Rock-cored drumlins on Bornholm, Denmark

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The surface morphology of Denmark is predominantly of glacial origin, created in depositional, deformational and erosional environments. In addition, postglacial marine, freshwater and aeolian processes have formed a variety of landforms. Overviews of the Danish landscape were published as geomorphological maps (Milthers 1948; Schou 1949; Smed 1981), and a new one is currently in preparation. On Bornholm, the morphology differs from the rest of the country because bedrock is present at or near the surface. This paper describes drumlins formed on bedrock on Bornholm, which have not previously been recognised.

New geomorphological map of Denmark 1:200 000

The purpose is to create a map based on the Geographical Information Systems (GIS). To draw the boundaries of the different landform types as precisely as possible, the morphology was re-interpreted on the basis of topographical maps, LiDAR (light detection and ranging) data, geological maps as well as available literature. The scale of the new map is 1:200 000, but it is compiled at 1:100 000 and will be published in both a printed and a digital version, the former in four map sheets (Jacobsen in press): (1) northern Jylland, (2) central Jylland, (3) southern Jylland and Fyn and (4) Sjælland, surrounding islands and Bornholm. So far, a preliminary version of southern Jylland has been published (Gravesen *et al.* 2004), and the map sheet covering Sjælland, the surrounding islands and Bornholm is completed.

Most of the surface features have already been described (Milthers 1948; Schou 1949; Smed 1981). However, the morphological elements shown on these maps vary to some degree. The new geomorphological map of Denmark also differs significantly from older maps, and some surface elements are re-interpreted. New elements include mega-scale glacial lineations and Rogen moraines, and on Lolland a valley formerly classified as a tunnel valley is re-interpreted as a fracture valley.

Bornholm

Large parts of Bornholm consist of pre-Quaternary crystalline bedrock with a discontinuous, thin cover of Quaternary sediments and is classified as glacially scoured bedrock on the geomorphological map (Fig. 1). During the Quaternary glaciations, the bedrock was affected by overriding glaciers. It mainly shows erosional features such as fracture valleys and mega-scale glacial lineations, but also smaller features, not shown on the map, such as roches moutonnées and glacial striae (Grönwall & Milthers 1916; Gravesen 1996).

One of the most pronounced terrain features on Bornholm is fracture valleys, which are subglacially eroded faults and fracture zones within the basement rocks. These valleys outline the fault systems from multiple deformation phases in the Sorgenfrei–Tornquist Zone (Grönwall & Milthers 1916; Graversen 2009). The main orientations of the fracture valleys are N–S, NNE–SSW and NE–SW. A few are oriented NW–SE.

On Bornholm, the orientations of glacial striae show two general directions: NE–SW and ESE–WNW (Fig. 2; Grönwall & Milthers 1916). Mega-scale glacial lineations within the glacially scoured bedrock terrain are parallel with the measured glacial striae, and most of them are oriented NE–SW.

In general, the two populations of glacial striae on Bornholm occur in two different groups of pre-Quaternary rocks. In the southern part of Bornholm, the pre-Quaternary geology is dominated by sandstone, shale and unconsolidated or poorly consolidated sediments, which are softer than the granites and gneisses in the rest of the island. The southern part of Bornholm is dominated by a till plain. Mega-lineations in this till plain show a slightly curved ESE–WNW trend and are parallel to the dominant orientation of glacial striae in the area (Figs 1, 2).

Marginal moraines are not as distinct as in other parts of Denmark. They occur as scattered sandy and gravelly hills, and outline three ice marginal stages in the central and northern parts of Bornholm (Fig. 2). A N–S-trending ridge in the south-eastern part of Bornholm, associated with a kame, is also interpreted as a marginal moraine (Fig. 1). It is a low ridge that separates a till plain with mega-lineations to the west from a smooth till plain to the east. A few small outwash plains are found in south-western Bornholm. Raised beaches and beach ridges from the Baltic Ice Lake are found along the coast at different levels, especially towards the east and north (Fig. 1).

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Rock-cored drumlins

In the northernmost part of Bornholm, within the glacially scoured bedrock terrain, there are ten elongated hills with typical drumlin shapes (Figs 1, 3). Drumlins are subglacial bedforms that were generated by the activity of overriding ice. Drumlins are oval-shaped hills that formed beneath an ice sheet and aligned in the direction of ice flow, and they are common and widespread in formerly glaciated regions. The formation of drumlins has been widely discussed, and they are one of the most studied glacial landforms on Earth (Clark *et al.* 2009; Johnson *et al.* 2010). On Bornholm, LiDAR data have been invaluable in recognising these features (Fig. 3). Like other drumlins, those on Bornholm are oval, and the surface has smooth contours with gradual fall to all

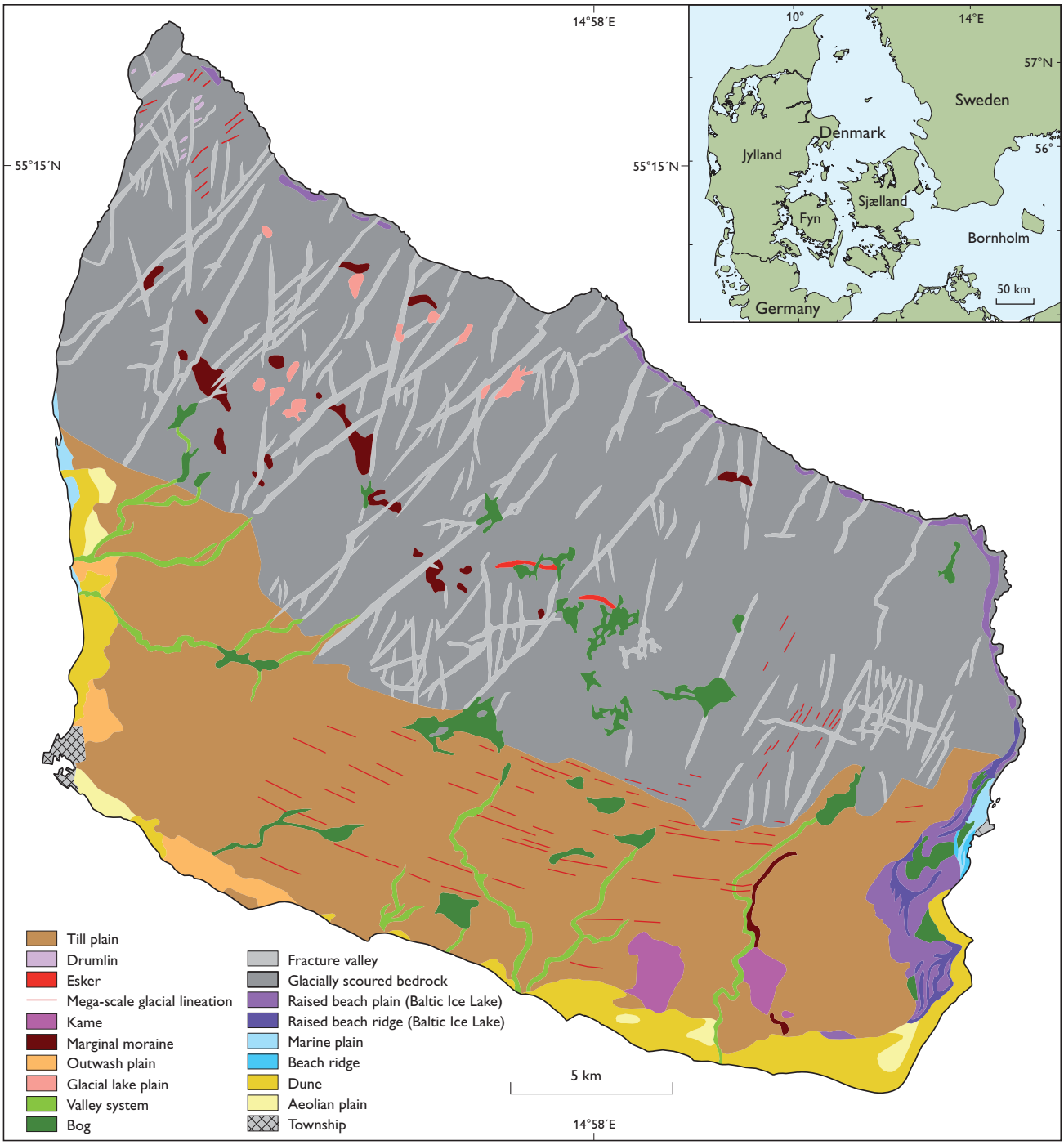

Fig. 1. Geomorphological map of Bornholm.

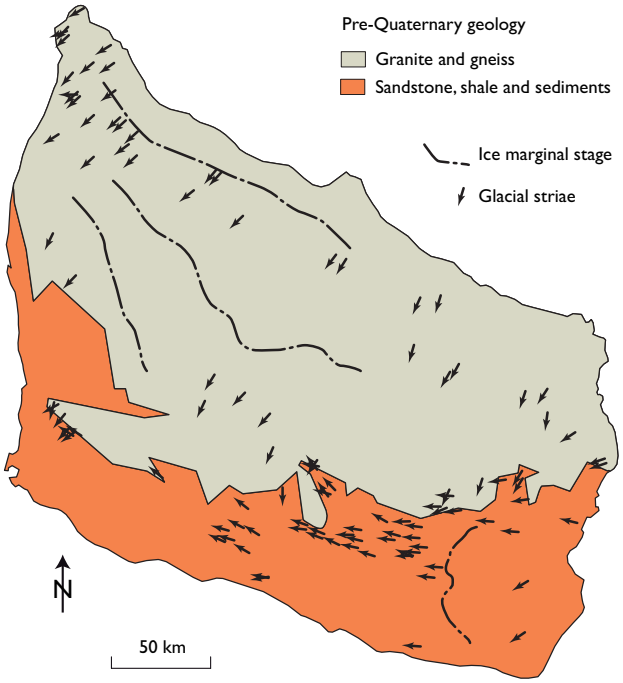

Fig. 2. Map of Bornholm showing orientation of glacial striae on bedrock, the distribution of crystalline and sedimentary bedrock types and ice marginal stages (after Grönwall & Milthers 1916; Hansen & Poulsen 1977).

sides. The length of the drumlins varies from 140 m to a little more than 600 m and their heights from 5 m to 31 m (Table 1). Their length to width ratio varies from 1.6 to 2.9 with an average of 2.3. The orientation of the hills is NE–SW, with an average of 50°.

The drumlins have a core of granite and are more or less covered by till (Fig. 3) that has predominantly been deposited towards the south-west on the lee side of the drumlins. The ice movement direction, indicated by glacial striae, is from the north-east (Grönwall & Milthers 1916), and the till cover is thickest on the south-western lee side of the drumlins.

Table 1. Dimensions of the drumlins on Bornholm

Number/ Name	Length (m)	Width (m)	Height (m)	L:W ratio	Orientation (°)
1 Langebjerg	612	211	31	2.9	60
2 Kælderbakke	140	67	7	2.1	65
3 Høje Meder	177	102	25	1.7	46
4 Kajbjerg	332	160	10	2.1	48
5 Byggehøj	532	205	8	2.6	46
6 Hestenshøj	330	145	10	2.3	56
7 Blåholtshus	395	137	10	2.9	51
8 Brogård	225	98	5	2.3	47
9 Blåholtsgård	391	148	10	2.6	43
10 Hammershus	389	239	25	1.6	39

Discussion

In the northern part of Bornholm, the drumlins and glacial striae indicate an ice-movement direction from the north-east to the south-west and are developed on crystalline bedrock. A few glacial striations have an E–W orientation (Fig. 2). In the southern part of Bornholm, only ice-movement directions from E to W are seen within the softer bedrock. These E–W erosional features were formed during a subsequent ice-stream event, which erased earlier NE–SW features in the southern part, but did not have the capacity to erode the harder crystalline bedrock. It appears that the subglacial conditions during the ice advances from the north-east were suitable for erosion of the granites on the northern part of Bornholm.

As indicated by the fracture valleys, the fault pattern is in N–S, NNE–SSW and NE–SW directions in this part of Bornholm, which is probably also true for the joint pattern. This joint and fault pattern could also favour formation of the elongated hills in this NE–SW direction, and would result in a preferred direction of erosional features by the ice advances from the north-east.

The orientations of the erosional features range from 39° to 65° and could reflect several ice advances, although they cannot clearly be separated into two or more directions. Investigations of drumlins in Sweden (Hättestrand *et al.* 2004) show that rock-cored drumlins are formed by successive phases of erosion. If this also holds for the drumlins of Bornholm, then they may have been formed during several ice advances or even ice ages, and only by glaciers advancing from the north-east.

Conclusions

On the northern part of Bornholm, ten bedrock-cored drumlins are recognised and are included in the new digital, geomorphological map of Denmark at a 1:200 000 scale. The LiDAR data were of great value in recognising them, although they are also recognisable from the contours of the topographic maps. The drumlins have a core of granite and are more or less covered with till that was predominantly deposited towards the south-west on the lee side of the drumlins. The lengths vary from 140 m to 612 m, and the height from 5 m to 31 m.

The orientation of the drumlins is NE–SW, with an average strike of 50° formed by subglacial processes during one or several ice advances from the north-east. The orientation of the fracture valleys could very well intensify the preferred erosional orientation parallel to the drumlins, and thus be an important factor in the drumlin formation.

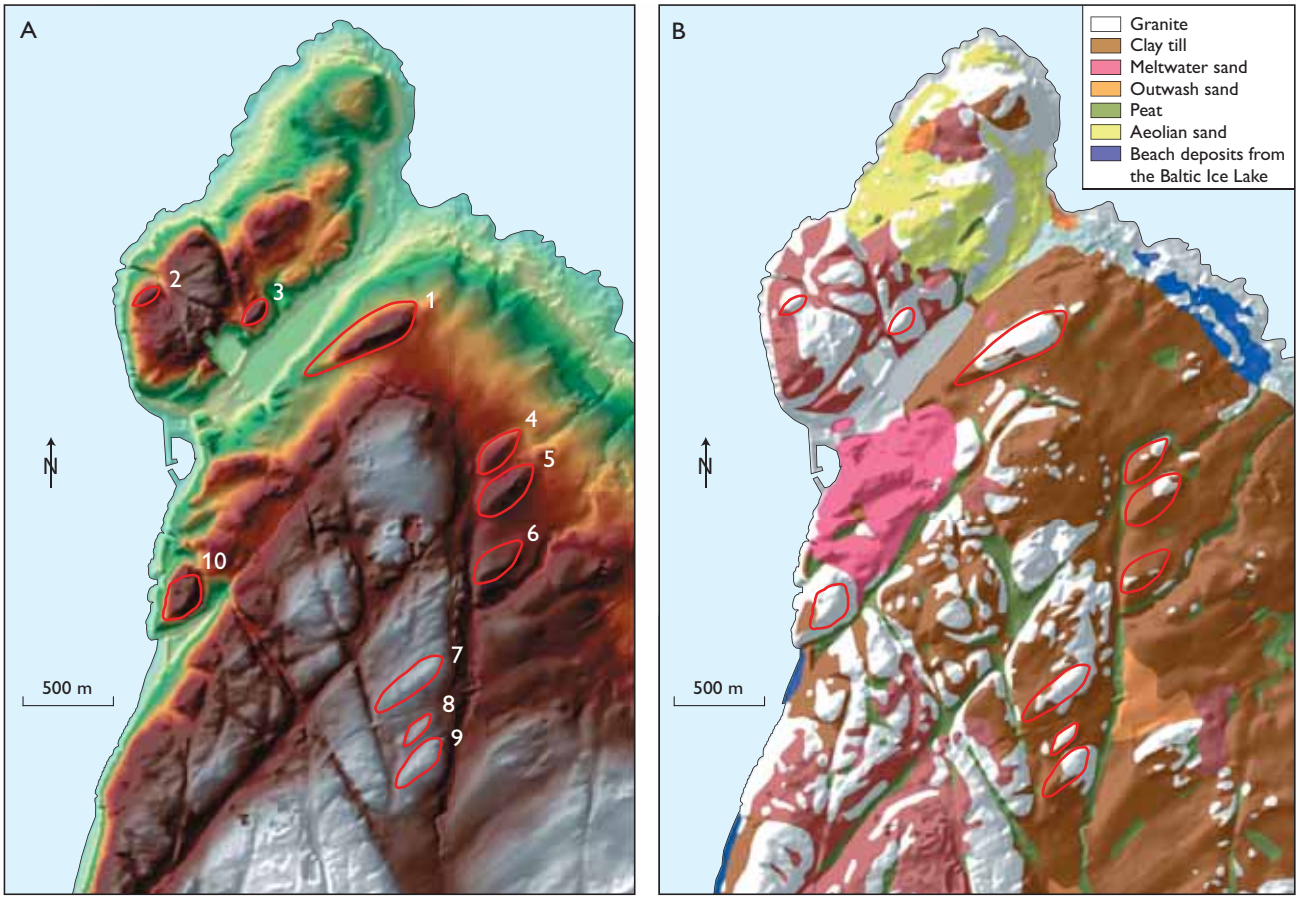

Fig. 3. **A**: LiDAR map of the northernmost part of Bornholm. The elevation varies from sea level to 118 m, and the highest parts are shown in white. The drumlins are indicated with red lines. The numbers refer to Table 1. **B**: Geological map of the same area.

References

Clark, C.D., Hughes, A.L.C., Greenwood, S.L., Spagnolo, M. & Ng, F.S.L. 2009: Size and shape characteristics of drumlins, derived from a large sample, and associated scaling laws. Quaternary Science Reviews **28**, 677–692.

Gravesen, P. 1996: Geologisk set – Bornholm. En beskrivelse af områder af national geologisk interesse, 208 pp. København: Miljøministeriet, Skov- og Naturstyrelsen og Danmarks og Grønlands Geologiske Undersøgelse.

Gravesen P., Jakobsen, P.R., Binderup, M. & Rasmussen, E.S. 2004: Geologisk set – Det sydlige Jylland. En beskrivelse af områder af national geologisk interesse, 188 pp. København: Miljøministeriet, Skov- og Naturstyrelsen og Danmarks og Grønlands Geologiske Undersøgelse.

Graversen, O. 2009: Structural analysis of superimposed fault systems of the Bornholm horst block, Tornquist Zone, Denmark. Bulletin of the Geological Society of Denmark **57**, 25–49.

Grönwall, K.A. & Milthers, V. 1916: Beskrivelse til geologisk Kort over Danmark i Maalestok 1:100 000, Kortbladet Bornholm. Danmarks Geologiske Undersøgelse I. Række **13**, 281 pp. + atlas.

Hansen, M. & Poulsen, V. (eds) 1977: Geologi på Bornholm, 96 pp. Varv ekskursionsfører **1**. København: Tidsskriftet Varv.

Hättestrand, C., Götz, S., Näslund, J.O., Fabel, D. & Stroeven, A.P. 2004: Drumlin formation time: evidence from northern and central Sweden. Geografiska Annaler **86A**, 155–167.

Jakobsen, P.R. in press: Geomorphological map of Denmark, 1:200 000, 4 map sheets. Copenhagen: Geological Survey of Denmark and Greenland.

Johnson, M.D., Schomacker, A., Benediktsson, Í.Ö., Geiger, A.J., Ferguson, A. & Ingólfsson, Ó. 2010: Active drumlin field revealed at the margin of Múlajökull, Iceland: a surge-type glacier. Geology **38**, 943–946.

Milthers, V. 1948: Det danske Istidslandskabs Terrænformer og deres Opstaaen. Danmarks Geologiske Undersøgelse III. Række **28**, 233 pp.

Schou, A. 1949: Atlas of Denmark, **I**, Landscapes, 160 pp. + atlas. Copenhagen: Det Kongelige Danske Geografiske Selskab.

Smed, P. 1981: Landskabskort over Danmark, sheet 4, Sjælland, Lolland, Falster, Bornholm. Brenderup: Geografforlaget.

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