ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT
Abh. Geol. B.-A. | ISSN 0378-0864 | ISBN 978-3-85316-043-5 | Band 62 | S. 193–195 | Wien, August 2008
Veränderter Lebensraum – gestern, heute und morgen
Hauptversammlung der Deutschen Quartärvereinigung e.V. (DEUQUA) in Wien: 31. August – 6. September 2008

Mechanisms of Moraine Formation under Different Glaciological Boundary Conditions – Implications for Interpreting the Dynamics of Quaternary Ice Masses

SVEN LUKAS*)

Schweiz
Schottland
Quartär
Gletscher
Moräne

Contents

Mechanismen der Moränenbildung unter verschiedenen glaziologischen Randbedingungen – Zur Interpretation der Dynamik quartärer Eismassen

Zusammenfassung

Moränen, die an Eisrändern gebildet wurden, sind die am häufigsten benutzten Landformen, die zur Gletscher- und Paläoklimarekonstruktion herangezogen werden. Trotz ihrer wichtigen Rolle als Anzeiger von Paläoklima- und Paläogletscherdynamik sind die Bildungsbedingungen dieser Landformen nicht zureichend verstanden. Die vorliegende Studie fasst Ergebnisse aus Studien an Moränen in den Alpen, Schottland und Spitzbergen zusammen. Das Ziel dieser Arbeit ist, die Prozesse der Moränenbildung unter verschiedenen glaziologischen Randbedingungen (warme bis größtenteils kalte Gletscher) zu vergleichen, um daraus Schlüsse für die Interpretation älterer Landformen ziehen zu können.

Abstract

Latero-frontal moraines are the most commonly used landforms in glacier and palaeoclimate reconstruction. However, our understanding of how these landforms form and what their palaeoclimatic significance is in terms of glacier dynamics is still very limited. This paper synthesises data from the Alps, Scottish Highlands and Svalbard to compare different processes of moraine formation under different glaciological regimes (temperate to largely cold-based) with the aim of distilling an interpretative framework for palaeoenvironments.

1. Introduction

In glaciated valley landsystems, prominent latero-frontal moraines commonly mark the maximum extent of Holocene and earlier, e.g. lateglacial, glacier advances. Consequently, these landforms are widely used to constrain the extent of former glaciers, mostly in order to derive palaeoclimatic parameters or to calculate volume loss between successive periods of glaciation. However, despite this widespread use of moraines, a thorough understanding of the modes of their formation based on modern process observations and detailed sedimentological analyses is largely lacking for these environments; hence, links between process and (land)form have not yet been established with confidence. To the contrary, most workers simply use these landforms, largely ignoring the additional information about glacier dynamics that could be gained. A second group of workers prefer to use occasional exposures to make some basic assumptions about moraine formation, but do not employ detailed sedimentological methods. An interesting and common misconception in these studies is that moraines, being glacial land-

*) SVEN LUKAS, University of London, Department of Geography, Queen Mary, Mile End Road, London E1 4NS, England.
S.Lukas@qmul.ac.uk

forms, are expected to be composed of till (see LUKAS [2006a] for a summary).

The gap in knowledge sketched out above presents a number of problems for palaeoclimatic studies since the processes of moraine formation can give reliable insights into glacier dynamics, and hence climate-glacier interactions, at the time of moraine formation (e.g. BENN & LUKAS, 2006; LUKAS, 2007). This short contribution aims at summarising recent findings from three glaciated environments, Svalbard, the Central European Alps and the Scottish Highlands. A multi-proxy approach involving process observations, sedimentological investigations and ground-penetrating radar (GPR) has been employed to achieve a great deal of data that can be meaningfully interpreted.

2. Study Areas

The study areas used in this study are

a) the forelands of the temperate valley glaciers Findelengletscher (7°52' E, 46°00' N) and Gornergletscher (7°46' E, 45°58' N) in the Central Alps, east of Zermatt;
b) three polythermal glaciers south of Longyearbyen, Svalbard (15°26' E, 78°12' N) and
c) an area of ca. 600 km^2 in the far NW Highlands of Scotland that were last glaciated during the Younger Dryas.

3. Results

Polythermal, largely cold-based glaciers on Svalbard are characterised by low flow velocities, dominant supraglacial and englacial debris entrainment and transport. Supraglacial debris load is very large and results in the formation of partly thick (0.1–4 m) debris covers that inhibit glacier melt and reduce ablation so much that most glacier fronts are still at the neoglacial maximum that was reached in 1900 (LUKAS et al., 2007). Moraine formation in these environments is limited, and glaciers in these environments are not capable of building large moraine complexes; the only evidence that is likely to be preserved over longer time spans is erosional evidence such as marginal meltwater channels (LUKAS et al., 2005).

Temperate valley glaciers in the Alps are at the opposite end of the spectrum to those mentioned above: they are characterised by medium to fast flow, are largely temperate (Gornergletscher is known to contain some frozen patches in areas where the ice is thinner) and transport large quantities of debris subglacially and have a relatively small supraglacial debris load (GRAF, 2007; KELLERER-PIRKLBAUER, 2008). Dead ice in the foreland is less widespread than in arctic systems and, if present, concentrated to lower altitudes of the foreland. As a consequence of the aforementioned components, latero-frontal moraines tend to be very prominent features, often reaching 20–100 m height and several kilometres in length. Sedimentological processes are dominated by debris flow deposition: water-saturated supraglacial debris slides down the glacier surface to accumulate along the ice margin where it forms a debris flow-dominated ice-contact fan or ramp. Discrete runoff events produce thinner sorted-sediment units and partly mini-deltas in puddles on the fan or ramp surface. When the glacier retreats, the proximal sides of these fans lose their support and collapse, forming steep ice-contact faces where material is at the angle of repose. Ground-penetrating radar investigations in these sediments show very good agreement between radar facies and lithofacies observed in control exposures along trenches. This allows individual lithofacies units to be traced into the deep subsurface revealing a thickness of up to 10 m of stacked, conformable debris flow units with dips parallel to moraine surface slopes. Glacier readvances can lead to oversteepening, and lateral drag and compression can induce glaciotectonisation, leading to partial deformation and overconsolidation of typically the lower parts or bases of laterofrontal moraine complexes (GRAF, 2007). This material is not the same as (lodgement) till since primary depositional structures that are the result of debris flow deposition are preserved (cf. EVANS et al., 2006; LUKAS, 2006a). Observations have shown that the material that forms debris flows is frequently brought to the glacier surface along englacial debris bands and consists dominantly of subglacially-transported material (GRAF, 2007; LUKAS & SASS, unpublished). The preservation potential of alpine latero-frontal moraines is very high, and, based on the process observations at modern glaciers, sedimentological studies in such moraines that predate neoglacial advances are a fruitful avenue of research to investigate in how far glaciological boundary conditions have changed, e.g. during the Lateglacial.

In NW Scotland, the author has collected a large amount of data from >50 exposures in latero-frontal moraines that allow the modes of moraine formation to be reconstructed in considerable detail. The details of this research have already been published extensively (e.g. LUKAS, 2005, 2006b; BENN & LUKAS, 2006) and will only briefly be considered here. Latero-frontal moraines formed during the Younger Dryas are typically 5–15 m high moraine fragments that have been dissected by glacial meltwater and/or snowmelt. They form a landform assemblage that is often referred to as "hummocky moraine" due to the pointed and sharp-crested nature of individual moraine mounds. These mounds themselves are aligned along chains and represent fragments of once-continuous ice margins (LUKAS & BENN, 2006). Sedimentologically, these moraines are very similar to those described from the Alps above, i. e. terrestrial ice-contact fans or ramps being the norm. The only differences with aforementioned landforms are

a) their scale (being up to an order of magnitude lower) and
b) the more extensive nature and variety of deformation structures within these smaller moraines.

The latter form a continuum from undeformed through to complexly-deformed and overridden moraines with coeval glaciotectonisation (LUKAS, 2005). The difference in scale perhaps results from the nature of retreat which has been interpreted to have been very rapid, partly resulting in the formation of annual moraines (LUKAS & BENN, 2006) whereas glaciers in the Alps have frequently been observed to readvance to similar points, increasing the height of moraines and forming more complex landforms (RÖTHLISBERGER & SCHNEEBELI, 1979).

4. Conclusions

The results presented above have shown that detailed sedimentological studies are useful and critical to understand the modes of moraine formation in different environments. The data suggest that interpretations of the palaeolandform record should include such investigations in order to derive palaeoclimatic inferences of a holistic nature. More work of this nature is required, however, before a model of moraine formation that incorporates spatial and temporal variability in different environments can be constructed with confidence.

References

BENN, D.I. & LUKAS, S. (2006): Younger Dryas glacial landsystems in North West Scotland: An assessment of modern analogues and palaeoclimatic implications. – Quaternary Science Reviews, **25**, 2390–2408.

EVANS, D.J.A., PHILLIPS, E.R., HIEMSTRA, J.F. & AUTON, C.A. (2006): Subglacial till: Formation, sedimentary characteristics and classification. – Earth-Science Reviews, **78**, 115–176.

GRAF, A. (2007): Genese alpiner Seitenmoränen am Beispiel des Findelengletschers bei Zermatt (VS). – Unpublished MSc Thesis, University of Bern, 126 pp.

KELLERER-PIRKLBAUER, A. (2008): The supraglacial debris system at the Pasterze Glacier, Austria: Spatial distribution, characteristics and transport of debris. – Zeitschrift für Geomorphologie Supplement, **52**, 3–25.

LUKAS, S. (2005): A test of the englacial thrusting hypothesis of "hummocky" moraine formation – case studies from the north-west Highlands, Scotland. – Boreas, **34**, 287–307.

LUKAS, S. (2006a): Moräne oder Till? Ein Vorschlag zur Beschreibung, Interpretation und Benennung glazigener Sedimente. – Zeitschrift für Gletscherkunde und Glazialgeologie, **39**, 141–159.

LUKAS, S. (2006b): Morphostratigraphic principles in glacier reconstruction – a perspective from the British Younger Dryas. – Progress in Physical Geography, **30**, 719–736.

LUKAS, S. (2007): Early-Holocene glacier fluctuations in Krundalen, south central Norway: palaeo-glacier dynamics and palaeoclimate. – The Holocene, **17**, 585–598.

LUKAS, S. & BENN, D.I. (2006): Retreat dynamics of Younger Dryas glaciers in the far NW Scottish Highlands reconstructed from moraine sequences. – Scottish Geographical Journal, **122**, 308–325.

LUKAS, S., NICHOLSON, L.I., ROSS, F.H. & HUMLUM, O. (2005): Formation, meltout processes and landscape alteration of high-arctic ice-cored moraines – examples from Nordenskiöld Land, central Spitsbergen. – Polar Geography, **29**, 157–187.

LUKAS, S., NICHOLSON, L.I. & HUMLUM, O. (2007): Comment on Lønne and Lyså 2005: Deglaciation dynamics following the Little Ice Age on Svalbard: Implications for shaping of landscapes at high latitudes. – Geomorphology, **72**, 300–319; Geomorphology, **84**, 145–149.

RÖTHLISBERGER, F. & SCHNEEBELI, W. (1979): Genesis of lateral moraine complexes, demonstrated by fossil soils and trunks: indicators of postglacial climatic fluctuations. – In: C. SCHLÜCHTER (ed.): Moraines and varves, 387–419, Rotterdam (Balkema).

Manuskript bei der Schriftleitung eingelangt am 18. Juni 2008