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The Young Baltic advance in the western Baltic depression

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The last Weichselian glacial advance into the western Baltic depression, the so-called "Young Baltic" glacier advance is described. In the southern Baltic depression, ice masses flowed westwards and fanned out in the western Baltic region where they terminated along the end moraines of the East Jutland advance (Denmark), Sehberg advance (Schleswig-Holstein) and Mecklenburg advance (Mecklenburg-Vorpommern). The westward ice advance is likely due to the rapid melting of Norwegian and Swedish ice masses which had previously blocked the more easterly ice masses from draining to the west and north-west. The deposition of a purely eastern-sourced debris facies by a Baltic ice stream in the far west might be the result of ice/bed separation during flow.

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INTRODUCTION

The term "Baltic ice" is used by Danish geologists (e.g. Andersen, 1945; Berthelsen, 1973; Houmark-Nielsen, 1985) to describe a glacier mainly sourced in northern Scandinavia and which, flowing southwards, passed the Baltic depression between Sweden and the Baltic States, as reflected by the composition of its drift. A high proportion of Palaeozoic limestone derived from rock outcrops on the bottom of the Baltic Sea, especially around the islands of Gotland and Öland, is typical. A "Central Baltic"drift (or facies) is additionally typified by distinctive dolomite and crystalline rock clasts from the islands of Åland and their northern and southern vicinity, and an "East Baltic" drift by abundant dolomite and Åland rocks. Yet another facies occurs, with predominating east Swedish crystalline rocks together with Palaeozoic limestones and locally also some dolomites. This facies probably orginated from an ice stream along the present Swedish coast or — if containing dolomites and central Swedish rocks — from a confluence of contributory ice streams from the Swedish uplands with the Central Baltic main stream. I propose the term "Svecobaltic" for this composition.

In most Baltic facies significant amounts of Precambrian red-violet sandstones (Jotnian Sandstone or Nexø-Sandstone, Table 1) are also found (*cf.* Schuddebeurs, 1981).

The term "Young Baltic" is used for the last Weichselian glacier advance reaching Denmark and Schleswig-Holstein, in contrast to an early Weichselian, the "Old Baltic" and the latest Saalian, the "palaeobaltic" advance.

THE YOUNG BALTIC GLACIATION

In Denmark the Young Baltic advance is separated into two (or three) individual phases. The oldest reached the East Jutland marginal line, the next (the Belt Sea advance) reached a line crossing the Flensburg fjord, the island of Funen and then followed a line north of the Great Belt and Sealand. A third and last active phase in the West Baltic area had its margin along the Darßer Schwelle, the threshold in the Baltic Sea between North Mecklenburg and the island of Falster. Further to the north it embraces the Fakse Bight, the Køge Bight, the southern part of the Øresund, and the south-westernmost area of Skane (Smed, 1994).

In North Germany the glacial margins are locally uncertain or disputed. A connection of the East Jutland line with the Pomeranian line as long suggested by many geologists (e.g. Sjörring, 1981; Stephan, 1994) has been rejected by others on the basis of clast composition in the tills (Smed and Rühberg, pers. comm.). In Mecklenburg-Vorpommern the W3-ground moraine wedging out north of the Rosenthaler Staffel (Heerdt,

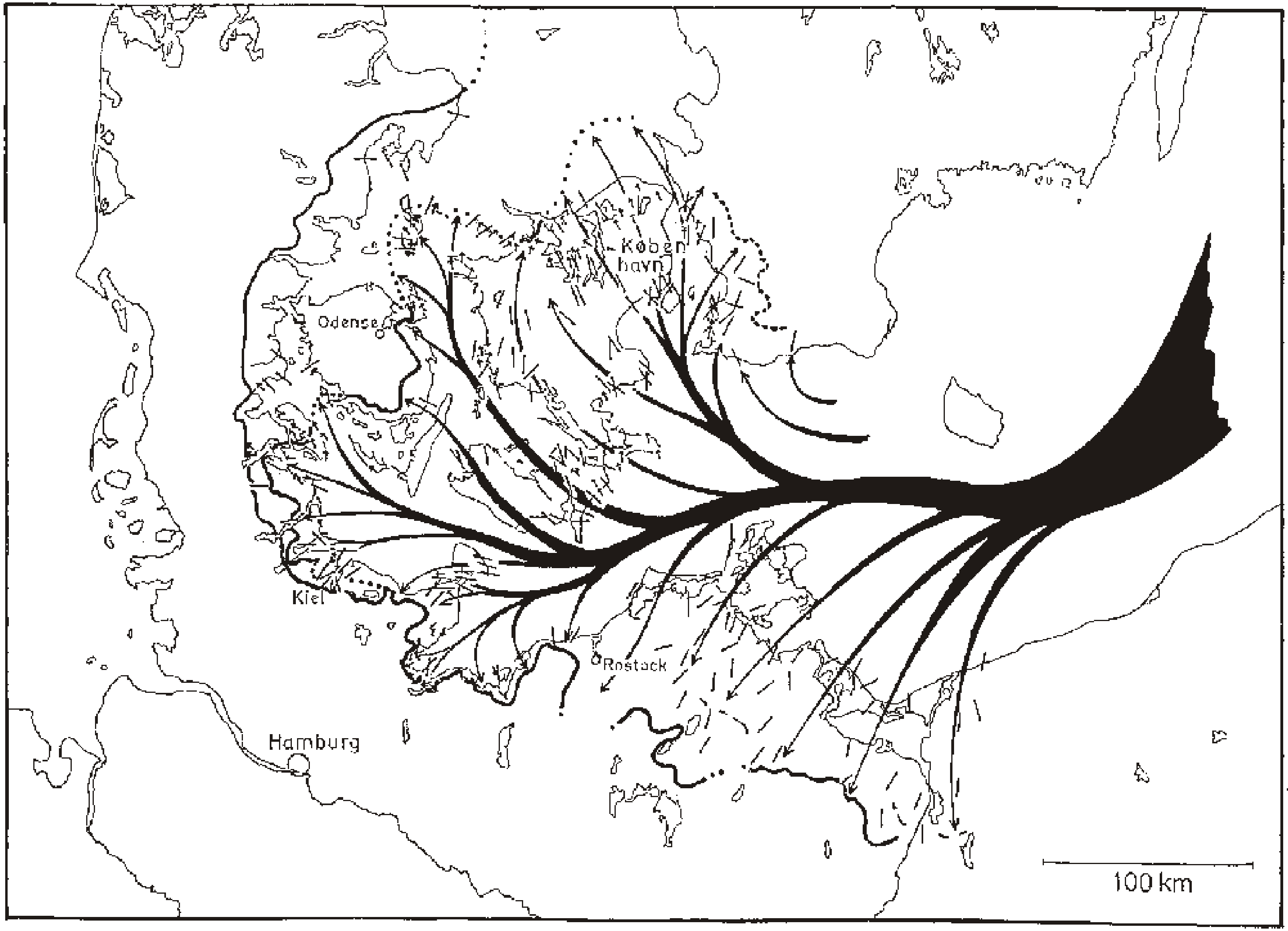

Fig. 1. Flow lines of the Weichselian Young Baltic advance in the western Baltic depression (after Stephan, 1994, modified)

short lines — direction of local ice flow deduced from fabric measurements or striations; short arrows — local ice push-direction; solid outer line — margin of the first Young Baltic advance (East Jutland advance in Denmark, Sehberg advance in Schleswig-Holstein, Mecklenburg advance and extent of the W3-till in Mecklenburg-Vorpommern); solid and broken inner line — margin of the second Young Baltic advance (Belt Sea advance in Denmark, Warleberg advance in Schleswig-Holstein)

1965; Cepek, 1967) belongs to the Young Baltic advance, there called the Mecklenburg advance (Eiermann, 1984, “Mecklenburger Stadium”; Rühberg, 1987; Rühberg *et al.*, 1995). In Schleswig-Holstein a Young Baltic till is known, for instance north of Kiel and at the northern side of the Eckernförde Bay. It is typified by crystalline rocks from the islands of Åland (Table 1) and, where unweathered, by abundant Palaeozoic limestone clasts and some of dolomite. It is likely that the Sehberg end moraine (Stephan *et al.*, 1983) represents the margin of the Young Baltic ice.

Table 1

Clasts indicative of provenance recovered from the decalcified surface of the Young Baltic till between Knoop and Friedrichshof, north of Kiel, Schleswig-Holstein, North Germany, counting by Schlüter, 1998; unpublished

Rock type	Quantity
Åland Aplitgranite	1
Other Åland rocks	28
Red Baltic Sea Quartz Porphyry	8
Brown Baltic Sea Quartz Porphyry	2
Baltic Sea Diabase	1
Garberg Porphyry	1
Red Växjö Granite	12
Grey Växjö Granite	1
Virbo Granite	6
Sala Granite	3
Uppsala Granite	1
Oskarshamn Granite	2
Bornholm Granite	1
Rhombe Porphyry	1
Hardeberga Sandstone	1
Chiasma Sandstone	1
Nexø Sandstone	14

TGZ: λ 17.62°/ϕ 57.49°; TGZ — Theoretisches Geschiebe-Zentrum (theoretical center of indicator rocks; Lüttig, 1957); λ — longitude, ϕ — latitude

YOUNG BALTIC FLOW LINES

Stephan (1994) compiled directions of local ice flow deduced from fabric analyses and from striations from all countries bordering the Western Baltic Sea. Most measurements from Denmark, many of them unpublished, were made available by S. Sjörring, and from Sweden by B. Ringberg. Together with published information (e.g. Richter, 1937) and many of my own measurements from Schleswig-Holstein they provided the basis for detailed reconstruction of flow lines of the Young Baltic ice (Fig. 1). This ice had its source in northern Scandinavia and the northern Baltic region and, forming a large ice stream, first flowed along the eastern Baltic depression southwards where it terminated in the Pomeranian uplands. The ice flow then turned west, passing the depression between South Skane and North Germany, the main stream flowing through the “gate” between the islands of Bornholm and Rügen. It fanned out in the western Baltic region with widely varying flow directions: SW-wards from the island of Rügen to Lübeck Bay (though S-wards around the island of Poel); W-wards from the island of Fehmarn to Eckernförde Bay in Schleswig-Holstein (with some deflections towards the SW at older landforms), and from there NW-wards to the Little Belt. Further to the east NNW- to N-directions predominated in Denmark. In south-west Skane NNE- to NE-directions have been found (*cf.* Ringberg, 1988).

MODELLING THE BALTIC ICE STREAM

For more than a century, geologists have tried to explain the different composition of tills in Denmark and North Germany by the existence of different ice streams in glaciated Scandinavia. Early observations and interpretations were made by De Geer (e.g. 1888, tab. 2 with a Baltic glacier advance in the western Baltic depression) and Gottsche (1883).

Zeise (1889) and Madsen (1898), from their studies of the “Baltic moraine girdle”, inferred repeated glaciations with Baltic (E–W flowing) ice masses separated by ice from the north. Torell (in: Zeise, 1889) explained the E–W flow direction by deflection of the normally southwards moving ice mass at the uplands at the southern margins of the Baltic depression and then by the flow of the ice along this depression towards the W. This concept was repeated by Gripp (1981).

Eissmann (1967), Woldstedt and Duphorn (1974) and others later explained the dominance of Baltic ice masses during the late phases of glaciations by a shift of the ice shed or the main ice accumulation centre (ice dome) in Scandinavia from W to E. Such a shift was first mentioned by Enquist (1918), then postulated by Ahlmann *et al.* (1942) and Ljunger (1943).

Zeise (1889) thought N–S ice flow to be restricted to the time of maximum glaciation in Scandinavia, preceded and followed by E–W flow along the Baltic depression. This fundamental model was modified by Wennberg (1949). He explained the late Baltic ice stream by turning of the primary main flow within the Scandinavian ice shield, due to the decay of the Småland- and the Dalarna-ice during the melt phase. Baltic ice masses should therefore have displaced central and south Swedish ice masses in the western Baltic region. A very similar idea was published by Stephan (in: Ehlers *et al.*, 1984, melting of blocking western ice masses). The similarity with the concept proposed by De Geer (1888) is striking.

Current understanding suggests that during all larger Pleistocene glaciations or stadia there were likely cyclic changes of the main ice streams within the Scandinavian ice shield: N–S to radial ice flow during the ice maxima and a dominance of Baltic ice masses during the late phases of glaciations. Theoretically conditions occurring during the late phases (ice dome accumulation in the NE) should have existed also during the very early phases. Evidence for this view is the existence of the Early Weichselian "Old Baltic" till (e.g. Andersen, 1945). No such early Baltic tills are known from older glaciations, perhaps because of erosion of such tills during the following main glaciations.

Discussion concerning the behaviour of the E–W ice stream still continues. The striking composition of "red tills" (*cf.* Kabel, 1982; Ehlers, 1992; Stephan, 1998) has been explained by an englacial transport of East Baltic material, not mixed with other material from the glacier sole between the source area and the glacier margin (e.g. Ehlers, 1981; Schuddebeurs, 1981). Movement over large fields of "dead ice" of the preceding glaciation phase without contact with the ground may also be an explanation for the more or less pure East Baltic till facies found in the west (Woldstedt and Duphorn, 1974). A modified version of this mechanism was proposed by Müller *et al.* (1997) who believe that the Young Baltic ice — because of the striking lack of a till deposit — was moving over a frozen ice-dammed lake in front of the Wismar Lobe.

But movement over unfrozen water-oversaturated sediment or even over a water film is also a possibility. The first of these mechanisms is discussed by Boulton and Jones (1979). In their theory of such "deformable bed" conditions the ice could have been moving rapidly over a steadily and strongly deforming bed with little frictional resistance. In the second case the ice could have rapidly slid over a wet base with no or little contact with the ground (ice/bed-separation, Shaw and Kvill, 1984), an idea already published by Tyndall and Thomson (in: Haas, 1890; *cf.* Richter, 1937). Piotrowski and Kraus (1997) and Piotrowski and Tulaczyk (1999) postulated this for the last ice sheet in northwestern Germany. Such behaviour of the ice sheet in the Baltic depression is all the more likely since the ice flow followed the main (melt) water discharge towards the Kattegat, Skagerak, and the Norwegian Trough. This movement could have occasionally culminated in a surge.

The strong fanning out of the Young Baltic ice in the western Baltic region into older glacial depressions and the deposition of a commonly strikingly thin till bed could be additionally supported by the development of proglacial ice-dammed lakes between the glacier front and marginal uplands that were subsequently overridden ("overslid") by the ice. The frequent observation of thin glaciolacustrine sediments at the base of Young Baltic tills in the east of Schleswig-Holstein fits well with this explanation.

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