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Melt-out till and ribbed moraine formation, a case study from south Sweden

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ABSTRACT

Hummocky moraine with dispersed agglomerations of ribbed moraine – here named 'Åsnen-type ribbed moraine' – forms a 20–40 km wide zone over Småland, south Sweden, terminated to the north by a sharp boundary to streamlined terrain. The hummocky/ribbed moraine zone can be geomorphologically linked to the subaqueous Göteborg Moraine, formed at an oscillation/stand-still phase during the deglaciation of the Swedish west coast. Based on detailed sedimentological and structural investigations of ribbed moraine ridges it is concluded that diamict sequences and associated sorted sediment were deposited due to passive melt-out from stagnant, debris-rich ice with synsedimentary deposition of sorted sediments, preferentially at a melting ice/bed interface. To accommodate for the geomorphological expression, such an interpretation further implies that debris-rich ice formed in an intermediate adfreezing zone between ice at the pressure-melting point and a frontal frozen zone at deglaciation. Basal debris-rich ice was stacked into transversally arranged zones (controlled moraine), forming ribbed moraine 'embryos', the active phase of ridge formation. The stacked sequences of debris-rich ice eventually melted out beneath a stable and melt-retarding supraglacial ablation complex to form the final moraine ridges, the passive phase of ridge formation. In areas with no stable supraglacial ablation complex, the resulting landform after final de-icing was a hummocky moraine landscape. Internal composition of moraine hummocks suggests that most of them are composed of sediment gravity flow sediments, intercalated with stream-deposited sediments, all resting on a platform of subglacial melt-out till. De-icing of the zone now occupied by hummocky and ribbed moraine took a considerable time; deglacial ^{14}C age differences from lake basins on either side of the geomorphic boundary to the streamlined terrain indicate a separation between active and stagnant ice along that boundary, and that it took another 200–300 yr for the stagnant ice zone to melt during the final formation of present-day landforms.

1. Introduction

Melt-out till, as defined by Evans et al. (2006), is "sediment released by melting or sublimation of stagnant or slowly moving debris-rich glacier ice, and directly deposited without subsequent transport or deformation". However, Evans et al. (2006) argue that it likely is spatially restricted in the geological records due to poor preservation potential (e.g., Paul and Eyles, 1990) and thus "remain predominantly theoretical constructs" (Evans et al., 2006, pp. 167–168). Also, sedimentological characteristics used by, e.g., Shaw (1979, 1982, 1983), Haldorsen and Shaw (1982) and Piotrowski (1994) to discriminate melt-out tills from other generic till types have lately been suggested to form also in traction till forming settings, and are thus not diagnostic for melt-out tills (Evans et al., 2006). However, the suggestion that melt-out till has a very low preservation potential, and thus should – more or less – not be expected to be found even if it possibly forms, is possibly as much a theoretical assumption as is argued for the sedimentary characteristics that are suggested to be used to discriminate melt-out till in ancient till sequences. It must be acknowledged that modern glacial environments might not totally cover and being perfect analogues to those deglacial environments that formed during down-wasting of the large Laurentide and Eurasian Ice Sheets (e.g. Shaw, 1994), and that the contribution of melt-out processes to formation of glacial landforms is still unclear. Also, based on investigations in western Arctic Canada on contemporary melt-out processes, Murton et al. (2005) state that Paul and Eyles' (1990) conclusion on the very low preservation potential of melt-out till "is sometimes unduly pessimistic".

A large area of transverse moraine ridges in southern Sweden (Fig. 1), what today would be classified as ribbed moraine (e.g. Dunlop and Clark, 2006), was formed due to in situ melt-out of transversely arranged zones of debris-rich ice according to Möller (1987). This interpretation was based on extensive sedimentological investigations in trenches across those moraines, as well as across moraine hummocks in interfingering hummocky moraine areas. The sedimentological parts of these investigations were briefly summarized in a paper by Björck and Möller (1987), but the emphasis was here on deglaciation chronology and environmental history, and much of the

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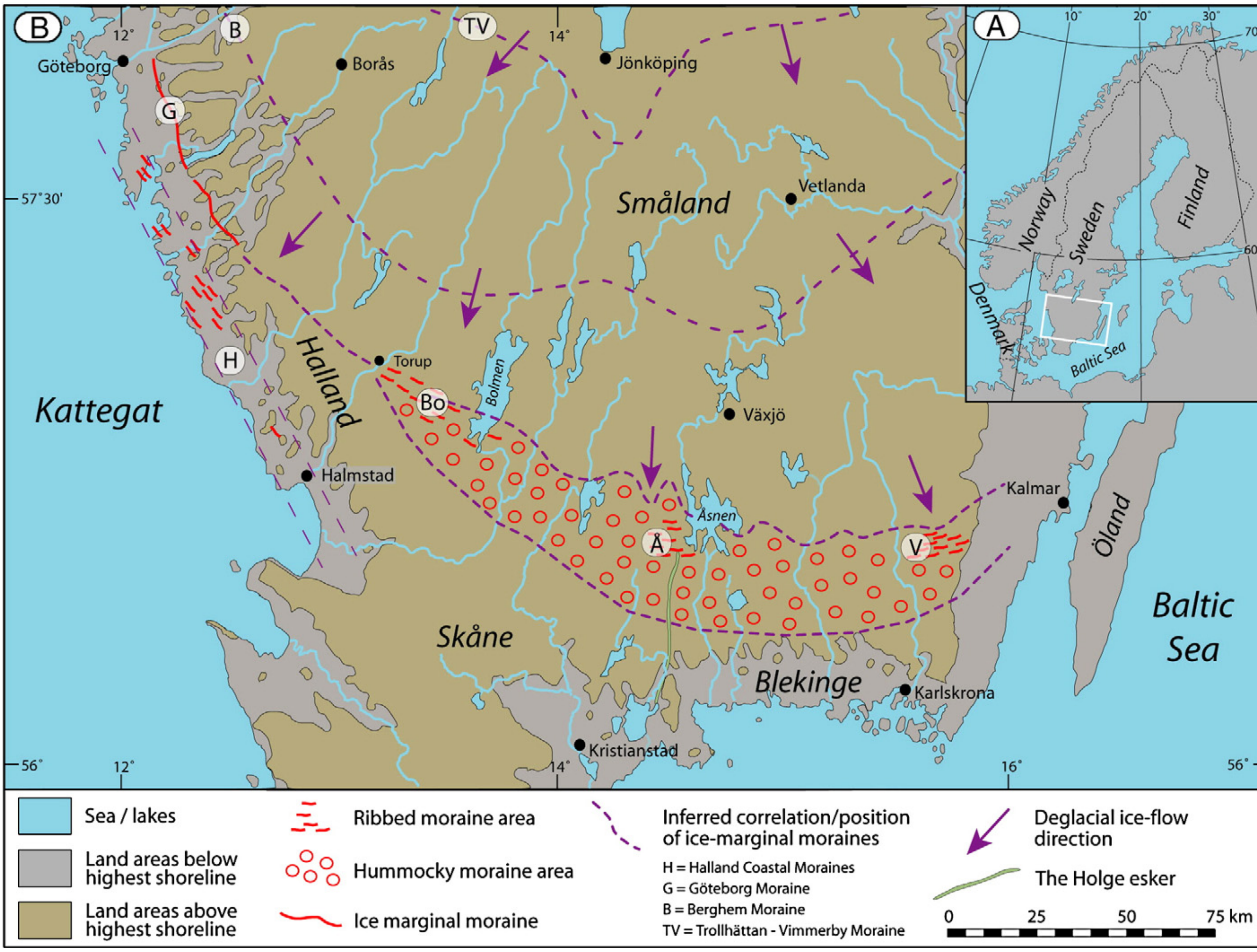

Fig. 1. Map of southern Sweden (for location, insert (A)), showing areas above and below the highest shoreline (marine limit in the west) at deglaciation, and inferred ice-marginal positions according to Lundqvist (2002). The continuation of the Göteborg moraine (G) into a regional coverage of hummocky moraine and ribbed moraine is indicated. Larger ribbed moraine areas are: Bo = the Bolmen area (cf. Johnsson, 1956), Å = the Åsnen area (Möller, 1987), V = the Vissefjärda–Karlslunda area (cf. Bergdahl, 1953). Ribbed moraine areas occur at a number of other sites within the demarcated zone, but on smaller scales, intercalated with hummocky moraine.

sedimentological work is thus still hidden in the unpublished thesis of Möller (1987). The present paper will summarize these sedimentological investigations and review previously made interpretations in light of the scientific advances in glacial sedimentology made during the last 20 yr.

2. Glacial geomorphology and chronological constraints of the case-study area

The case-study area is situated in the southern part of the province of Småland, southern Sweden (Fig. 1). Here, a fissure valley landscape to the south transforms into a crystalline bedrock upland plain of low relief at altitudes between 125 and 185 m a.s.l. (above sea level). Following the formation of the Last Glacial Maximum (LGM) terminal moraines in northern Germany and Denmark at c. 22–21 kyr BP (e.g., Ehlers et al., 2004) and a number of lobate ice-marginal oscillations in the Baltic basin into Denmark and southern Skåne (cf. Houmark-Nielsen, 2004; Larsen et al., 2009), the late Weichselian deglaciation in the south-eastern sector of the map area (Fig. 1) proceeded with a freshwater-terminating ice margin in the Baltic basin (the Baltic Ice Lake) and with no known ice-margin oscillations. When the east- to west-trending ice margin reached altitudes which today are at ~65 m a.s.l., the deglaciation proceeded northward in a subaerial environment and the highest shoreline evolved (Björck, 1981), demarcating the highest position of the Baltic Ice Lake in Blekinge and NE Skåne, a shoreline that formed more or less synchronously as it parallels the isobases for isostatic recovery (e.g., Björck and Möller, 1987).

Ice recession in the south-western sector over the province of Halland was within a marine environment, but as opposed to the south-eastern sector, the deglaciation was here characterized by a number of stand-still or oscillation events. The first is indicated by the ~15 km wide zone of the Halland Coastal Moraines (HCM; Fig. 1, zone H), radiocarbon dated to approximately 14.0 ^{14}C kyr BP on incorporated marine molluscs (Påsse, 1992), which corresponds to c. 18–16 cal kyr BP (Lundqvist and Wohlfart, 2001; also references therein on HCM). The next oscillation deposit, ~10 km towards the east, is the quite continuous Göteborg Moraine (Fig. 1; line G), which forms high ice-contact deposits in many valleys from east of Göteborg and southeast-wards, linked by smaller ridges over higher areas in between (Wenner, 1951; Wedel, 1971; Hillefors, 1975, 1979). Marine molluscs in clay, incorporated into glacitectonics on the proximal side of some of these ice-marginal deltas and subaqueous fans are dated to 12800–12600 ^{14}C yr BP (Hillefors, 1975, 1979). This time frame coincides with atmospheric ^{14}C plateaux and is thus hard to transfer into calendar years, but Lundqvist and Wohlfart (2001) suggest that the Göteborg Moraine could have formed any time between 15400 and 14500 cal yr BP. The Göteborg Moraine is readily traceable in its subaqueous parts, but as it approaches the marine limit (~70 m a.s.l.) towards the SE it becomes smaller and discontinuous.