# The Storebælt gateway to the Baltic

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The present-day Storebælt (Great Belt), the waterway between the islands of Fyn and Sjælland (Fig. 1), contains deeply incised valleys, locally more than 50 m deep, and is of crucial importance to the water exchange between the fully marine Kattegat and the brackish Baltic Sea. The role of this important gateway changed significantly during the late and post-glacial period (since 15 000 B.P.), when the Baltic Basin experienced alternating freshwater, brackish and marine conditions as a result of changes in relative sea level (Figs 2, 3).

The importance of the Storebælt in understanding the dynamics of the Baltic Basin is reflected in the large number of studies carried out (see Bennike *et al.* 2004). The first detailed sedimentological and stratigraphic studies in the Storebælt area that demonstrated the presence of early Holocene freshwater deposits below the seabed were those of Krog (1960, 1965, 1971), who also presented the first shore-displacement curve for the area (Krog 1979).

## The *BALKAT* project

The late and post-glacial evolution of the south-western Baltic Sea has been studied in detail during the past 15 years as part of the multi-disciplinary *BALKAT* project, a co-operation between the Geological Survey of Denmark and Greenland (GEUS), the Baltic Sea Research Institute in Warnemünde, and other partners (Jensen *et al.* 2002). Acquisition and interpretation of shallow seismic data and sampling of vibrocores form the basis for sequence stratigraphic and sedimentological studies, which together with micro- and macropalaeontological studies have resulted in detailed interpretations of depositional environments. The chronology has been established by numerous radiocarbon dates.

Initial studies focused on the Fakse Bugt and Gedser Rev region and the history of the Baltic Ice Lake (Jensen & Stecker 1992; Lemke & Kuijpers 1995; Jensen *et al.* 1997) and were followed by detailed studies of the Ancylus Lake stage (Jensen *et al.* 1999). Further studies of relative shore-level changes in the region (Bennike & Jensen 1998) and the Femer Bælt threshold (Lemke *et al.* 2001) showed that local ice lakes developed in front of the retreating Fennoscandian ice sheet. Two major transgressions of the Baltic Ice Lake are recorded, with maximum highstand levels of approximately 30 m and 20 m below present sea level (Figs 2, 3; Björck 1995). The Ancylus Lake transgression reached just above the southern threshold of the Storebælt, and was followed by a regression that presumably exposed large parts of the former lake bottom (Figs 2, 3). The identification of these lake stages in the Femer Bælt area show a much wider distribution than previously expected, with possible connections to the Kattegat (Yoldia Sea, Littorina Sea) via the Storebælt (Fig. 3).

Studies in southern Kattegat and the northern Storebælt region have revealed that a late Pleistocene relative sea-level

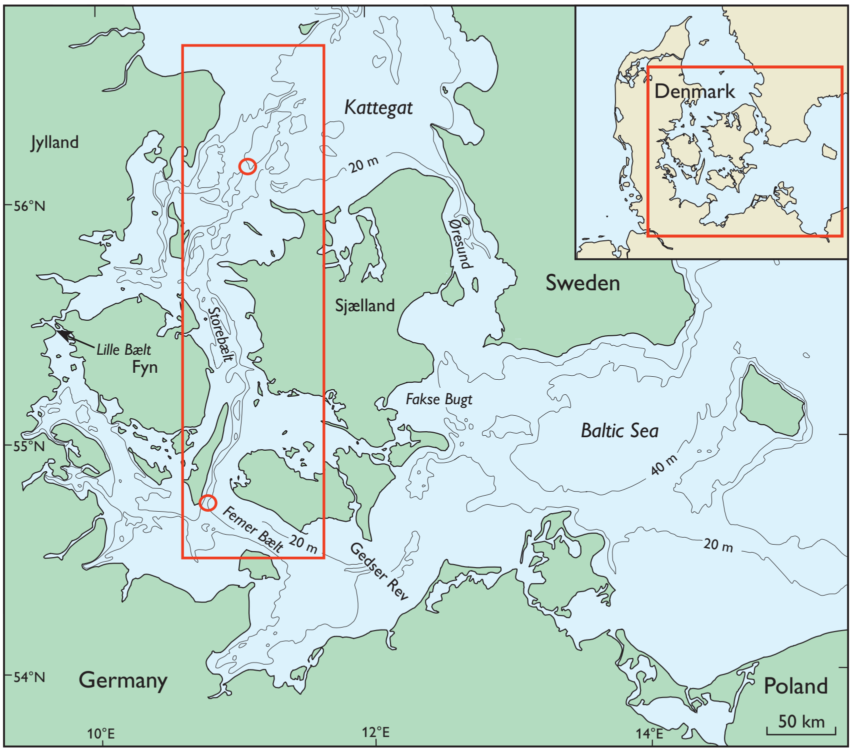


Fig. 1. Present-day general bathymetry of the south-western Baltic Sea. Location of Fig. 5 (**red frame**) and the northern and southern thresholds in Storebælt (**red circles**) are shown.

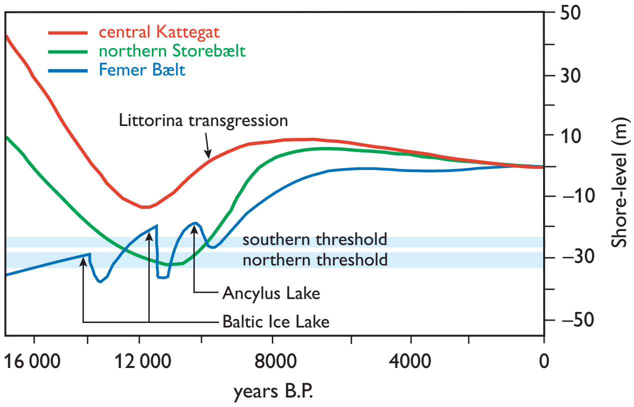


Fig. 2. Shore level changes relative to present-day sea level in central Kattegat, northern Storebælt and Femer Bælt. The levels of the thresholds in the Storebælt are indicated.

highstand was followed by a lowstand during the latest Pleistocene (12 000 – 11 500 B.P.; Fig. 2). This was in turn succeeded by the Littorina Sea transgression, which resulted in a series of back-stepping coastal deposits (Jensen *et al.* 2002).

Recent studies under the *BALKAT* project have been concentrated in the central Storebælt area and the northern and southern threshold areas in order to obtain a more detailed understanding of the interaction between the Kattegat and the Baltic Basin.

## The Storebælt gateway

The central Storebælt area, between the fully marine Kattegat and the brackish Baltic Basin, has been influenced by drainage from lakes in the Baltic area and marine transgressions from the Kattegat. Both depend on the relative levels of the southern and northern thresholds. In this area the incised valley fills provide a unique opportunity to study the initial effects of drainage and transgression, as well as the timing of these events, that – with some delay – had a great influence on the Baltic area.

During the later stages of the *BALKAT* project, shallow seismic data and vibrocores have been collected for the area extending from the northern entrance to the southernmost part of the Storebælt. The relative sea level changes in the southernmost Kattegat region (Fig. 2) are clearly recognised at the entrance to the Storebælt, where late glacial marine highstand sediments are cut by the Younger Dryas lowstand erosional unconformity and followed by an early Holocene succession of channel fill, estuary river mouth sediments and backstepping shoreface deposits (Fig. 4A, B; Bennike *et al.* 2000; Jensen *et al.* 2002).

The northern Storebælt threshold is located in a less than 1 km wide incised valley (Figs 1, 5). Profiles north and south of the threshold (Fig. 4C, D) show that marine transgressive deposits are found in the incised valley north of the threshold, whereas a transitional brackish unit exists below the Littorina Sea deposits south of the threshold. Radiocarbon datings of the brackish sediments using terrestrial plant macrofossils indicate that the initial transgression of the Littorina Sea took place at about 9400 B.P.

The central Storebælt incised valley (Figs 1, 4E) was formed by meltwater during the deglaciation about 17 000 B.P. (Bennike *et al.* 2004), and the initial fill is represented by late glacial lake sediments. The youngest late glacial unit is restricted to the channels, and is believed to be the Baltic Ice Lake extension into the Storebælt area. The late glacial sediments are truncated by an erosional unconformity overlain by Lower Holocene freshwater sediments that include river and lakeshore deposits, and followed by extensive lake deposits formed in the time interval between 10 900 and 8800 B.P. (Bennike *et al.* 2004). Deposition of the early river deposits is coeval with the maximum level of the Ancylus Lake. The initial sign of the marine transgression in the central Storebælt area is dated to 8100 B.P. by marine shells.

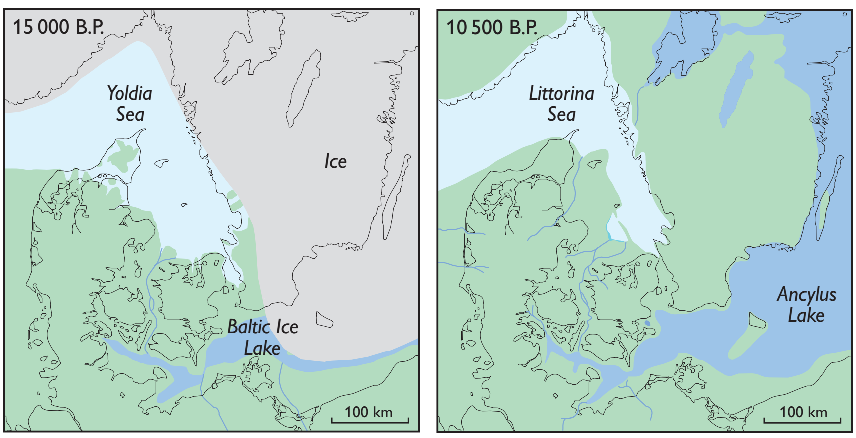


Fig. 3. Palaeogeographical maps showing the distribution of land and sea/lake at 15 000 years and 10 500 years B.P.

The threshold in the southernmost part of the Storebælt is found in a few hundred metres wide channel at about 25 m below present sea level (Figs 1, 4F, 5). However, fine-grained freshwater sediments dated to the time of maximum Ancylus Lake transgression at 10 300 B.P. brings the pre-Ancylus Lake threshold down to about 30 m below present sea level. There is no evidence of a rapid Ancylus Lake drainage (Dana River) as earlier proposed by Björck (1995).

## Initial marine transgression of the Storebælt

Based on the recently collected data it is possible to reconstruct a palaeogeographical scenario for the initial Holocene marine transgression (10 000 – 9500 B.P.) of the Storebælt area (Fig. 5).

At about 10 000 B.P. the Ancylus Lake was mainly drained by a river system located in the Storebælt area with an outlet in the southern Kattegat area (Bennike *et al.* 2000). In general, the drainage pathway through the Storebælt was restricted to channels less than 1 km wide. A transitional brackish estuary was restricted to the area immediately north-east of the northern threshold.

The transgression of the Littorina Sea resulted in flooding of the northern Storebælt threshold at about 9500 B.P. and a brackish environment extended to about 20 km south of the threshold. At the same time, a large local lake developed in the central and southern part of the Storebælt area due to a ground-water level rise, related to the relative sea level rise north of the northern Storebælt threshold, and brackish and marine conditions were gradually established in these areas around 9400–9100 B.P. (Winn *et al.* 1998; Bennike *et al.* 2004).

## Future perspectives

During the 15 years of *BALKAT* co-operation a unique database covering the late and postglacial sediments in the south-western Baltic region has been generated. The main key areas have now been studied, but further biostratigraphical investigations and datings are required for Lillebælt, Øresund and parts of Kattegat. When this work is completed, a detailed model of the postglacial evolution of the western Baltic region can be developed including data on palaeogeography, fauna and flora evolution, and climatic changes.

This model will be of great importance for future scientific co-operation involving marine geological, archaeological, ecological and palaeo-climatic studies in the rest of the Baltic region. Furthermore a detailed knowledge on the palaeogeographic evolution is important in locating potential sand and gravel resources. Large offshore construction works may also

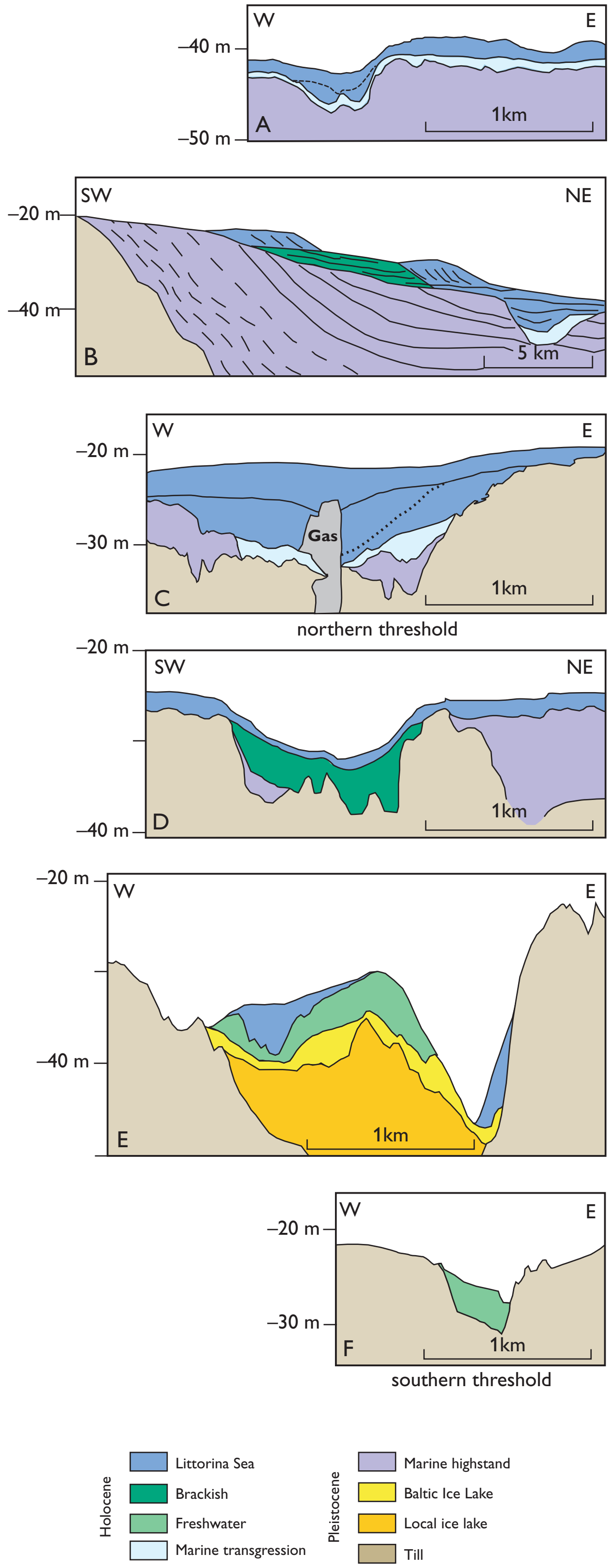


Fig. 4. Profiles illustrating the influence of the northern and southern thresholds in the zone between the fully marine Kattegat and the brackish to lacustrine central and southern parts of the Storebælt. For location of profiles, see Fig. 5.

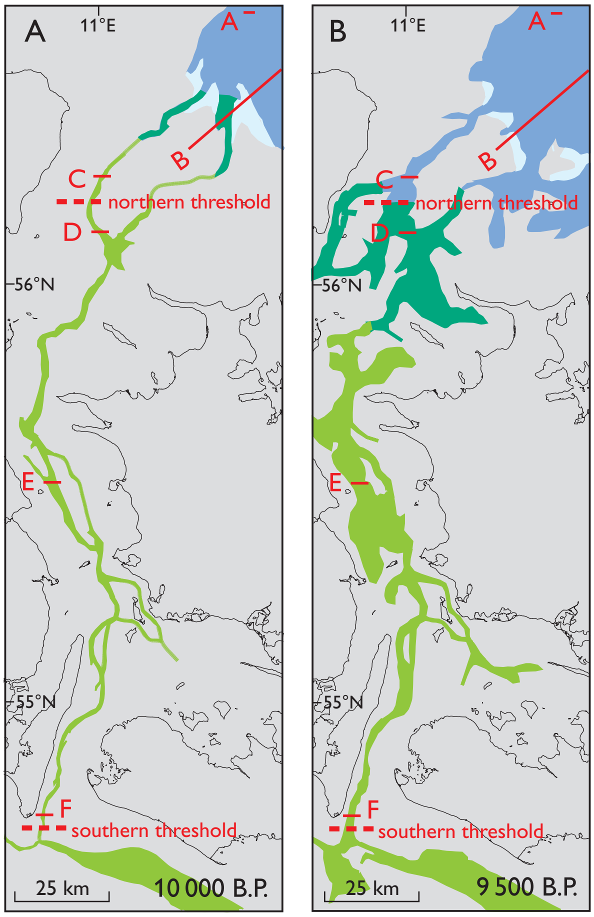


Fig. 5. Palaeogeographical maps of the Storebælt area during initial Holocene transgression. **A**: At *c.* 10 000 years B.P., before the transgression of the northern threshold, the Ancylus Lake was connected to Kattegat via a river system ending in a narrow, brackish estuary. **B**: After the threshold was transgressed at *c.* 9000 years B.P., a much more extensive brackish water estuarine complex developed at the mouth of the river, and a major lake was formed in the central part of the Storebælt area. For legend and sections A–F see Fig. 4.

benefit from the studies. For example, the planned Femer Bælt Link bridge requires seabed information for geotechnical, raw material and hydrographic evaluations, as well as for monitoring possible impacts on the environment.

## Acknowledgement

Our friend and colleague, Wolfram Lemke, unexpectedly passed away on 21 April 2005. We wish to acknowledge his enthusiastic participation in our joint projects and his inspiring contributions to our long-standing co-operation. His premature death is a great loss to the scientific community.

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