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Natural Sea Level Indicators Recording the Fluctuations of the Mean High Tide Level in the Southern North Sea

Due to coastal erosion on the seaward side of the East Friesian barrier islands, horizons consisting of subfossil tidal flat and salt marsh deposits are exposed which embrace the time span of the last 2000 years. These deposits are natural sea level indicators recording former fluctuations of the mean high tide level in the German Bight. By the use of various palaeoecological techniques, including pollen, plant macrofossil and diatom analyses, it has been possible to reconstruct those fluctuations. The information gap between the geological record of Holocene sea-level fluctuations, on the one hand, and those of recent tide gauge measurements, on the other hand, has thus been partially bridged.

Quaternary Sea Level Fluctuations in the Southern North Sea

The depositional history of the southern North Sea and the facies changes are strongly related to climatic variability during the Quaternary. Sea-level history in the area is characterized by several marine regression and transgression phases. In this connexion, the transgression cycle that started in the Weichselian Late-glacial and still continues today is best known. During the last glacial maximum, i.e. between 22 000 to 18 000 B. P., the North Sea was about 110-130 m below present sea level so that most parts of the North Sea basin were dry land (Jelgersma 1979). In the subsequent period climatic amelioration triggered an eustatic sea-level rise, which inundated pre-existing Pleistocene landscape *(Geest)*. This hampered drainage of the hinterland. A belt of mires was formed which continuously migrated in landward direction. Parts of these mires were eroded by tidal currents, however, over most of the coastal area they are preserved as the basal peat of the Holocene sedimentary sequences. The Holocene transgression did not advance continuously, but was interrupted by repeated phases of regressive coastal development. This can be clearly recognized by the presence of peat layers which are intercalated in the otherwise sandy, silty and clayey coastal sediments.

Methods

For the reconstruction of former sea-level stands, organic deposits formed in the course of Holocene transgression and regression cycles are key sources of evidence. These are peat layers, palaeosoil horizons (Dwog horizons), tidal flat and salt marsh deposits. They bear material that is amenable to radiocarbon dating and that offers the opportunity to fix former mean sea levels by decoding the environmental record contained in the form of macro- and microfossils, in other words the reconstruction of the facies.

It is widely recognized that the system of the East Friesian barrier islands is not stable, the position of the islands being closely tied-in with marine morphodynamic processes. In general, there are two directions of movement. Firstly, there is W-E migration, but here the movement is limited as it has been shown by reconstructions of the contours of the Pleistocene landscape. Secondly, there is a distinct N-S dislocation. Investigations of Barckhausen (1969), Hanisch (1980) and Streif (1990) show that the dunes and most probably the shoreline of the East Friesian Islands must have moved about 500 m to the south during the last 2000 years. Subsequently, the salt marsh deposits of the Islands were covered by dune sand and thus were preserved. Fig. 1 shows that these salt marsh deposits, which were originally formed on the landward side of the barrier islands, are nowadays exposed on the beach of the seaward side due to coastal erosion and shoreline displacement (Freund & Streif 1999). Sometimes the sequences show superimposed fossil horizons, separated from each other by small cliff-like structures that document in a particular way this dislocation pattern.

Although salt marshes look uniformly flat, there are recognizable differences which find expression in vegetation zoning. Under natural conditions this zoning reflects frequency and duration of inundation and soil salinity. The plant communities of the salt marshes leave behind distinct signatures in the form of pollen and macroremains (leafs, seed, fruits, etc.), which can be studied by pollen and macrofossil analyses. The deposits are therefore archives from which the environmental conditions at the time of formation can be reconstructed. Not only vegetation but also diatom assemblages in salt marsh deposits show a distinct relationship to tidal levels, which makes them a useful tool for the reconstruction of fluctuations of the mean high tide level (Zong & Horton 1999).

Salt Marsh and Tidal Flat Deposits as Natural Sea-level Indicators

Investigations on subfossil salt marsh and tidal flat deposits have been carried out to date on the islands of Borkum, Juist, Memmert, Langeoog, Wangerooge and Mellum. In this paper, first results are presented from Juist where conditions are favorable for the study of former sea-level fluctuations. Nowadays, subfossil horizons are particularly well exposed on the beach in the western part of the island between the Hammersee and the western end of the Bill dunes. In the course of field work during 1997-1999 more than 20 profiles were sampled which embrace elevations from -0.20 to +2.50 m NN (NN = German zero datum, i.e. approximately mean sea level). Hence, a more or less complete sere extending from the former tidal flat to the upper salt marsh could be reconstructed which spanned the interval ca. 1500-300 B.P. Occasionally, the deposits also contain some hints on pastoral activity associated with the salt marshes or the settlement history of the island. These include ditch systems, hoof marks of horses, cattle and sheep or archaeological artifacts such as fragments of pottery, iron and lead objects and salt marsh sod-wells or bricks. The last mentioned probably relate to ancient villages which were destroyed in the period after 1651 A.D. when the island was stricken by a series of severe storm surges.

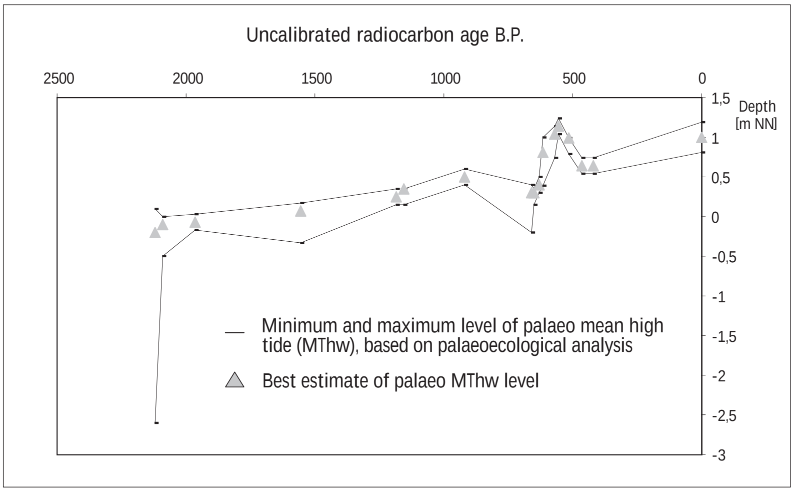
Fossil tidal flat deposits were sampled at altitudes of ca. -0.20 cm NN in the vicinity of the Bill dunes. Bivalves and snails of a tidal flat deposit at a corresponding altitude on the island of Borkum gave ^{14}C dates of 2090 ± 115 B.P. (Hv 22942) and 2120 ± 115 B.P. (Hv 22943). These dates relate to NN -0.30 to -0.23 m (*Hydrobia ulvae*) and NN -0.50 to -0.30 m (*Cardium edule*), respectively. The tidal flat on neighboring Juist was presumably also deposited at this time so that a mean high tide level at ca. 0 m NN can be postulated for this time slice. In the same profile three thin weakly humus-rich layers were recorded intercalated in marine sandy deposits but at a higher level (NN +0.27 to +0.51 m). Pollen and diatoms analyses show that these layers were formed under saline conditions of the intertidal zone. Large amounts of allochthonous material such as brown moss and *Sphagnum* moss leaves or dinoflagellate cysts, as well as high *Salicornia*-type pollen representation, indicated reworking of older peat layers, however, enable correlation with *Salicornia*-dominated communities. This is complemented by the results of diatom analysis which reveal an assemblage that includes *Diploneis didyma, Scoliopleura tumida, Caloneis formosa and Navicula digitoradiata*. Such an assemblage points to tidal flat deposits at the salt marsh boundary. The presence of reworked material makes dating more difficult in this context so AMS ^{14}C dating of selected seeds is required. At +0.64 to +0.72 m NN, the tidal flat deposits give way to lower salt marsh. This is demonstrated by the frequent occurrence of *Diploneis interrupta*, a benthic diatom, as well as increased pollen representation of typical salt marsh species such as *Artemisia maritima, Glaux maritima and Plantago maritima*. This horizon can be correlated with a nearby profile published by Streif (1990) and which was dated to between 1555±160 B.P. and 1155±130 B.P. (Hv 13130, 13131, 13133). These horizons document the oldest salt marsh deposits recorded on Juist and so add substantially to our knowledge of the late Holocene sea-level change. Mean high water level rose at an even rate only in the interval between formation of the subfossil tidal flat on Juist (ca. 2100 B.P.) and the first salt marsh horizon (ca. 1555 B.P.). Evidence of several other salt marsh horizons from Juist which correspond to various vegetation zones (upper and lower salt marsh and dune slacks) as well as to various periods (ca. 600-200 B.P.) have been described elsewhere (Freund & Streif 1999).

Figure 1: Saltmarsh deposits, which were originally formed on the landward side of the barrier islands, exposed on the beach of the seaward side of Juist due to coastal erosion and shoreline displacement (Photo: H. Freund).

First Approximation of Mean High Tide Level Fluctuations

On the basis of ^{14}C dates and facies analysis, local patterns of mean high tide level fluctuations during the last 2000 years were initially reconstructed for the islands of Borkum, Juist, and Memmert (Fig. 2). Subsequently a further synthesis has to be made of the evidence for the entire German Bight. On the basis of the studies mentioned above, a slow rise of the mean high tide level from 0 to +0.40 m NN has been demonstrated over the period 2000-1200 B.P. At about 550 B.P. the mean high tide level was practically the same as today, i.e. +1.25 m NN. The sea-level rise was not continuous, however, in that it was interrupted by a short phase of lowering at about 660 B.P.

Figure 2: Reconstruction of the fluctuations of the mean high tide level over the last 2000 years around the islands of Borkum, Juist and Memmert, FRG.



An explanation for this short period of lowering may be the creation of new tidal bays such as the Jadebusen, and the Dollard as a consequence of breaching of dykes during the Middle Ages. From the Netherlands, it is known that the dyking of the IJsselmeer and the Lauwers Zee in recent times led to substantial changes of the tidal range in the adjacent tidal flat areas. It has yet to be shown if there was a counter effect on the mean high tide level at the barrier islands due to the formation of extensive tidal basins in the former coastal marshes. Overall, any effects appear to have been local and of very short duration, since by ca. 500 B.P. the mean high tide level reached a maximum level and was very similar to the one recorded today. A later phase of sea-level lowering that is dated to ca. 400 B.P. is probably attributable to climatic deterioration during the Little Ice Age.

In the context of the recent discussions of climate variability and sea-level rise (global change), it should be kept in mind that over the last 2000 years fluctuations of the mean high tide level were recorded which were not influenced by human activity. These fluctuations were similar or even stronger than those predicted on the basis of the anthropogenic greenhouse effect. The East Friesian islands as a whole were not endangered by the demonstrated fluctuations, though radical changes in the shape of the islands and the destruction of single islands (e.g. the island of Buise) were recorded. In order to evaluate the degree to which human activity may modify climate, it is essential to improve our knowledge of natural climate processes and how these affected other phenomena such as sea-level fluctuations.

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References

Barckhausen, J., 1969. Entstehung und Entwicklung der Insel Langeoog - Beispiele zur Quartärgeologie und Paläogeographie eines ostfriesischen Küstenabschnittes. - Oldenburger Jb., 68, Oldenburg i. O., pp 239-281.

Freund, H. & Streif, H., 1999. Natürliche Pegelmarken für Meeresspiegelschwankungen der letzten 2000 Jahre im Bereich der Insel Juist. Petermanns Geographische Mitteilungen 143, Gotha, Stuttgart, pp. 34-45.

Hanisch, J., 1980. Neue Meersspiegeldaten aus dem Raum Wangerooge. Eiszeitalter u. Gegenwart 30, Hannover, pp. 221-228.

Jelgersma, S., 1979. Sea-level changes in the North Sea basin. In: Oele et al., Hrsg. 1979. The Quaternary History of the North Sea. Acta Univ. Ups. Symp. Univ. Ups. Annum Quingentesimum Celebrantis, 2, Uppsala, pp. 233-248.

Streif, H., 1990. Das Ostfriesische Küstengebiet - Nordsee, Inseln, Watten und Marschen, 2. edit., Berlin, Stuttgart (Borntraeger), pp. 376.

Zong, Y. & Horton, B., 1999. Diatom-based tidal-level transfer functions as an aid in reconstructing Quaternary history of sea-level movements in UK., Journal of Quat. Sc. 14/2, Chichester, pp. 153-167.

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