Glacial geomorphological maps of the Glasgow region, western central Scotland

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Abstract: This paper presents a 1:25,000 scale geomorphological map of the Glasgow region, western central Scotland, an area that was glaciated during the Last Glacial Maximum and, in part, during the Younger Dryas glaciation. The text accompanying the map sets out the historical context of the mapping exercise and describes the process of geomorphological mapping at 1:10,560 scale. The text outlines briefly the results of the mapping exercise, in terms of the map evidence recorded and the interpretation of Quaternary landscape evolution. The paper is not designed to provide a comprehensive review of the geomorphology and Quaternary history of the area which can be found in the references cited therein.

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1. Introduction

This paper presents a 1:25,000 scale geomorphological map of the Glasgow area, western central Scotland supported by a text which describes the historical context for the work, the methods of mapping and the main findings. In accordance with the format of Journal of Maps the text is brief and relates specifically to the map and mapping process. Further details of the geomorphology and Quaternary history of the area can be found in the references cited.

2. The Mapping Area

The Glasgow region of western central Scotland was last glaciated during the Last Glacial Maximum (LGM) and, in the area around Loch Lomond, during the Younger Dryas (YD) glaciation (LGM is an informal term used to relate to the global expansion of ice in Marine Isotope Stage 2. The precise timing of the LGM and YD ice limits are different in different regions of the globe). For the Glasgow area the LGM ice reached a maximum extent c. 20 cal. ka BP, and melted from the regional c. 14.5 cal. ka BP. The YD glaciation in the Glasgow area reached its maximum extent c. 12 cal. ka BP, and deglaciation occurred c. 11.5 cal. ka BP. The most comprehensive reviews of the glacial and Quaternary history of the area can be found in Sutherland and Gordon (1993) and Evans (2003) and the basis of the dates given above can be found in these publications and unpublished work. See Lowe et al. (2008) for a globally accepted timescale for the period 30 - 8 ka BP. The region is in the western part of the Midland Valley of Scotland and is located between the Grampian Highlands to the north and west (a major zone of ice accumulation resulting from both higher elevation and higher precipitation rates) and the Southern Uplands to the south. The dominant ice flow direction in the region was west to east during the LGM, and north to south within the area of YD glaciation (Figure 1).

Glacial landforms recorded in the region include streamlined hills, drumlins, eskers, moraine ridges, kames, kame terraces, kettle holes, outwash fans and till hummocks, and glacial drainage channels. Till covers much of the area and is typically a matrix-rich diamicton dominated by subjacent lithology, or the lithology of the rocks immediately up-glacier of the site.

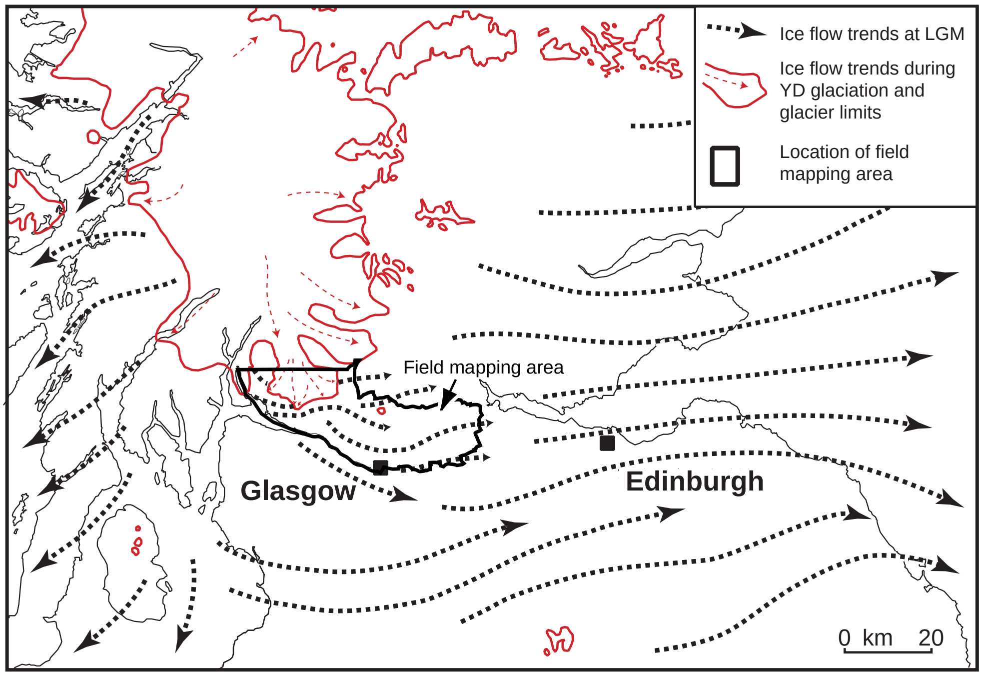


Figure 1. Location of field mapping area and patterns of ice movement in western central Scotland during the LGM and the YD glaciations.

The region covers about 750 km^2 and was mapped by Jim Rose between 1965 and 1976. Most of the area was mapped between 1965 and 1968 as part of a University of Glasgow PhD, and the remainder was completed while he was a lecturer at Birkbeck College, University of London carrying out other research activities.

3. Historical Context

The project to map the glacial geomorphology of the Glasgow area was part of a wider objective of the time, to understand the glacial and shoreline history of northern Britain. The work is typical of a programme of geomorphological mapping that began with John Rice (1959; 1962) and was continued and developed by Brian Sissons (Sissons, 1958; 1967; Sissons and Smith, 1965; Sissons and Cornish, 1982) and a large number of his research students (for example: J.C. Stone, R.J. Price, C.M. Clapperton, D.E. Smith, R.A. Cullingford, J.M. Gray to name some of his early students). Subsequently this style of mapping was followed through at other institutions such as Birkbeck College, University of London where Jim Rose carried out similar work in northern England in collaboration with Jocelyn Riley (née Letzer) (Letzer, 1978; Riley, 1987), John Boardman (Boardman, 1981) and Wishart Mitchell (Mitchell, 1991; 1996; Mitchell and Riley, 2006) and others.

The main findings of this approach resulted in:

1. A better understanding of ice flow directions in the areas of study.
2. Determination of the limits of the Loch Lomond Readvance (LLR) (YD glaciation) in Scotland (Sissons, 1979), Wales (Gray, 1982) and England (Sissons, 1980; Mitchell, 1996).
3. Recognition that drumlins are glacier bedforms (Rose and Letzer, 1977; Rose, 1987).
4. Identification of patterns of superimposed drumlins or cross-cutting lineaments as evidence for changes in glacier dynamics caused by variations in ice thickness and/ or rate of movement (Rose and Letzer, 1977; Rose, 1987). These patterns also provided evidence for different ice flow directions through parts of a glacial cycle (Rose, 1987; 1989).
5. A new understanding of the form, distribution and origin of isostatically displaced shorelines. This field mapping was supported by precise instrumental levelling. The work resulted in the total revision of the history of isostatic shoreline development in Britain (Sissons et al., 1966; Sissons, 1967).
6. The discovery of landforms such as fault scarps produced by postglacial tectonic activity (Sissons and Cornish, 1982). This provided the stimulus for the development of glacio-seismotectonics in Britain (Stewart et al., 2001; Firth and Stewart, 2001).

Full digital geomorphological mapping using remotely sensed data and, in particular, digital elevation models (DEMs), has been applied to the study of glacial and Quaternary geomorphology (e.g. Smith and Clark, 2005). Full details of this development and application to part of the Glasgow area can be found in Smith et al. (2006). The results indicate that DEMs can provide an effective data source for identifying some of the landforms represented on Map 1, but other landforms are difficult to identify with confidence and the composition of all the landforms needs field verification. The ground-truth evidence reported in Map 1 and Figure 2 remains essential, although DEMs can vastly improve the quality of landform representation and rate of acquiring this morphological information.

4. Geomorphological Field Mapping

Mapping was based upon recording the shape of the landforms on to Ordnance Survey (OS) 1:10,560 scale (subsequently 1:10,000 scale) topographic base maps. This involved "walking across" all areas that were surveyed, marking breaks-of-slope (vertical resolution of <1 m), with no assumptions concerning the genesis of landforms. All breaks of slope were examined from different viewpoints in order to eliminate distortion created by perspective. Often breaks-of-slope visible in the field were not represented on topographic maps or evident on stereo aerial photos (Rose and Letzer, 1975). Location was fixed against features recorded on the maps such as field boundaries, buildings and infrastructure. Orientations of landforms were measured in the field with a compass. Initially only the morphology was recorded, but at the end of each day the maps were "inked-in" and the genesis of the landform was interpreted according to landform categories. The 1:10,560/1:10,000 scale field maps were later transcribed on to OS 1:25,000 scale maps or 1:63,360/1:50,000 scale as appropriate. Mapping symbols have been developed in a hierarchical fashion in order to most effectively represent the scales. Examples of maps at each of the scales are given in Figure 2, and the mapping symbols are shown on Figures 3a and 3b.

Typically line thickness covers 2 m of ground at the 1:10,560 scale and 10 m of ground at the 1:25,000 scale. Accuracy of the representation is evaluated and discussed in Smith et al. (2006). For archival purposes the 1:25,000 maps have been photographed onto 34 individual A4 sheets (a method also used by Letzer, 1978; Boardman, 1981; Mitchell, 1991).

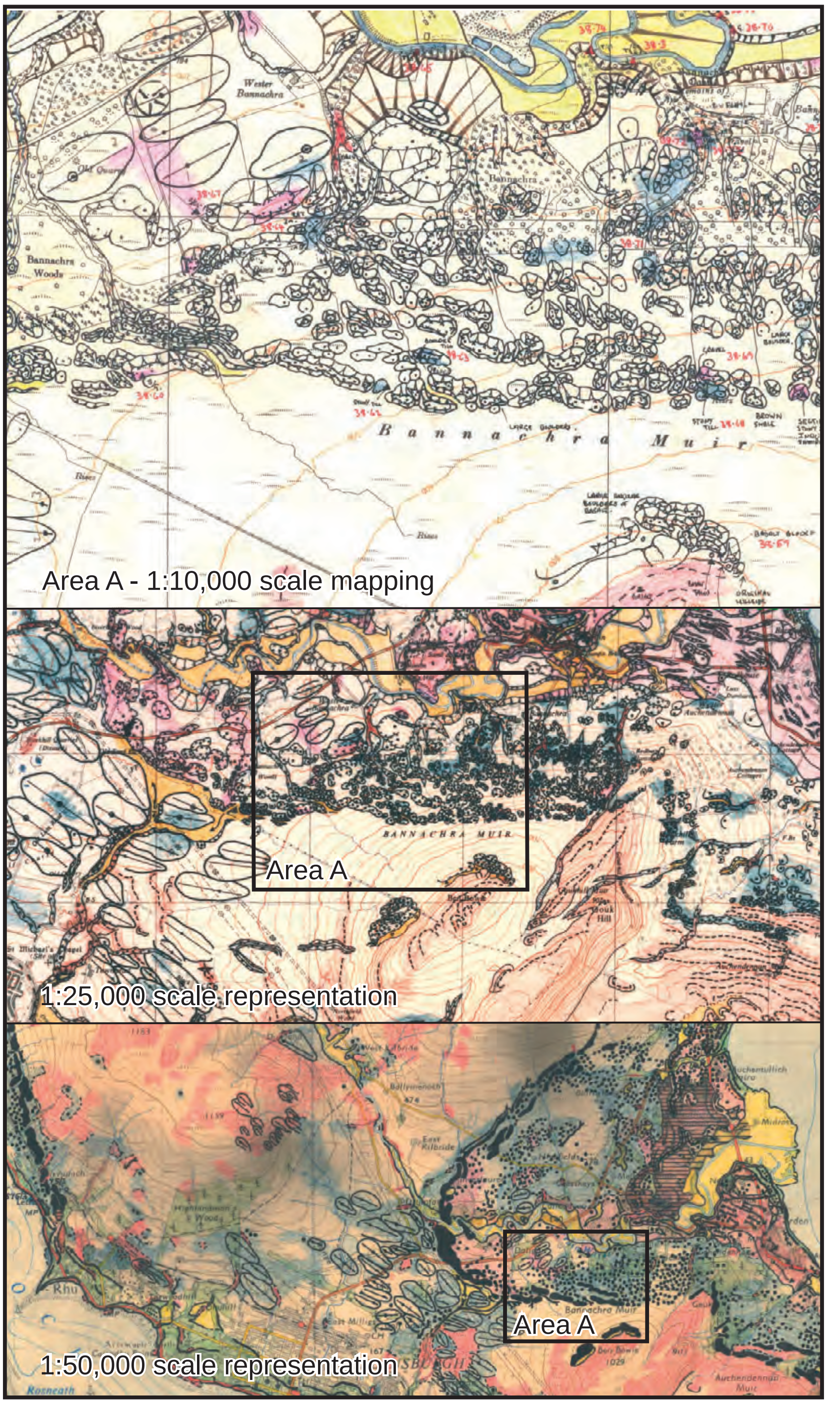
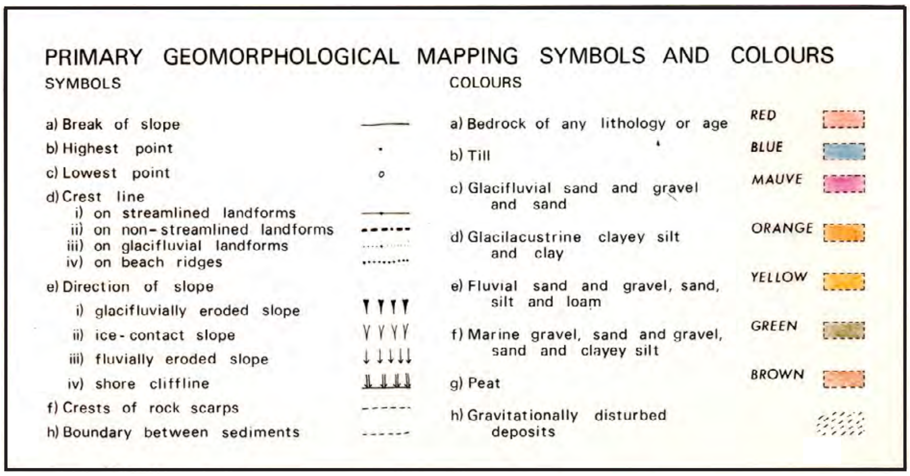
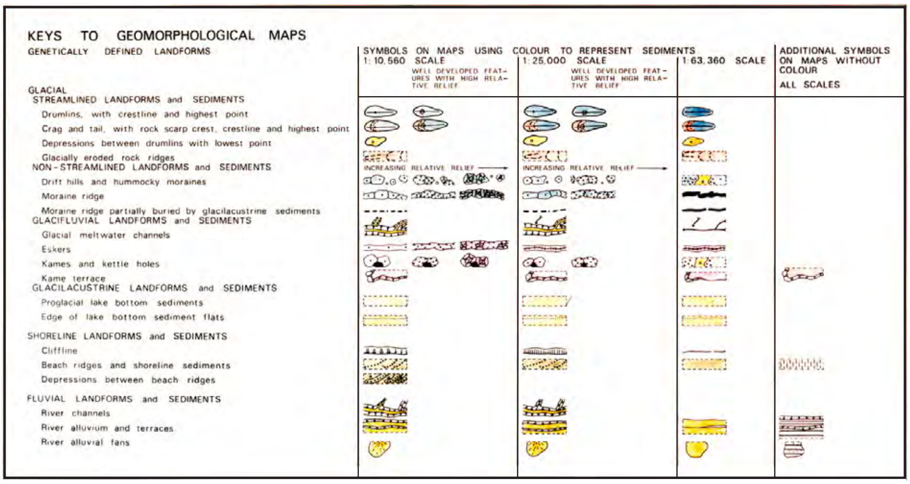


Figure 2. Examples of 1:10,560/1:10,000 scale field mapping, with the 1:25,000 and 1:63,360/1:50,000 scale reductions. The area covered is at the western side of Loch Lomond centred around Ben Bowie and the lower part of Glen Fruin.



(a)



(b)

Figure 3. a) Primary geomorphological mapping symbols and colours used to build up the symbols for the landforms defined in (b). b) The geomorphological mapping symbols used on the 1:10,560/1:10,000, 1:25,000 and 1:63,360/ 1:50,000 scale geomorphological maps. Note that on (b) the terms glacifluvial and glacilacustrine are used as these were preferred at the time of mapping, but preference is now for the use of glaciofluvial and glaciolacustrine.

5. Glacial and Shoreline Geomorphology of the Glasgow Area - outline description of area

The glacial and shoreline geomorphology of the Glasgow area is shown on Map 1 and, for convenience, all localities mentioned in the descriptions below are shown on Figure 4.

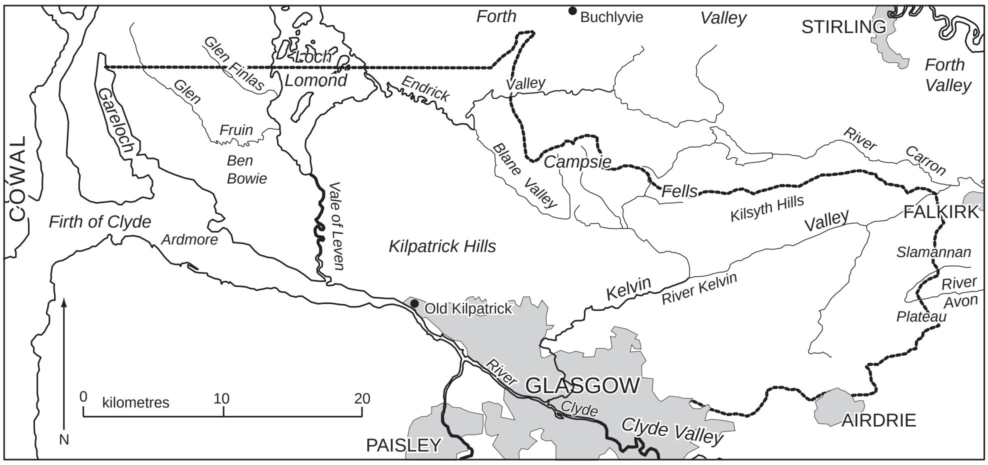


Figure 4. Location of places in western central Scotland named in the text.

The area covered by the attached map extends from the west coast of Scotland at the Firth of Clyde, almost to the east coast in the Firth of Forth. The area is mainly low relief, but includes hill ranges of the SW Highlands in the west, the Kilpatrick Hills and Campsie Fells in the central parts of the region and the Slamannan Plateau in the east. Most of the area is covered by till, except on the tops of the Kilpatrick Hills and Campsie Fells where there is extensive bedrock outcrop and some peat cover. The bottom of the Kelvin and Leven valleys are mainly glaciofluvial sands and gravels at the surface with a complex sequence of glaciogenic sediments below. Glaciolacustrine silts and clays cover a large area of the lower Blane and Endrick valleys, beyond the limit of the LLR.

Most of the area is characterized by glaciogenic landforms, although fossil shoreline landforms exist around the coast of the Clyde estuary and the Gareloch, and in Loch Lomond. River landforms, in the form of narrow trenches cut into superficial deposits and bedrock, or large spreads of sandy silty alluvium where glacially formed depressions (glacially eroded basins, kettle holes) coincide with the routes of the rivers, characterise the river routes. Bedrock forms distinctive landforms in the Kilpatrick Hills, where effective glacial erosion has produced small irregular hills and enclosed basins known as 'knock and lochan' topography (Linton, 1963), and on the higher slopes of the Campsie Fells where the basalt lavas produce scarps. At lower levels, glacial erosion has sometimes produced a rock hillock-and-depression topography in areas of Carboniferous sandstone. As theses features are on the same scale as kames and kettle holes it is difficult to distinguish them from the constructional forms without detailed augering.

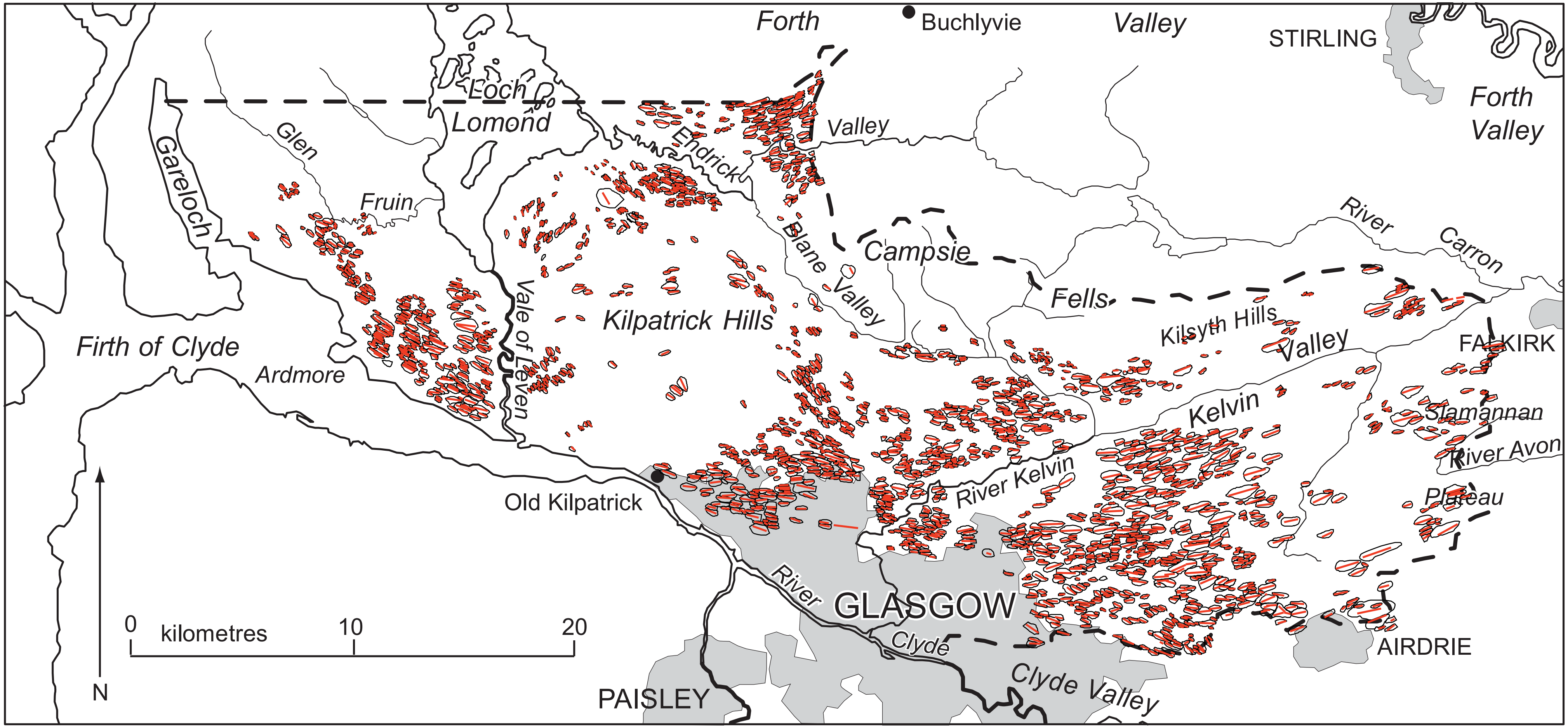
The dominant glacial landforms are glacier bedforms, which cover most of the lower terrain. Drumlins are most abundant and vary in size and form, and include complexities such as megadrumlins and superimposed drumlins (Figure 5; Rose and Letzer, 1977). Most of the drumlins are formed of till, but some include sands and gravels and others are mainly incompetent bedrock. There are a number of crag and tail hills where small outcrops of resistant bedrock are surrounded by relatively non-resistant lithologies. Streamlined bedrock hills are developed on some of the less competent Old Red Sandstone (ORS) rocks (Linton, 1962; Rose, 1987). Throughout the area there are locally-developed, irregular (as opposed to streamlined) till hillocks. These are typically of low relief and are characteristically formed between or on the lower slopes of drumlins. Within the area of the LLR the drumlins are smaller and the till hillocks are smaller and more abundant.

Glacial meltwater landforms are developed throughout the area and, indeed, dominate some areas. Meltwater channels are exceptionally well developed on the southern slopes of the Kilsyth Hills, and on the hillside between the Kelvin Valley and the Clyde Valley. The largest meltwater channel is at the eastern end of the Kelvin Valley, forming the watershed between this valley and the Forth Valley (between western and eastern Scotland). Meltwater channels are less abundant in the area of the LLR, and are universally smaller, except for the single channel that crosses the watershed between the Clyde and Forth drainage systems and was formed as an overflow from a proglacial lake dammed by the ice of the LLR. Glaciofluvial landforms include kames and kettle holes in the Kelvin Valley and less commonly on the plateau area between the Kelvin and Clyde valleys. Outwash and kame terraces are more limited in extent, occurring mainly along, or at the east of the Kelvin Valley. Within the area of the LLR, kames and kettles are well developed in the lower part of the Fruin and Finlas valleys and outwash terraces are well developed in the Leven Valley. Extensive spreads of glaciolacustrine silts and clays fill the lower parts of the Blane and Endrick valleys due to the formation of a proglacial lake at these locations during the wastage of the LGM ice and during the LLR.

The LLR moraine ridge is a classic landform, although there are lateral changes in its morphology that reflect the geomorphological processes that operated at the locality and the sediment available at the glacier margin. Across most of the hillsides it forms a well developed ridge of till, sometimes associated with small kame terraces and small meltwater channels. However on the hillside below Ben Bowie (Figure 2) it is very fragmented in its form, and across the Leven Valley it forms a massive ridge, that has since been partially dissected by meltwater. In the area where the moraine ridge crosses the Endrick Valley it takes on an entirely different form: a number of low relief ridges made mainly of glaciotectonized lacustrine clay with sands and gravels and till. These ridges have a maximum elevation of 64 m OD which coincides with the highest level reached by the proglacial lake that formed beyond these moraines. Apart from some distinct till ridges that are aligned north-south across the Avon Valley on the Slamannan Plateau; no other moraine ridges have been recognised in the area.

Fossil shorelines are developed at both the eastern and western parts of the area. In the east, the outwash terraces in the Kelvin/Carron valleys merge with fossil shorelines in the Forth that have been described and interpreted in Sissons and Smith (1965). In the west, fossil shorelines are developed along the Clyde and the Gareloch, and in the Leven Valley and Loch Lomond (Dickson et al., 1978). Nearly all these shorelines are eroded into ORS bedrock or till, and all are associated with well sorted beach deposits which often form beach ridges. At Ardmore, the fossil shoreline extends around a hill of resistant ORS conglomerate. Ardmore would have been an island at its time of formation, linked to the mainland by a tombolo.

Figure 5 (next page). A digitized map of the drumlins of the Glasgow area shown in Map 1.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River
Carron
Blane
Valley
Campsie
Fells
Kilsyth Hills
Valley
FALKIRK
Firth of Clyde
Ardmore
Vale of Leven
Kilpatrick Hills
Kelvin
Slamannan
River Avon
Plateau
River Kelvin
Old Kilpatrick
River
GLASGOW
Clyde
Clyde Valley
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6. Interpretation of the Glacial and Shoreline Geomorphology

LGM. The glacial geomorphology indicates that the ice flowed across the area from the west with the glacial source area over the mountains and sea lochs of Cowal. Meltwater beneath, within and on the ice sheet drained from western Scotland to the east and into the Firth of Forth. It is possible that the process of ice wastage was interrupted by a readvance to push-up the ridges that can be interpreted as a moraine on the Slamannan Plateau, and this may be the equivalent of the ice marginal stage known as the Perth Readvance that is associated with the formation of an ice contact slope, outwash terrace and a raised shoreline in the Firth of Forth near Carron (Sissons and Smith, 1965), but there is no lithostratigraphic evidence to support this interpretation and correlation. During the thinning of the ice sheet the glacier bedforms indicate that the main trajectory of ice movement changed from west to east to northwest to southeast up the Clyde Valley (Rose, 1987). This change in ice flow direction may have been a response to thinning ice and the effects of local topography, rather than the general configuration of the ice sheet which was the case when the flow was from west to east. On the plateau's and interfluves the ice margin retreated from west to east, but thinned around the hills with a configuration determined by the shapes of the hills.

During the wastage of the ice, meltwater flowed to the east through the Kelvin Valley and into the Forth, toward the south and into the ice-dammed lakes within the Clyde valley and to the northeast through a gap in the Campsie Fells and into the Forth lowlands. During the last stages of ice wastage, around and east of Glasgow, the extensive kame and kettle topography indicates that the ice became stagnant and disintegrated in-situ in the base of the Kelvin Valley. West of Glasgow the ice margin retreated towards the west and the sea first entered the Glasgow area from the Lochwinnock Gap (to the southwest of Glasgow) causing marine shorelines to form around Glasgow and as far west as Kilpatrick (Rose, 1975). With further retreat of the ice margin to the west, the sea entered the Firth of Clyde from the south and extended across all the lowland, including that in Loch Lomond, below about 30 m OD. Isostatic rebound took place as the ice margin retreated and the marine limit became progressively lower towards the west. The presence of drumlins throughout the western part of the region suggests that the ice remained competent, deforming its bed as the margin retreated northwestwards across the western part of the mapping area.

The interval between the LGM and the LLR. The main landforms that formed in the interval between the LGM and the LLR were the river trenches cut into areas of steep relief. Following the formation of the high raised shoreline landforms and deposits that developed as the ice wasted across the region, a progressive fall of relative sea-level meant that the sea-level dropped to elevations lower that the present day, and there is an absence of raised shorelines for most of this period.

LLR. The glacial geomorphology indicates that the ice moved southward into the mapping area, along the valley of Loch Lomond and the valley of the Gareloch. At both localities the limit of LLR glaciation is clearly marked by a moraine ridge and associated meltwater landforms. At the southern end of Loch Lomond the pattern of glacier bedforms indicates that the ice radiated out as a piedmont lobe with ice flows towards the Leven and Endrick Valleys and a distinct ice-flow divide between the two. During movement across the area this ice deformed its bed, and during wastage it decayed at its margins to produce small ice disintegration landforms. Beyond the LLR ice limit, a large proglacial lake formed in the Blane and Endrick valleys, and this lake overflowed across the col between the Clyde and the Forth drainage systems to flow into and beneath the Forth Glacier lobe in the vicinity of Buchlyvie.

Elsewhere, outwith the area of the LLR ice, periglacial processes shaped the landscape, causing extensive gelifluction which partially degraded many of the previously formed landforms. Periglacial activity also produced specific landforms such as a large protalus rampart on Ben Bowie and rock-cut shore platforms and clifflines around the Clyde and Loch Lomond (Main Lateglacial Raised Beach).

Holocene. River activity is the dominant process (other than Human induced processes) throughout the Holocene. River incision is extensive on the hillside slopes and alluvial infills are thick and extensive in the valley bottoms. Landslips are common along parts of the south-facing slope of the Campsie Fells where the competent basalts overlie incompetent mudrocks. Shoreline landforms are developed along the Clyde and in Loch Lomond, and in both localities the Main Postglacial Raised Beach is a well developed landform with extensive beach sediments (although in some cases this is due to re-working the Main Lateglacial Raised Beach).

7. Digital Map Production

The archived A4 photographs of the original geomorphological maps formed the basis for the digitization and presentation of this work. All 34 A4 sheets were scanned at 300 dpi and saved in compressed TIFF format. These files were then imported in to ERDAS Imagine and georeferenced using the OS grid on the original map sheets. Once complete, all 34 A4 sheets were mosaiced together to form, for the first time, a single, seamless, geomorphological map of the study area (Map 1).

8. Conclusions

- This paper outlines the methods used to map glaciogenic landforms in northern Britain during the second half of the 20^{th} Century.
- The main important findings of this type of data collection are outlined and the interpretation and significance of these findings are outlined in terms of the concepts of the time.
- Examples of 1:10,560 scale field maps are presented to show examples of mapping different types of glaciogenic landforms.
- A seamless 1:25,000 scale geomorphological map of the area is produced for the first time
- The types of landforms found within the region are summarized within their glaciodynamic and topographic context
- A very brief interpretation to the geomorphological maps shows that the ice flowed from the west to the east during most of the LGM, then changed to flow towards the southeast at the later stages of ice thinning and wastage, in response to topographic control. During the YD glaciation the ice flowed southwards as a piedmont lobe into the southern end of the Loch Lomond Basin where it formed a well developed end-moraine ridge.
- The work reported here demonstrates the importance of ground-truthing geomorphological and geological data and highlights the need to combine information derived from remote imaging of landforms with field investigation of the geology.

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Software

The photographic archives were initially scanned and saved as TIFFs in Paint Shop Pro 8. These were imported in to ERDAS Imagine 9.0, individually georeferenced using the grid on the map sheets and then mosaiced together to form a single geomorphological map. Digitisation of individual drumlins (Figure 5) was performed in ESRI Arcview 3.3, with final map production in ESRI ArcMap 9.1.

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