier lakes of Eskdale, Mitterdale and Wasdale, Cumberland; and the retreat of the ice during the main glaciation. *Quarterly Journal of the Geological Society of London* 88, 57–83.
- Smith, D. B. 1994: *Geology of the Country around Sunderland*. 161 pp. Memoir of the British Geological Survey. HMSO, London.
- Smith, D. B. & Francis, E. A. 1967: *Geology of the Country between Durham and West Hartlepool*. 354 pp. Memoir of the British Geological Survey. HMSO, London.
- Smith, R. A. & Kimbell, G. S. 1999: *Geology of the New Cumnock District*. 34 pp. Memoir of the British Geological Survey. HMSO, London.
- Stoker, M. S. 1988: Pleistocene ice-proximal glaciomarine sediments in boreholes from the Hebrides Shelf and Wyville-Thomson Ridge, NW UK Continental Shelf. *Scottish Journal of Geology* 24, 249–262.
- Stoker, M. S., Bradwell, T., Howe, J. A., Wilkinson, I. P. & McIntyre, K. 2009: Lateglacial ice-cap dynamics in NW Scotland: evidence from the fjords of the Summer Isles region. *Quaternary Science Reviews* 28, 3161–3184.
- Stoker, M. S., Bradwell, T., Wilson, C., Harper, C., Smith, D. & Brett, C. 2006: Pristine fjord landsystem revealed on the sea bed in the Summer Isles region, NW Scotland. *Scottish Journal of Geology* 42, 89–99.
- Stoker, M. S., Hitchen, K. & Graham, C. C. 1993: *UK Offshore Regional Report: The Geology of the Hebrides and the West Shetland Shelves and Adjacent Deep Water Areas*. 159 pp. British Geological Survey. HMSO, London.
- Stoker, M. S., Long, D., Bulat, J. & Davison, S. 2006: Seismic geomorphology and Pleistocene ice limits off northwest Britain. In Knight, P. G. (ed.): *Glacier Science and Environmental Change*, 160–162. Blackwell, Cambridge.
- Straw, A. 1960: The limit of the last glaciation in North Norfolk. *Proceedings of the Geologists' Association* 71, 379–390.
- Straw, A. 1961: Drifts, meltwater channels and ice margins in the Lincolnshire Wolds. *Transactions of the Institute of British Geographers* 29, 115–128.
- Straw, A. 1969: Pleistocene events in Lincolnshire: a survey and revised nomenclature. *Transactions of the Lincolnshire Naturalists' Union* 17, 85–98.
- Straw, A. 1979: The Devensian glaciation. In Straw, A. & Clayton, K. M. (eds.): *The Geomorphology of the British Isles: Eastern and Central England* 21–45. Methuen, London.
- Sugden, D. E. 1968: The selectivity of glacial erosion in the Cairngorm Mountains, Scotland. *Transactions of the Institute of British Geographers* 45, 79–92.
- Sugden, D. E. & Clapperton, C. M. 1975: The deglaciation of upper Deesside and the Cairngorm mountains. In Gemmell, A. M. D. (ed.): *Quaternary Studies in North East Scotland*, 30–37. University of Aberdeen/Quaternary Research Association, Aberdeen.
- Sugden, D. E., Glasser, N. & Clapperton, C. M. 1992: Evolution of large roches moutonnées. *Geografiska Annaler. Series A. Physical Geography* 74, 253–264.
- Sutherland, D. G. 1981: *The raised shorelines and deglaciation of the Loch Long/Fyne area, Western Scotland*. Ph.D. Thesis, University of Edinburgh, 460 pp.
- Sutherland, D. G. 1984: The Quaternary deposits and landforms of Scotland and the neighbouring shelves: a review. *Quaternary Science Reviews* 3, 157–254.
- Sutherland, D. G., Ballantyne, C. K. & Walker, M. J. C. 1984: Late Quaternary Glaciation and Environmental-Change on St-Kilda, Scotland, and their palaeoclimatic significance. *Boreas* 13, 261–272.
- Synge, F. M. 1963: The Glaciation of Nephin Beg Range, County Mayo. *Irish Geography* 4, 397–403.
- Synge, F. M. 1966: The relationship of the raised strandlines and main end moraines on the Isle of Mull, and the district of Lorne, Scotland. *Proceedings of the Geologists Association* 77, 315–328.



- Synge, F. M. 1968: The Glaciation of West Mayo. *Irish Geography* 5, 372–386.
- Synge, F. M. 1979: Glacial landforms. In Houghton J. P. (ed.): *Atlas of Ireland*, p. 21. Royal Irish Academy, Dublin.
- Taylor, B. J., Burgess, I. C., Land, D. A. C., Mills, D. B. & Warren, P. T. 1971: *Northern England*, 4th edition. 183 pp. British Regional Geology. HMSO, London.
- Taylor, B. J., Price, R. H. & Trotter, F. M. 1963: *Geology of the Country around Stockport and Knutsford*. 183 pp. Memoir of the British Geological Survey. HMSO, London.
- Terwindt, J. H. J. & Augustinus, P. 1985: Lateral and longitudinal successions in sedimentary structures in the Middle Mause Esker, Scotland. *Sedimentary Geology* 45, 161–188.
- Thomas, G. S. P. 1971: *Isle of Man: Field Guide*. 123 pp. Quaternary Research Association, Cambridge.
- Thomas, G. S. P. 1984: The origin of the glacio-dynamic structure of the Bride Moraine, Isle of Man. *Boreas* 13, 355–364.
- Thomas, G. S. P. 1985: The late Devensian glaciation along the border of north-east Wales. *Geological Journal* 20, 319–340.
- Thomas, G. S. P. 1989: The late Devensian glaciation along the western margin of the Cheshire-Shropshire lowland. *Journal of Quaternary Science* 4, 167–181.
- Thomas, G. S. P. 1997: Geomorphology of the Usk valley. In Lewis, S. G. & Maddy, D. (eds.): *The Quaternary of the South Midlands and the Welsh Marches*, 49–60. Quaternary Research Association, London.
- Thomas, G. S. & Chiverrell, R. C. 2006: A model of subaqueous sedimentation at the margin of the Late Midlandian Irish Ice Sheet, Connemara, Ireland, and its implications for regionally high isostatic sea-levels. *Quaternary Science Reviews* 25, 2868–2893.
- Thomas, G. S. & Chiverrell, R. C. 2007: Structural and depositional evidence for repeated ice-marginal oscillation along the eastern margin of the Late Devensian Irish Sea Ice Stream. *Quaternary Science Reviews* 26, 2375–2405.
- Thomas, G. S. P., Chester, D. K. & Crimes, P. 1998: The Late Devensian glaciation of the eastern Llyn Peninsula, North Wales: evidence for terrestrial depositional environments. *Journal of Quaternary Science* 13, 255–270.
- Thomas, G. S., Chiverrell, R. C. & Huddart, D. 2004: Ice-marginal depositional responses to readvance episodes in the Late Devensian deglaciation of the Isle of Man. *Quaternary Science Reviews* 23, 85–106.
- Thomas, G. S. P. & Montague, E. 1997: The morphology, stratigraphy and sedimentology of the Carstairs Esker, Scotland, U.K. *Quaternary Science Reviews* 16, 661–674.
- Thomson, M. E. & Eden, R. A. 1977: *Quaternary deposits of the central North Sea, 3: the Quaternary sequence in the west-central North Sea*. 18 pp. Report of the Institute of Geological Sciences. HMSO London.
- Thorp, P. W. 1986: A mountain icefield of Loch Lomond Stadial age, western Grampians, Scotland. *Boreas* 15, 83–97.
- Thorp, P. W. 1987: Late Devensian ice sheet in the western Grampians, Scotland. *Journal of Quaternary Science* 2, 103–112.
- Thorp, P. W. 1991: Surface profiles and basal shear stresses of outlet glaciers from a Lateglacial mountain icefield in western Scotland. *Journal of Glaciology* 37, 77–88.
- Trotter, F. M. 1929: The glaciation of eastern Edenside, the Alston Block and the Carlisle Plain. *Quarterly journal of the Geological Society of London* 85, 549–612.
- Turner, A. J., Woodward, J., Dunning, S. A., Shine, A. J., Stokes, C. R. & Ó Cofaigh, C. 2012: Geophysical surveys of the sediments of Loch Ness, Scotland: Implications for the deglaciation of the Moray Firth Ice Stream, British–Irish ice sheet. *Journal of Quaternary Science* 27, 221–232.
- Turner, A. J., Woodward, J., Stokes, C. R., Ó Cofaigh, C. & Dunning, S. 2014: Glacial geomorphology of the Great Glen Region of Scotland. *Journal of Maps* 10, 159–178.
- Van Landeghem, K. J., Wheeler, A. J. & Mitchell, N. C. 2009: Seafloor evidence for palaeo-ice streaming and calving of the grounded Irish Sea Ice Stream: Implications for the interpretation of its final deglaciation phase. *Boreas* 38, 119–131.
- Vincent, P. 1985: Quaternary geomorphology of the southern Lake District and Morecambe Bay area. In Johnson, R. H. (ed.): *The Geomorphology of North-West England*, 159–177. Manchester University Press, Manchester.
- Warren, W. P. 1977: North East Iveragh. In Lewis C. A. (ed.): *South and South West Ireland*, 27–45. Guidebook for excursion A15 INQUA X Congress (Bowen, D. Q. Ed.), Norwich.
- Warren, W. P. 1988: The Pleistocene Geology and Geomorphology of Glen Behy, Co. Kerry. *Irish Geography* 21, 1–10.
- Warren, W. P. 1991: Fenitian (Midlandian) glacial deposits and glaciation in Ireland and the adjacent offshore regions. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial Deposits in Great Britain and Ireland*, 79–88. Balkema, Rotterdam.
- Warren, W. P. 1992: Drumlin orientation and the pattern of glaciation in Ireland. *Sveriges Geologiska Undersökning* 81, 359–366.
- Warren, W. P. & Ashley, G. M. 1994: Origins of the ice-contact stratified ridges (eskers) of Ireland. *Journal of Sedimentary Research* 64, 433–449.
- West, R. G. 1993: On the history of the Late Devensian Lake Sparks in southern Fenland, Cambridgeshire, England. *Journal of Quaternary Science* 8, 217–234.
- West, R. G., Andrew, R., Catt, J. A., Hart, C. P., Hollin, J. T., Knudsen, K. L., Miller, G. F., Penney, D. N., Pettit, M. E., Preece, R. C., Switsur, V. R., Whiteman, C. A. & Zhou, L. P. 1999: Late and Middle Pleistocene deposits Somersham, Cambridgeshire, U.K.: a model for reconstructing fluvial/estuarine depositional environments. *Quaternary Science Reviews* 18, 1247–1314.
- Whitehead, T. H., Robertson, T., Pocock, R. W., Dixon, E. E. L., Cantrill, T. C., Crookall, R., Dewey, H., Pringle, J. & Sherlock, R. L. 1928: *The Country between Wolverhampton and Oakengates*. 244 pp. Memoir of the British Geological Survey. HMSO, London.
- Whiteman, C. A. 1981: Drumlins around Appleby-in-Westmorland, Cumbria. In Boardman, J. (ed.): *Field Guide to East Cumbria*, 107–113. Quaternary Research Association, London.
- Wills, L. J. 1924: The development of the Severn Valley in the neighbourhood of Ironbridge and Bridgnorth. *Quarterly Journal of the Geological Society of London* 80, 271–314.
- Wingfield, R. T. R. 1990: The origin of major incisions within Pleistocene deposits of the North Sea. *Marine Geology* 91, 31–52.
- Worsley, P. 1991: Glacial deposits of the lowlands between the Mersey and Severn rivers. In Ehlers, J., Gibbard, P. L. & Rose, J. (eds.): *Glacial Deposits in Great Britain and Ireland*, 203–211. Balkema, Rotterdam.
- Worsley, P. 2005: The Cheshire-Shropshire Plain. In Lewis, C. A. & Richards, A. E. (eds.): *The Glaciations of Wales and Adjacent Areas*, 59–72. Logaston Press, Almeley, Herefordshire.
- Yates, E. M. & Moseley, F. 1958: Glacial lakes and spillways in the vicinity of Madeley, north Staffordshire. *Quarterly Journal of the Geological Society of London* 113, 409–428.
- Yorke, L., Fuller, I. C., Howard, A. J. & Passmore, D. G. 2007: Preliminary investigations of outwash environments in the Tyne Valley: implications for Late Devensian (Dimlington Stadial) deglaciation. *Proceedings of the Geologists' Association* 118, 201–211.
- Young, J. A. T. 1974: Ice wastage in Glenmore, upper Spey Valley, Inverness-shire. *Scottish Journal of Geology* 10, 147–158.
- Young, J. A. T. 1978: The landforms of upper Strathspey. *Scottish Geographical Magazine* 94, 76–94.