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Latero-frontal moraine formation and modification in Alpine environments

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In alpine glaciated valley landsystems, high latero-frontal moraines commonly mark the maximum extent of Holocene, but also lateglacial glacier advances (e.g. 1850, 1920, 1980 AD, Younger Dryas). A thorough understanding of the current modes of moraine formation based on detailed sedimentological analyses, however, is largely lacking for these environments. It is important to close this gap in knowledge since the processes of moraine formation can give a reliable insight into glacier dynamics, and hence climate-glacier interactions, at the time of moraine formation (e.g. Lukas, 2007). The apparent shortfall in knowledge is particularly problematic as such moraines are the most commonly-used landforms in glacier and palaeoclimate reconstructions, and it is in this field that the paucity of robust models of moraine formation has the largest impact.

Detailed sedimentological logging, clast shape and fabric measurements and process observations at some modern glaciers in the European Alps show that such moraines have been formed by a combination of submarginal glaciotectonisation of pre-existing sediments (forming the core/base of moraines) and supraglacial gravitational sedimentation in contact with the ice margin (forming the upper part of moraines). The latter sediments occasionally show signs of subsequent glaciotectonisation. Where this is the case, the highest sediments are usually devoid of deformation structures and therefore record the youngest stacking event that also shaped the present moraine surface. Sedimentological observations in Younger Dryas moraines reveal very similar sediments

suggesting a distinct Alpine glacial landsystem in which high latero-frontal moraines are formed by active, temperate to partly polythermal, valley or corrie glaciers. Clast shape analyses reveal that material is dominantly subglacially-transported and transferred to the glacier surface along englacial shear planes. Field observations over several years demonstrate that subsequent meltout of this subglacial sediment on the surface and saturation with meltwater produces ubiquitous supraglacial debris flows. These are then stacked against the ice-margin during stationary phases, thus providing an explanation for the supraglacial stacking of subglacially-transported sediments observed in moraine exposures.

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. Field observations also indicate that modern lateral moraines are partly modified by dead-ice meltout, especially along their lower slopes. Comparison with contemporary high-arctic environments such as Svalbard suggests that the processes of alteration have a large impact on the resulting landform assemblage and that preservation potential of ice-marginal moraines is limited under continuous permafrost conditions (e.g. Lukas et al., 2005). On the contrary, the degree of modification of Alpine lateral moraines is much less severe, possibly due to the discontinuous nature of mountain permafrost, the lower amount of dead ice contained within them and higher melt rates of dead-ice bodies.

Although research is ongoing, the model proposed here enriches previous attempts to synthesise moraine formative processes at large lateral moraines in Alpine regions and provides a working template for the interpretation of such moraines during other times such as the Younger Dryas.

References

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