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Glaciotectonic deformation pattern in the Mummocky moraine in the distal part of Saagjärv Drumlin Field, East-central Estonia

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Abstract. In the distal part of Saadjärv Drumlin Field, east-central Estonia, an area of hummocks resting on top of drumlins occur. Determined glaciotectonic structures indicated by lithostratigraphic and superposition records suggest that deforming processes took place during at least two different glacial episodes. Deformation structures are presented in two different diamicton layers which are separated from each other by undeformed in its upper part sand and gravel sequence. The dislocation of the lower, Early Weichselian Valgjärve Till, is a result of ice push or the structure is formed by gravitational loading of a semi-liquid plastic material into the basal crevasses. The upper, Late Weichselian Võrtsjärve Till, which is capping the hummocks was definitely deposited and deformed during the final glacial advance by deforming pressure from W to E. During the ice recession the study area was not only affected by dead ice processes but the front of massive ice was probably in equilibrium state for a short time intervals and a lateral pressure resulted sediment deformations at and below the ice margin.

Keywords: diamicton, glaciotectonic deformation, hummocky moraine, drumlins, Saadjärv Drumlin Field, Estonia

Introduction

Glaciotectonic features and origin of glaciodislocations has been discussed broadly (Croot 1988, Aber *et al.* 1989, Warren & Croot 1994). The term glaciotectonic refers to structures and landforms created by glacially induced deformation of pre-existing substratum (Aber 1982) by the active or dead ice condition (Levkov 1980). Many different kinds of glaciotectonic landforms and structures, resulting from the active glacier movement, have been recognized on the territory of Estonia. Among others ridges and hills, including drumlins, built of disturbed Quaternary sediments are the most common glaciotectonic landforms in Estonia (Rattas & Kalm 1999). Only a few studies have dealt with the deformation structures in greater detail describing the role of deformations on the formation of entire landform. Previous studies (Orviku 1930, Miidel *et al.* 1969) described glaciotectonic megablocks of pre-Quaternary deposits in northern Estonia, where the Quaternary cover is very thin or even lacking.

This paper describes glaciotectonic structures in hummocks resting on the drumlins in the distal part of Saadjärv Drumlin Field, east-central Estonia (Fig. 1). Previous studies (Raukas et al. 1971) have described this group of hummocks as kames or small kame field formed in dead-ice conditions in connection with the recession of the glacier from the drumlin field area. However, determined glaciotectonic deformations of sediments in the hummocks at Inglimägi Hill point to its complicated formation process at or below active ice margin.

The Inglimägi Hill rises up to 15 m above the surrounding area, whereas the altitude of the hill top reaches 85 m a.s.l. The hill rests on the top of drumlin and consists of massive or rhythmically-bedded gravel (Gms-Gm) and fine sand (Sm) in thickness of 16-23+ m which is covered by 2-6 m thick reddish-brown massive sandy diamicton layer (Dmm) (Fig. 2). According to drilling data there is a second till horizon below of the glaciofluvial deposits at a depth of 58-65 m a.s.l. Surface of the lower, greyish-brown diamicton (Dmg) apparently denotes also the drumlin's upper surface under the Inglimägi Hill.

Earlier, in the vicinity of the study area, the glaciotectonic deformation structures were described at the site of buried Holsteinian interglacial deposits at Kõrveküla. In this section interrupted layers and dissected blocks of sapropelite were described (Liivrand & Saarse 1983, Levkov & Liivrand 1988, Liivrand 1991). It is not clear during which ice advance and from where the interglacial deposits were taken and moved into their present location. The purpose of the present investigation is to demonstrate the role of glaciotectonic processes in formation of hummocky moraine relief, to determine the direction of deforming force and reconstruct glaciotectonic history of the study area.

Deformation pattern

All the studied deformed successions were found in the Inglimägi gravel pit, in NW part of the Inglimägi Hill, and described in open sections of a nongrooved remnant in the middle part of the pit (Fig. 2). In order to reveal the types of deformations and to determine the direction of deforming force, orientation and dip of deformed beds were measured in sections Inglimägi 1 and 2. In the sec-

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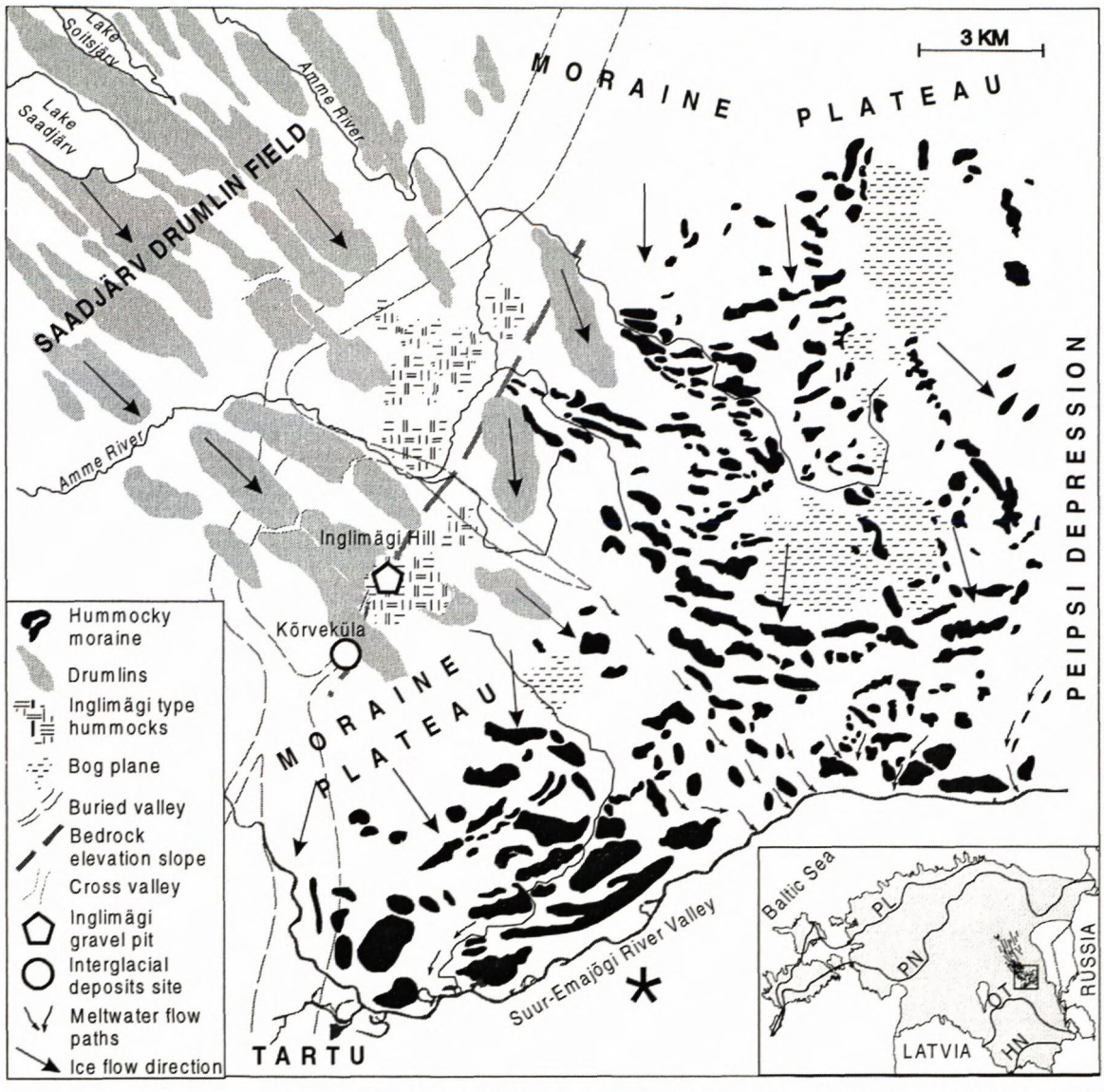

Fig. 1. A map showing the location of the Inglimägi Hill and the general morphology of the surrounding area. A scheme right blank on the map include ice margin positions during the Weichselian final deglaciation (HN-Haanja, OT-Otepää, PN-Pandivere, PL-Palivere ice marginal zones) and the location of the study area.

tion Inglimägi 3 an indistinct body of greyish-brown diamicton (Dmg) crops out. This diamicton is most probably derived from the till horizon underneath the meltwater sediment complex, which earlier was determined only in boreholes.

Section Inglimägi 1. Strongly deformed strata of the stratified diamicton (Dms) were found in NS oriented part of the open section (Fig. 2/1). Interrupted unconnected blocks of this diamicton (Dms) are incorporated into the basal layer of the overlaying massive silty-sandy matrix-supported diamicton (Dmm). Also lenses of fine sand and gravel from underlaying meltwater sequence are pushed to the surface of the stratified diamicton (Dms). Occasionally between the interrupted blocks of stratified diamicton (Dms) choatic pebbles are heaped up. The deformed part of the section is ovelain by 3-4 m thick massive, clast supported diamicton (Dmm).

Section Inglimägi 2. Glaciotectonic deformations in the basal layer of the uppermost massive diamicton (Dmm) are represented by thrust slices with dips of strata between 10-45°. Due to ice shoving of pre-existing meltwater deposits some sand and gravel lenses lie almost in vertical position (Fig. 2/2). Determined structures show that the deformations were caused by the pressure from 278° W (Fig. 2). Such structure could be interpreted as a part of fold or diapir formed during plastic deformation.

Section Inglimägi 3. An indistinct body of greyish-brown graded diamicton (Dmg) derived probably from the lower till horizon which is not cropping out in the gravel pit. The boundary between mixed unconsolidated diamicton and meltwater sand is not distinct (Fig. 2/3). According to drilling data the lower till horizon is laying at an altitude of 58-65 m a.s.l., that is about 4-5 m below the bottom of the gravel pit (Fig. 2). Most likely the body of the greyish-brown diamicton (Dmg) in the middle of rhythmically-bedded glaciofluvial sand (Sm) is a dislocation in the block or vein shape either pushed by the ice on the surface of earlier deposited sediments, or formed by

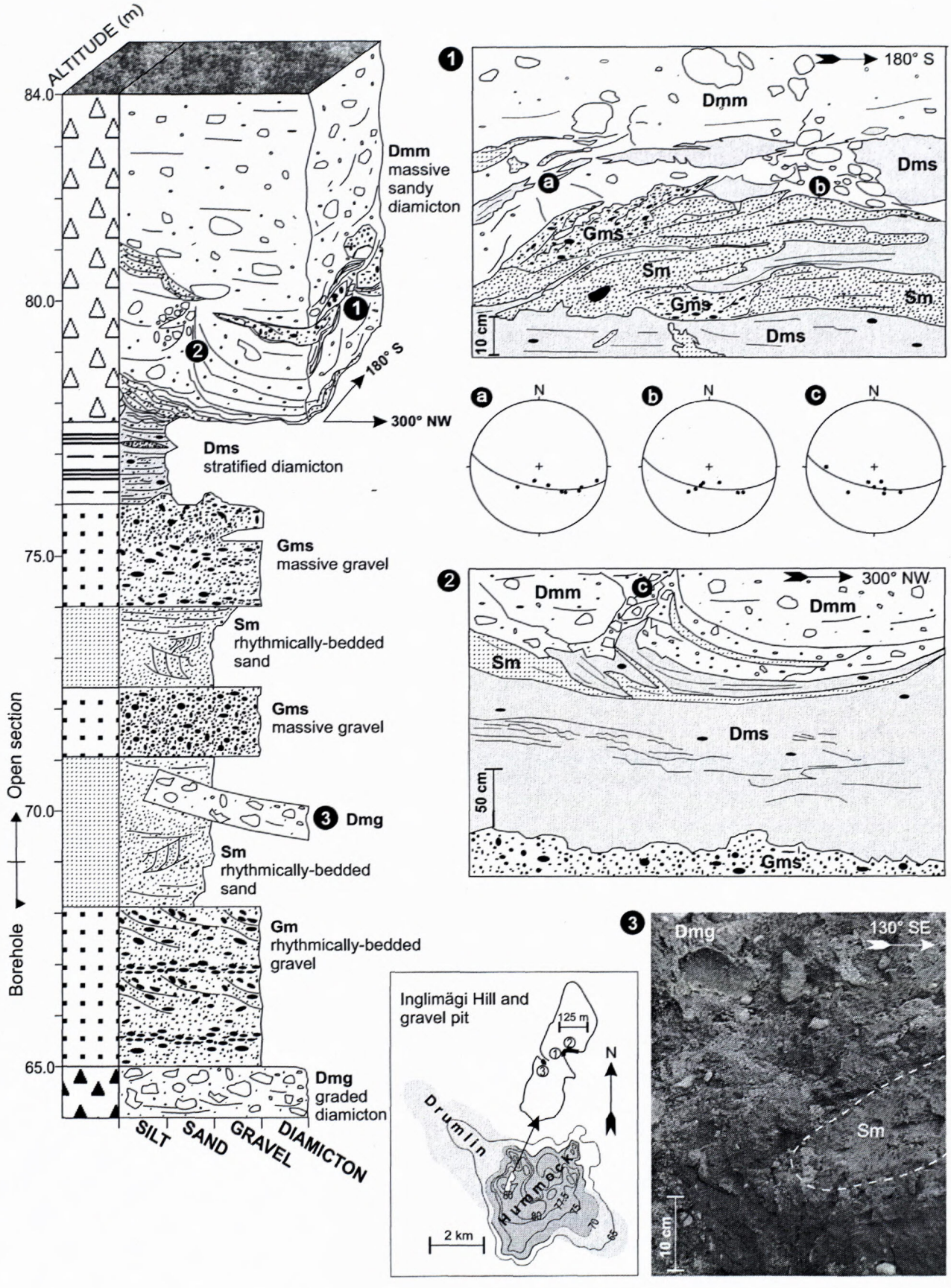

Fig. 2. General log of the hummocks at the Inglimägi Hill showing lithostratigraphy and deformed beds displayed in the Inglimägi gravel pit. Orientations of strata and shear plains are marked on the lower hemisphere of the stereographic Schmidt projection. Lithostratigraphical codes by Eyles et al. 1983.

gravitational loading of a semi-liquid plastic material into the basal crevasses of the ice.

Origin and history of deformation

Deformed suite of glacigenic deposits is located at the margin of Devonian sandstone terrain covered by till-cored hummocky moraine in south-east and drumlinized topography in north-west (Fig. 1). Deformation structures occur in two different diamicton layers which are separated from each other by undeformed meltwater sand/ gravel sequence (Fig. 2). According to the lithostratigraphic record of the area (Kajak 1965, Raukas 1978, Rattas 1997) the lower greyish-brown till horizon belongs to the Early Weichselian (Valgjärve Till) which occurs in cores of many drumlins in the Saadjärv Drumlin Field area. Controversial viewpoints were presented regarding the origin of the glaciofluvial deposits between two uppermost till horizons in drumlins' structure. In most cases they were interpreted as meltwater deposits of the Early Weichselian (Kajak 1965, Raukas 1978, Rattas 1997). However, in the southeastern part of the Saadjärv Drumlin Field they correlate with the meltwater deposits which accumulated during the Late Weichselian final deglaciation in stagnant ice phase, owing to kame and kettle topography (Raukas et al. 1971, Rõuk 1977). The uppermost reddish-brown massive till horizon has been correlated with the Late Weichselian (Võrtsjärve Till) and was deposited subglacially or by melting of dead ice rafts.

Presumably the deformations in the hummocks of Inglimägi Hill were formed at least during two different glacial episodes between of which accumulation of meltwater deposits took place. As indicated by the lithostratigraphy and the superposition records, the deforming process of Early Weichselian Valgjärve Till had to form before deposition of the glaciofluvial sequence overlaying the dislocation. The block or vein shape dislocation of the greyish-brown graded diamicton (Dmg) has inserted into the rhythmically-bedded fine grained sand (Sm) at the depth of 70 m a.s.l. Unfortunately, more detailed palaeogeographic reconstrustions are difficult, because of the lower boundary of dislocation can not be followed in the open section.

Deformations in the stratified diamicton (Dms) and uppermost massive diamicton (Dmm) were initiated by the final recession of the Late Weichselian ice sheet which receded from the area between Otepää and Pandivere stages, 12 600 and 12 250 BP, respectively. Hummocky moraine relief between the Saadjärv Drumlin Field and the Suur-Emajõgi River Valley (Rõuk 1977) refers to the contact of two different ice lobe flows - southerly direction flow along the Peipsi depression, and southeasterly direction flow over the drumlin field area, streamlining the drumlins. Adjoining of the two ice lobes caused the ice stagnantion and below the outer stagnant margins of ice lobes the hummocky moraine was produced. Deformations were caused by a small readvance of the active ice front from the west by the ice pressure to the underlaying semi-liquid glacial deposits.

Conclusions

The glaciotectonic deformation pattern in the hummocks of Inglimägi Hill has a relatively small size and the distribution of the structures suggests, that the deformations occured during two different ice advance episodes. As indicated by the lithostratigraphic record, the deforming process of the Early Weichselian Valgjärve Till had to take place before deposition of the glaciofluvial deposits overlaying the dislocation. Deformations in the Late Weichselian Võrtsjärve Till were initiated by the very last ice lobes in the area. The Saadjärv Drumlin Field area was not only affected by dead ice processes but the front of massive ice was probably for a short time intervals in equilibrium state, when a lateral pressure was causing sediment deformations at and below the ice margin.

Acknowledgements

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