# Sedimentary facies and architecture of the Holocene to Recent Rømø barrier island in the Danish Wadden Sea

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This paper describes an ongoing multidisciplinary study on the development of the barrier islands in the Danish Wadden Sea (Vadehavet), carried out by the Department of Geography and Geology at the University of Copenhagen and the Geological Survey of Denmark and Greenland (GEUS). Nine sediment cores each *c.* 25 m long and a total of *c.* 45 km ground penetrating radar (GPR) profiles have been acquired on the islands of Rømø and Fanø. Geochemical and palaeontological analyses and dating of 150 core samples using optically stimulated luminescence (OSL) are in progress. This multidisciplinary approach has given new insights into the sedimentary architecture and development of the island, and the study is expected to result in a new detailed facies model. Such models are essential for an assessment of the effects of rising sea level associated with global warming. The new facies model can also be used as an analogue for subsurface oil or water reservoirs in similar sedimentary settings. This article presents selected core and GPR data from the Rømø barrier island.

## Setting

The Rømø barrier island is situated in the northern part of the European Wadden Sea (Fig. 1). The maximum tidal amplitude is *c* 1.8 m (Andersen & Pejrup 2001). During the last *c.* 8000 years, the area has experienced an overall relative sea-level rise of ~15 m (Behre 2007).

The island of Rømø is *c.* 14 km long and *c.* 4 km wide and separated from the mainland by a *c.* 8 km wide lagoon (Figs 1, 2). The island is connected to the mainland by a dam. Tidal inlets, *c.* 1 km across, occur at the northern and southern tips of the island. The inlets continue as tidal channels into the lagoon and cut sand flats and mixed flats. Subtidal ebb-deltas are located where the tidal inlets terminate in the North Sea (Fig. 3). The inlets reach depths of up to 30 m, as in the Listerdyb south of Rømø, or 4–10 m in the Juvre Dyb north of the island. The salt marsh area fringing the lagoonal coast of the island is up to 2 km broad. Sand flats, up to 2.7 km wide, with three, 0.8–1.6 km broad bars that migrate towards the island, characterise the north-western and south-western parts of the island (Fig. 2). Tidal creeks, up to *c.* 50 m wide, separate the bars. Active eastward migrating aeolian dunes are found on large parts of the island.

## Sedimentary facies of the Rømø barrier island

### Core wells

Seven core wells were drilled on the island, and depositional units were defined on the basis of sedimentary structures, grain sizes, sorting, organic material, fossils, trace fossils and rootlets. Data from the Rømø-4 and -1 wells are presented here.

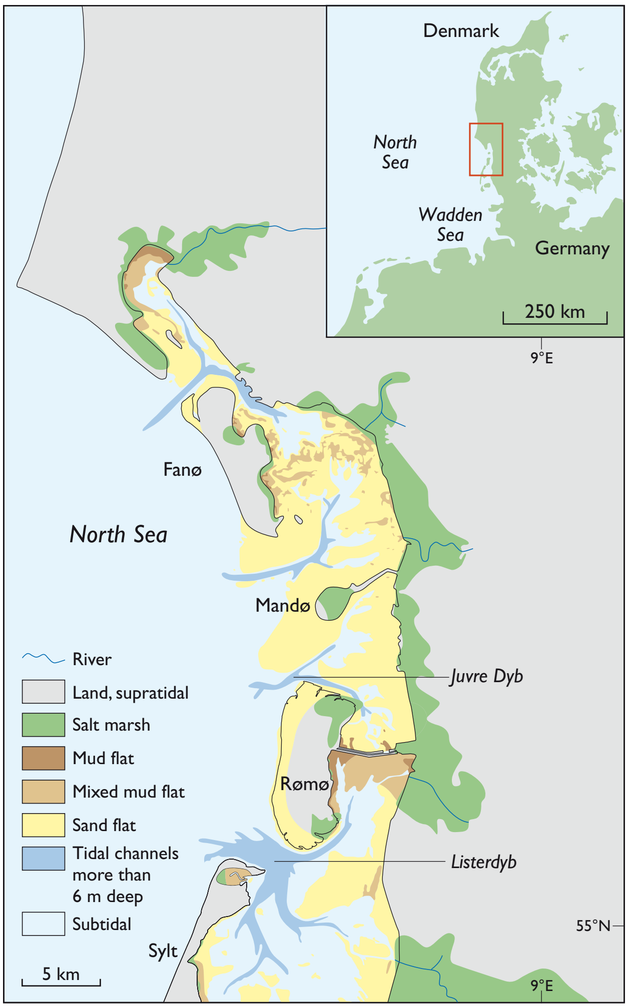


Fig. 1. The Danish Wadden Sea. The distribution of sediment types and subtidal channels are shown. The mainland of Jylland east of the lagoon consists of glacial deposits. Inset map shows the whole tidal Wadden Sea area. Modified from Pejrup (2006) and Sørensen *et al.* (2006).


Fig. 2. Orthophoto of the Rømø barrier island. The location of GPR reflection profiles and the seven core wells are shown. Very wide tidal sand flat characterise the north-western and south-western parts of Rømø. Rømø island is dominated by aeolian dunes that are migrating eastwards. Copyright Scankort.

In the Rømø-4 well the upper *c.* 3.5 m consist of well-sorted aeolian sand (Fig. 4). A mud bed, *c.* 20 cm thick and supposed to be deposited in a depression (swale) underlies the aeolian sand. About 11 m of medium-grained sand with numerous bivalve shells underlie the mud layer and are interpreted to have been deposited in a prograding to aggrading marine shoreface. At *c.* 2 m below mean s.l., a *c.* 0.3 m thick layer of coarse-grained sand may represent washover fans.

The Rømø-1 well that was drilled in the lagoon east of the island shows *c.* 8 m of bioturbated heteroliths of sand and mud with numerous bivalve shells, especially *Mytilus*, and gastropods below the dam (Figs 2, 4). The heteroliths represent back-barrier lagoonal mud- and sand flats and overlie 3 m of sand-streaked mud with numerous bivalve shells. Gyttja and peat layers, respectively 20 and 25 cm thick, underlie the mud (Fig. 4). The peat layer was probably deposited during the initial Holocene sea-level rise. Continued rise in sea level caused flooding of the peat swamp and formation of gytja, followed by lagoonal mud- and sand flats. The Holocene sediments overlie Pleistocene and Eeminan deposits.

The variation in composition of the dinoflagellate assemblages and other fossil algae from the core samples reflects shallow marine to lagoonal environments, in part with lowered salinity. The fauna of bivalves, snails and sea urchins in the cores is similar to that seen on the beaches of Rømø today. The rich but low-diversity fauna seen in the lagoonal deposit in the Rømø-1 well differs from the more diverse fauna with thick shells that is washed ashore on the open western coast at present. The fauna in the Rømø-4 well consists of small shells of the west coast fauna only. This suggests that the sand was deposited by washover events from the North Sea and that larger shells were left behind. The interpretations of the palynomorph assemblages and the macrofauna support the sedimentological interpretations and will be used in the reconstruction of the physical development of Rømø.

## Ground penetrating radar (GPR)

W–E and N–S-trending GPR sections with a total length of *c.* 30 km were acquired from Rømø using unshielded 100 MHz antennae manufactured by Sensors & Software Inc.


Fig. 3. Landsat image (+ETM 9 May 2001) of the Danish Wadden Sea with distinct tidal sand flats and subtidal channels. Note the subtidal ebb-deltas where the main channels terminate in the North Sea.

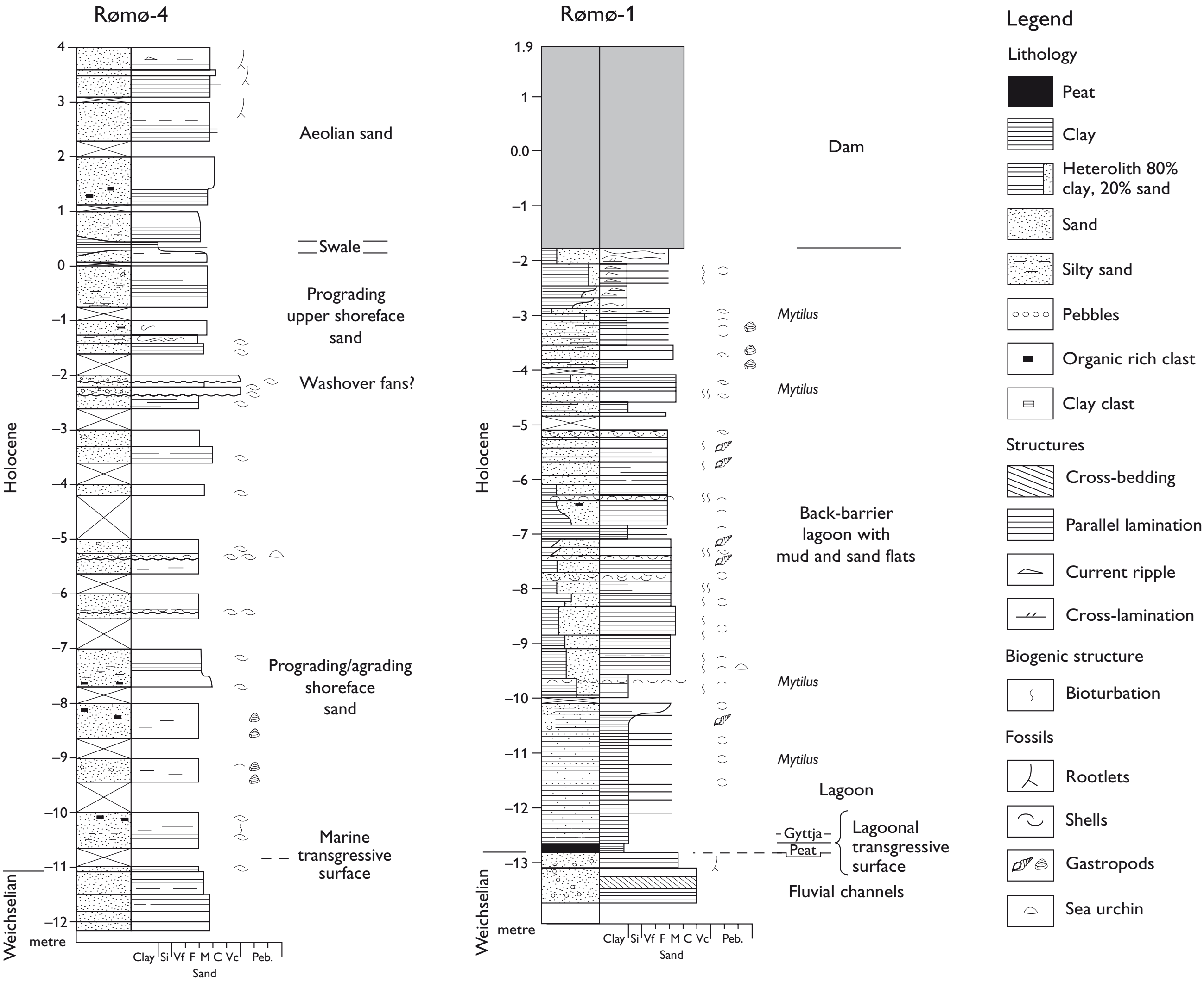


Fig. 4. Sedimentological core logs from the Rømø-1 and -4 wells, situated in the lagoon and the centre of Rømø, respectively. For locations see Fig. 2.

(Fig. 2; Nielsen *et al.* in press). Maximum signal penetration is *c.* 15 m in the central parts of the island where fresh groundwater is thickest, and the vertical resolution is 0.2–0.3 m. The reflected signal only reaches about 1 m depth at the margins of Rømø because of strong damping of the electromagnetic waves due to saltwater intrusion. Salt marsh, peat and mud layers also significantly reduce the signal penetration.

A GPR section from the central part of the island shows a beach ridge, *c.* 1.25 m high and *c.* 70 m wide, with a steep erosional side towards the west and a less steep side towards the east (Fig. 5). The top of the beach ridge is *c.* 0.5 m above mean s.l. Two superimposed cross-bedded units with east-dipping foresets occur upon the beach ridge. The lower unit is 0.8 m thick and *c.* 30 m long and the upper unit is *c.* 1 m thick and *c.* 50 m long (Fig. 5). East of the washover fans large, gently eastward-dipping clinoforms occur with much higher amplitude signal, which indicates that the sediments are organic or mud rich. Data from the Rømø-4 core well situated *c.* 75 m north of the section indicate that the high amplitude layer correlates with a 20 cm thick mud layer deposited in a swale (Fig. 4), consistent with previous findings elsewhere on the island (Nielsen *et al.* in press).

A more than 125 m wide set with clinoforms, *c.* 1.5 m thick, dipping in an eastward direction is found in the westernmost part of the section (Fig. 5). The set terminates eastwards in a channel-like structure. The clinoform set is interpreted as an eastward-migrating tidal bar filling in the western side of a 1.5 m deep tidal channel, forcing the channel eastwards, which is comparable to the modern situation illustrated in Fig. 3. The amplitude of the reflections in the channel sediments differs from those of the bar, suggesting that the channel fill is slightly muddier due to channel abandonment. The top of the channel and the bar are situated at the modern mean s.l.

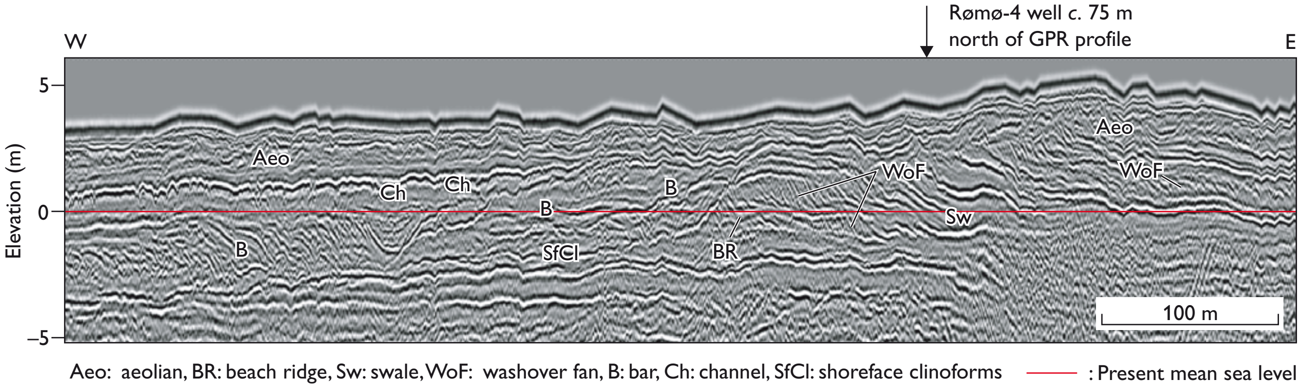


Fig. 5. West–east-trending ground penetrating radar profile T07a-1 from Rømø. The upper part of the section consists of aeolian sand. For location see Fig. 2.

Between the bar-channel complex and the beach ridge occur two sediment wedges, altogether *c*. 150 m across (Fig. 5). The eastern wedge onlaps the relatively steep western side of the beach ridge, whereas the western wedge onlaps the eastern wedge and is truncated by the channel to the west. The wedges were probably deposited by landward migrating bars that welded to the coast, causing a stepwise shoreface progradation. Aeolian sand lies on top of these foreshore sediments (Fig. 5). The gently westward dipping, high amplitude reflections in the deeper part of the section are interpreted as representing westward shoreface progradation, in agreement with the core data (Figs 4, 5).

## Discussion and conclusions

The cores and GPR sections provide high quality data for the identification of the depositional units that compose the Rømø barrier island, and a few examples of the units are presented here. The interpretations of the cores and the GPR sections show that the Rømø barrier island was never located as far east as the Rømø-1 well. Furthermore, lagoonal sediments are not present at the position of the Rømø-4 well suggesting that lagoonal conditions were never established at this location. However, data from the cores of the Rømø-6 and -3 wells (to be described in forthcoming papers) suggest that the western fringe of the lagoon reached the positions of these wells, because lagoonal deposits are identified below aeolian sand (Nielsen *et al*. in press).

Samples of sand from the cores have been submitted for OSL dating, and shells and organic matter are being dated by the $^{14}$C method. When the ages of the depositional units become available the development of the depositional units through time will be described in detail. Plots of sample depths against ages will be constructed to portray the relative sea level history and will, together with analyses of the mollusc fauna and palynomorph assemblages, provide additional constraints on the reconstructions of the development of the barrier island. The study will be concluded with a detailed reconstruction of the Holocene development of the Rømø barrier island.

## Acknowledgements


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