Journal of Maps, 2008, 378-398

Glacial striae observations for Ireland compiled from historic records

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(Received 5^{th} August 2008; Revised 14^{th} October 2008; Accepted 17^{th} October 2008)

Abstract: Glacial landform mapping is one of the primary inputs for the reconstruction of past glacial environments and processes, potentially inferring maximum ice sheet extent and dynamics. Depositional landforms (e.g. drumlins, end moraines, ribbed moraines, eskers) are often used to infer former ice sheet conditions, with erosional indicators receiving less attention. For nearly 200 years, striae (linear, subglacial erosional marks on bedrock up to several metres long) have been recorded as evidence for former ice flow direction. Cumulative data collection by many researchers in Ireland since ~1850 has led to a large published and unpublished archive of striae observations. This research has collated over 5000 individual observations from Geological Survey of Ireland maps and memoirs, the published (peer-reviewed) literature, and unpublished work (theses and fieldnotes). These records are now unified in a single database, georeferenced to the Irish National Grid, with the accuracy of individual observations qualitatively assessed.

ISSN 1744-5647
http://www.journalofmaps.com

1. Introduction

Landform mapping has been a primary method of data collection across the spectrum of earth sciences. These include, for example, hard rock geology (e.g. Gold et al., 1973), glaciology (e.g. Wright, 1912; Welch and Howarth, 1968), hydrology (e.g. Hooke et al., 1994), hillslope geomorphology (e.g. Evans, 1977), planetary geology (e.g. Baker, 1981), volcanology (e.g. Thouret, 1999) and coastal geomorphology (e.g. Chandler and Brunsden, 1995). Landforms can be mapped directly in the field, although this is now augmented with remotely sensed data, meaning that larger areas can be mapped, at different scales, by fewer people and in less time (e.g. Clark, 1997).

Research programs that have employed remotely-sensed data have often mapped glacial landforms ranging from several hundreds of metres to several kilometres in dimension, such as drumlins, end and ribbed moraines, and eskers (Welch and Howarth, 1968; Ford, 1984). Assumptions of former ice sheet dynamics based upon landform dimensions and properties (e.g. Kleman and Borgström, 1996) allow tentative reconstructions of the extent and dynamics of former ice sheets (e.g. Clark and Meehan, 2001). In particular, it is possible to reconstruct ice flow direction and changes in flow regime (including subglacial thermal and hydrological conditions). Striae observations have previously been incorporated into palaeo-ice sheet reconstructions (Kleman, 1990), however observations are often widely distributed, with limited areal coverage. Whilst striae are rarely used for ice sheet reconstructions over large areas, where a high density of observations exist they have great potential to aid the regional inference of ice sheet flow regime because they are direct measures of basal ice flow direction. In addition, because they are the result of erosional processes, they are often mutually exclusive with respect to depositional indicators of ice flow (e.g. eskers), and their spatial patterns are therefore complementary. The age of formation of striae is also an important limitation in their use in ice sheet reconstruction, but this lies outside the scope of the present paper.

Much of the early work of the Geological Survey of Ireland (GSI) involved the mapping of both hard rock and surficial geologies (Warren and Horton, 1991). In particular, extensive suites of both erosional and depositional glacial landforms inspired detailed and extensive field mapping and observation, although this was not a mandatory requirement and was often ignored in some areas, depending on the mapper's own interests. The

results of this mapping were presented in the First Series (1"-scale) geological map sheets, published principally between 1860 and 1890. The geological memoirs accompanying the map sheets contained further detail and, in many instances, tabulated field observations, including striae.

This paper presents the first compilation of over 5000 historic striae observations, and is accompanied by the "raw" source data, for the island of Ireland (covering ~84,000 km^2), principally based upon the memoirs accompanying the First Series geological map sheets, but also including published (peer-reviewed journal articles and reports) and unpublished (field notes, theses) observations.

2. Methods

The principal data source for this research was tabulated striae observations contained within memoirs accompanying the First Series GSI map sheets (e.g. Kinahan et al., 1871). Memoirs that contain striae observations are not equally distributed around the island, in part due to the diligence and experience of individual field geologists. However it should also be noted that striae are most clearly recorded on bedrock substrates, which are generally more exposed in the west of Ireland, with central and eastern regions having a thicker till cover. Opportunities for striae observations were therefore more limited in these latter areas. As a final note, some observations also record overprinting (or cross-cutting) of different striae sets and the relative ages of these different sets were often noted.

The information recorded in tables contained within memoirs varies, depending upon the individual geologist with at least the general location, orientation and a detailed description listed. By 1837 the Ordnance Survey had completed First Series topographic mapping of the country at the Six Inch scale (1:10,560) and these maps were principally used by the field geologists to identify likely sites where striae would be found. Indeed many of the tables record the county, sheet number, quadrant and townland that the observations fall within. However the map projections used were not consistent and varied between counties. The simplest and most effective method of transcribing the location of striae in this project involved locating the observation on an original Six Inch map sheet, identifying the same point on a modern 1:50,000 Ordnance Survey of Ireland map sheet,

and recording a 12 figure grid reference in Irish National Grid co-ordinates.

Since the completion of this striae database the GSI have made freely available digital copies of the original Six Inch fieldsheets (http://www.gsi.ie). These are Six Inch Series sheets that have been hand-annotated by the GSI officers, including noting the location and orientation of striae. Whilst these contain a large amount of information, they also represent a huge dataset with ∼70 sheets required to cover a single One Inch map sheet. Further discussion is presented below.

In transcribing striae records or data, it was also evident that descriptions of locations in the original source had different levels of locational accuracy. A subjective assessment of this accuracy was recorded on a scale from 1 to 6, ranging from the most accurate (value of 1, where a full grid reference or precise identifiable location is given) to least accurate (value of 6, where only a general area is known). The qualitative accuracy scale notionally corresponds to approximate accuracies of 1 m (value of 1), 10 m, 100 m, 1 km, 10 km and unknown (value of 6).

For the GSI memoirs, orientation was usually recorded with reference to cardinal points on a compass (rather than in degrees), generally to within 5°. Thus a value of 035° could be recorded as N35E in the memoirs, but the notation can be utilised with respect to each of the four cardinal points and so 035° could also be recorded as E55N. This has added some complexity to the interpretation of the original observations.

In addition to the GSI memoirs, striae were transcribed directly from the First Series geological maps (Geological Survey of Ireland, 1869-1890). There is undoubtedly duplication between these two data sets; however there are fewer observations recorded on the maps than in the memoirs and these are often in different locations. Both sets have therefore been included for completeness and the database can distinguish between these different data sources.

Striae observations taken directly from the published literature vary in presentation of results. Some articles provide full grid references (e.g. Meehan, 1999), whilst others have outline maps marking striae locations (e.g. Wright, 1912). In addition to peer-reviewed articles in academic journals, PhD and MSc theses were also consulted. Included in this latter category are modern observations from the GSI which formed part of a Quaternary, county based, mapping program structured through a series of

Layer	*Description*
Striae: non directional	non-directional striae observations where a preferred orientation is determined, but not a direction
Striae: directional	direction striae observations where a preferred orientation and direction is determined
Striae: high accuracy	striae observations with a locational accuracy of 1, 2 or 3
Striae: low accuracy	striae observations with a locational accuracy of 4, 5 or 6
Striae: GIS data	modern GSI striae observations
Striae: literature data	striae observations from the published and unpublished literature
Striae: map data	striae observations from the First Series geological maps
Striae: memoir data	striae observations from the GSI memoirs
Striae: all data	all striae observations

Table 1. List of data layers available for manipulation within the Acrobat PDF map.

PhD projects (Geological Survey of Ireland, 2007).

All observational data were collated in a relational database comprising six components:

- 12-figure Irish National Grid reference
- the source of the record (full bibliographic reference)
- orientation of striae observed at this location
- presence and orientation of any cross-cutting striae, including any observations on their relative age
- locational accuracy of the record
- elevation (m OD Dublin)

The records were then imported into ESRI ArcGIS for production of the final map. The base map was constructed from a relief shaded digital elevation model (Shuttle Radar Topography Mission; http://www2.jpl.nasa.gov/srtm/), hydrographic data comprising lakes and rivers (Digital Chart of the World; http://www.maproom.psu.edu/dcw/) and a coastal outline (University of Ulster, Coleraine, UK). The final map is a GeoPDF, retaining the map coordinate system and therefore allowing measurements to be made. The layers tab within Acrobat allows access to themed layers which can be switched on and off (Table 1).

3. Results

Striae observation coverage of Ireland is extensive, however it is far from uniform. Areas of dense observations are to be found in the west (County Connemara), north-west (County Donegal) and north-east (County Down) of the island. Additional clusters can also be noted on mountain blocks in the east (County Wicklow) and south-west (County Kerry). All these regions are either bedrock scoured (County Connemara) or mountainous and therefore have little surficial cover. Other areas with observations are predominantly coastal (e.g. mouth of the River Shannon). Note the almost complete lack of observations in the central and southern areas of the island. These data are currently being used to reconstruct ice flow patterns during the late Devensian, and will be reported upon separately.

Individual records were collated from (approximate number in brackets):

- GSI memoirs (2300)
- Geological Survey maps (1400)
- Published and unpublished literature (600)
- Modern GSI observations (700)

The database therefore totals around 5000 individual striae measurements, although there is some duplication of individual records between sources. Here we present the complete data set for Ireland showing the positions and orientations of striae that most likely date from the last (late Devensian) glaciation (~25,000-13,000 BP).

4. Discussion

In order to test the appropriateness of striae observations annotated on the Six Inch map sheets, 72 individual sheets covering the same area as sheet 104 of the One Inch Series were downloaded from the GSI and mosaiced together. Individual striae observations were digitized and their orientation noted. A total of 407 striae observations was present on the Six Inch map

sheets, and 430 noted in the memoirs. Figure 1 shows rose diagrams for these two datasets, highlighting their close similarity. We believe that the tabulated data from the memoirs are based upon the direct field observations that were subsequently annotated on to the Six Inch Map sheets. These two datasets should therefore be identical, however it is likely that transcription on to the map sheets has introduced positional errors, as well as the possibility of missing records. We have therefore not incorporated any Six Inch map sheet measurements in to this database.

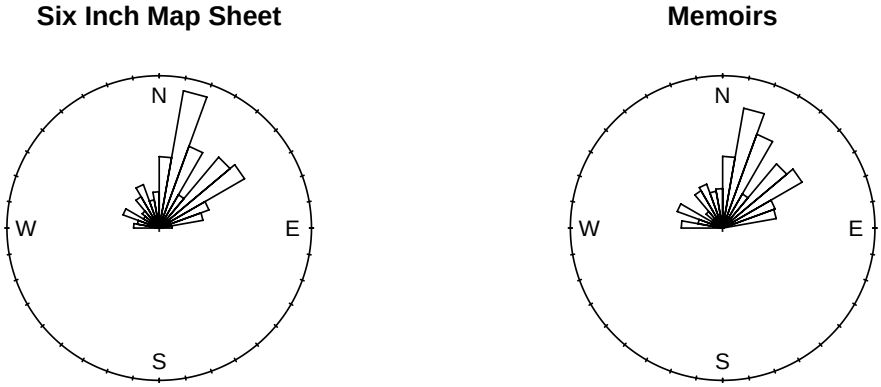

Figure 1. Rose diagrams of striae orientation for the area covered by sheet 104 of the One Inch Geological Map Series. Note the close similarity between striae recorded on the Six Inch Map sheets and in the Memoirs accompanying the One Inch Map sheet.

It is important to note that there are limitations to the data related to, firstly, the accuracy of the source data and, secondly, the transcription and presentation process. As noted above, striae observations have been recorded from tabulated data in the published memoirs and directly from the First Series Geological map sheets. The data are not directly comparable as cross-checking has demonstrated fewer observations from map sheets, often in different locations to the memoirs. However they almost certainly contain duplication. Additionally, the accuracy of striae location (in planform) is also variable; this has been assessed qualitatively, suggesting that 53% are accurate to <10 m and 88% are accurate to at least ~100 m. The remaining 12% of observations are accurate to at least 10 km.

The transcription process can also introduce errors in both identifying the location of individual striae and recording these in the database. Quality control checks have identified obvious "blunders" (e.g. located in the ocean), however it is possible that further errors exist. It should be noted that some observations appear just offshore and likely fall within the

inter-tidal zone. The quality of the base map may also give the impression of error, for example where observations fall on islands that are not recorded. The base map data are of different provenance and, whilst fit for display purposes, are not representative of the "best available" data. It is recommended that detailed interrogation of the database is performed using the raw data.

Finally, the database remains a "work in progress" and whilst we believe that we have captured all primary published striae observations, there will be some observations that have not been included. We would encourage further submissions to enlarge the database, where appropriate.

5. Conclusions

- Research presented here displays one of the largest single databases of striae observations ever compiled, comprising over 5000 individual observations.
- Striae observations have been collated using historic records dating from the 1850s onwards, and published (peer-reviewed) and unpublished literature.
- Striae observations are not uniformly distributed, being strongly clustered around bedrock scoured regions, mountains (e.g. Mourne Mountains, Wicklow, Macgillicuddy's Reeks) and coastal zones.
- These observations will form the basis of a reconstruction of former ice flow.

Software

Striae data were collated in Microsoft Access before being imported in to ESRI ArcGIS 9.3 for cartographic production and PDF generation.

Data

The author has supplied data in the form of a spreadsheet (CSV text file) used in the production of the accompanying map. This PDF has a ZIP archive embedded within it (stored as a .ZI file extension) containing the data and can be accessed by right-clicking on the "paperclip" icon at the beginning of this section (you will need to save the file and edit the file extension to .ZIP). Whilst the contents of the ZIP file are the sole responsiblity of the author, the journal has screened them for appropriateness.

Acknowledgements

We would like to thank Robbie Meehan, Michael Sheehy, Steve Booth and Jaap van der Meer for assistance in collating striae data.

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