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Glaciation style and the geomorphological record: evidence for Younger Dryas glaciers in the eastern Lake District, northwest England

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ABSTRACT

The Younger Dryas (*c.* 12,900–11,700 years ago) in Britain witnessed renewed glaciation, with the readvance of ice masses that had survived the preceding Lateglacial Interstadial as well as the formation of new glaciers. The extents of these former glaciers have been mapped by many workers over the past fifty years, usually as a basis for palaeoclimatic investigations. It has frequently been asserted that the landform record is sufficiently clear to allow accurate ice mass reconstructions at or near maximum extents. Detailed geomorphological mapping in the eastern Lake District in NW England, however, demonstrates that this confidence may not always be warranted. Whereas previous workers have interpreted the well-developed moraines that exist in some locations as evidence for an alpine-style of glaciation, with ice restricted to a small number of valleys, this study shows that the most recent glaciation to affect the area was characterised by: (i) extensive summit icefields, which supplied ice to the surrounding valleys; and (ii) a much greater volume of ice in the valleys than previously thought. The discovery that summit icefields were relatively common at this time is consistent with recent studies elsewhere in the Lake District and beyond. More significant, however, is the recognition that changing glacier–topographic interactions over both space and time appears to have had a profound impact on valley-floor glacial landform development, with the absence of clear moraines not necessarily indicating ice-free conditions at this time. This complicates glacier reconstructions based solely on the geomorphological record. Similar geomorphological complexity may be present in other areas that previously supported summit icefields, and this needs to be taken into account in glacier reconstructions.

1. Introduction

The Younger Dryas (Greenland Stadial 1; 12.9–11.7 cal. ka BP; Lowe et al., 2008), the last major cold period before the onset of the present interglacial, is one of the most intensively studied events in the palaeoclimate record (Broecker et al., 2010). It occurred during a time of high summer insolation at the end of the Last Glacial, and its impact appears to have been most pronounced in the northern hemisphere, especially the North Atlantic region where a return to a full glacial climate is indicated by a range of proxy data (*e.g.* Lowe et al., 2008; Palmer et al., 2012). The Younger Dryas in Britain (where it is also known as the Loch Lomond Stadial) witnessed renewed glaciation, with the readvance of ice masses that had survived the preceding Lateglacial Interstadial (Greenland Interstadial 1; 14.7–12.9 cal. ka BP; Lowe et al., 2008) (*e.g.* Finlayson et al., 2011) as well as the formation of new glaciers. Studies have shown that the main area of glacierisation was in the western highlands of Scotland, where an ice cap developed, with smaller ice masses forming in other parts of upland Britain (*e.g.* Gray and Coxon, 1991; Golledge, 2010) (Fig. 1).

The extents of these former glaciers have been mapped by many workers over the past fifty years, usually as a basis for palaeoclimatic reconstructions, and the result is a large and growing volume of published work. To some extent this level of interest stems from the striking clarity of many Younger Dryas moraines in upland Britain, which is considered to contrast markedly with the more subdued appearance of depositional landforms associated with the last (Late Devensian) ice sheet (*e.g.* Manley, 1959). Indeed, it was frequently asserted in studies published during the 1970s and early 1980s that the well-defined nature of the geomorphological evidence allowed the accurate reconstruction of Younger Dryas glaciers at or near maximum extents (*e.g.* Lowe and Walker, 1984, p. 27; Ballantyne and Harris, 1994, p. 18). More recent studies, however, have shown that this confidence is not always warranted, and there is a growing body of evidence to suggest that previous investigators underestimated the extent and importance of summit glaciation in Britain during the Younger Dryas (*e.g.*

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Fig. 1. Glacier development in northern Britain during the Younger Dryas (after Price, 1983; Golledge, 2010; Brown et al., 2011; Finlayson et al., 2011). Glaciers also developed in other parts of Britain, most notably in the Welsh uplands (*e.g.* Hughes, 2009; Bendle and Glasser, 2012).

McDougall, 2001; Finlayson, 2006). This is not altogether surprising; investigations in contemporary glacial environments demonstrate that the geomorphological impact of summit icefields tends to be limited due to low basal shear stresses and locally cold-based ice, which in turn makes them difficult to recognise in the landform record (*e.g.* Gellatly et al., 1988; Rea et al., 1998). The failure to account for such icefields may result in outlet glaciers being incorrectly reconstructed as valley glaciers, which in turn will produce an over-estimation of equilibrium line altitude (ELA) lowering (Rea et al., 1998).

Although much work remains to be done, there is now a better understanding of the glaciological significance and geomorphological impact of the summit icefields that developed in Britain during the Younger Dryas. Unfortunately, less attention has been devoted to investigating the influence this style of glaciation had on valley-floor landform development at this time. Evans (1990), working in NW Ellesmere Island, demonstrated that glacier morphology is one of a number of factors influencing moraine development on valley floors, in part because it determines the extent and location of extraglacial debris source areas. Nevertheless, the extent to which such observations have informed the interpretation of the geomorphological record in Britain is not entirely clear, although some examples exist in which marked variations in valley-floor glacial landform development have been attributed, at least in part, to glacier morphology (*e.g.* McDougall, 1998).