



Recent formation of terminal moraines at temperate glaciers in South Norway

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Due to the dominating trend of retreat at the majority of mountain glaciers worldwide, there are few potential opportunities to study recent terminal moraine formation at these temperate (warm-based) glaciers. A number of glaciers in Jotunheimen alongside with some outlets of Jostedalsbreen, both South Norway, have been studied. These temperate glaciers experienced the formation of terminal moraine formation during the 1990s when they underwent a frontal advance or stationary front. Detailed observations during moraine formation, morphological moraine profiles, and the results of sedimentological analysis (e.g. clast roundness) are presented to reveal some insights into the processes and mechanisms involved in this recent moraine formation. The interpretation of terminal moraines for their information about related frontal dynamics in connection with the investigation of Holocene glacier chronologies requires detailed knowledge about the predominating processes of moraine formation. Any study of recent processes of moraine formation could, therefore, improve this interpretation.

As all glaciers studied were warm-based, glaciotectonic processes and thrusting did not occur during moraine formation. However, at few glaciers in Jotunheimen with relatively flat glacier tongues located in an altitude just below the regional limit of sporadic permafrost, freezing on of subglacial sediment slabs due to penetrating winter frost is very likely to have taken place. The morphological structure of the moraine ridges and a higher percentage of subrounded sediment clasts of subglacial origin point towards this assumption. By contrast, at the low-lying outlets of Jostedalsbreen this process can be ruled out due to relative high winter air temperatures as one characteristic of their maritime "glaciological regime". Except for one glacier classified as special case, dumping of supraglacial debris was neither involved in moraine formation in Jotunheimen, nor at the normally debris-free outlets of Jostedalsbreen. For the latter mentioned, bulldozing was clearly confirmed as dominating process. Sediment characteristics of the sediment in the glacier foreland proximal to the recent terminal moraines were similar to those of the moraine ridges itself and the distal area. The sedimentological properties of the proglacial sediment are, in combination with the dynamics of the glacier front like e.g. (seasonal) advance distances, responsible for the morphology and size of the recent terminal moraines. Where the glacier front of these outlets rested on bedrock during the advance, no moraine formation took place.

Limited oscillation around the culmination of the recent advance around the year 2000 caused partly multi-ridged moraine systems. Other processes merely occurring locally depending on special environmental conditions include a snow-foot push mechanism over marginal snow beds and melt-out of englacial debris at shear-planes near the glacier front later deposited along the terminus. At most of the glacier studied, there was none or only a thin layer of subglacial debris at the base of the marginal glacier tongue. Pre-existing moraines could have acted as obstacle in the recent moraine formation at one glacier.

There is no simple regional mode of moraine formation but rather several processes involved. Their participation and impact is considerably variable, depending on local environmental factors and individual glacier dynamics. This spatial differentiation and local individuality has to be taken into account in the interpretation of moraine formation. The mode(s) of recent terminal formation presented are considered as representative examples for moraine formation during the "Little Ice Age".