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The late Holocene sea level rise at the East Frisian coast (North Sea): New time constraints provided by optical ages of coastal deposits

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Abstract

A high spatial density of core data (available from the Niedersächsisches Landesamt für Bodenforschung, NLfB, Hannover) on the sediment body constituting the East Frisian coast provided an optimal opportunity to study late Holocene sea level oscillations and, as a result, to establish a more detailed curve of Holocene sea level rise based on sedimentological data.
Firstly, core data were analysed to recognise transgressive and regressive phases during the Holocene sea level rise at the East Frisian coast, and secondly, samples were collected from newly drilled cores to establish a time framework based on optical ages.
By applying sequence stratigraphy on the NLfB core data two phases of transgressions and at least one phase of regression were recognised within the siliciclastic sedimentary record after the formation of the so called Upper Peat at about 1000 BC. These phases were also identified in the new cores and sampled for optical dating.
The first transgressive phase started before ca 400 AD and lasted until 800 AD. The regressive phase occurred from ca 800 to ca 1220 AD and the second transgressive phase occurred from ca 1220 to nut much longer than 1400 AD.

1 Introduction

At the East Frisian coast deposition of unconsolidated sediments started after about 7500 BP (Hanisch 1980) during the post-glacial sea level rise. The resulting coastal sequence is a wedge-like sediment body consisting of fine-grained sand, silt and clay, in which layers of peat are intercalated (Streif 2004). Almost all studies on depositional history and on sea level oscillations of the North Sea are based on a time framework provided by radiocarbon ages of these peat layers (e.g. Streif 1990, 2004; Allen 1995; Baetemann 1999; Behre 2004). However, oscillations of sea level rise may occur, which do not lead to peat formation but result in facies change in the siliciclastic sedimentary record.

This study focussed on sea level data available from a siliciclastic sediment record overlying the 1000 BC Upper Peat (Behre 2004), a stratigraphic marker of the North Sea coastal Holocene. Core data were analysed in terms of base level cyclicity within the siliciclastic sedimentary record (Gensous et al. 1993; Cross & Lessenger 1998). Optical ages of layers representing sea level changes yield the time framework for a sequence stratigraphic model and a curve of 'coastal onlap' of the Holocene sediments. As a result, a more detailed curve of sea level rise based on sedimentological data can be established.

2 Study area

The area of interest is located in the East Frisian Wadden Sea, which is part of the Wadden Sea system of the Southern North Sea. Its western (Dutch) and central (East Frisian) sections are separated from the open North Sea by 13 barrier islands. For the area south of the East Frisian barrier island of Langeoog core data were provided by Niedersächsisches Landesamt für Bodenforschung (NLfB, Hannover). Based on the authors' interpretation of the NLfB core data, the study site covering about 5 km^2 was chosen in a setting on the mainland south of Langeoog (Fig. 1).

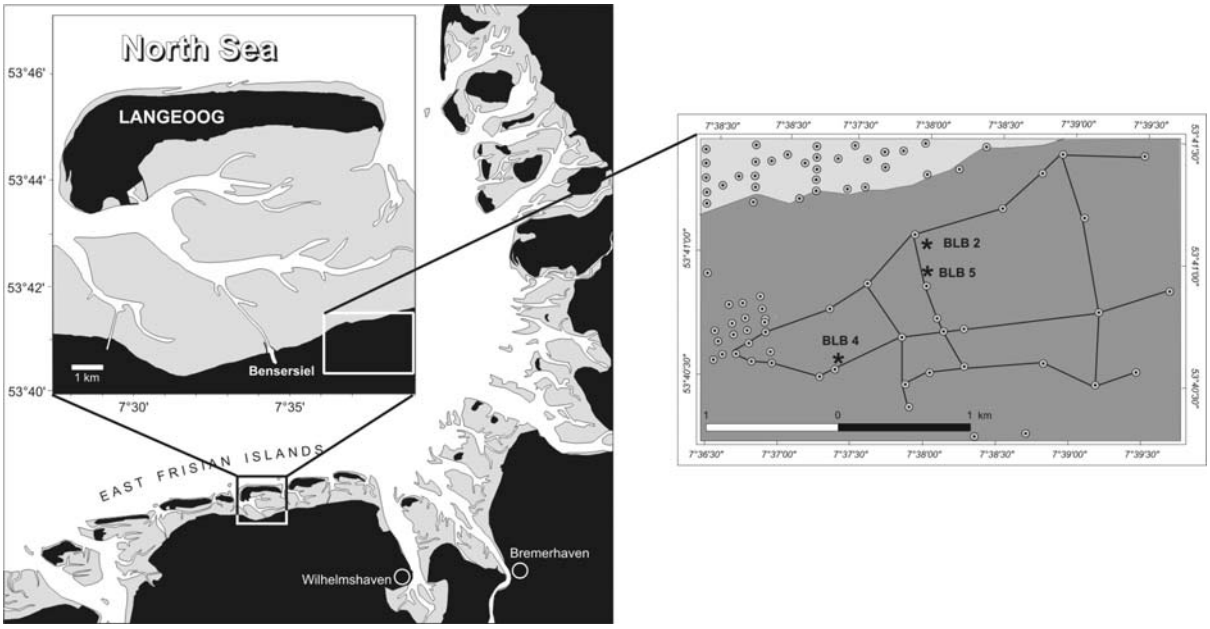

Fig. 1: Left: The location of the whole study area, where NLfB cores were investigated. Right: The cores taken by the NLfB are marked with dots, the new cores taken for this study are marked with stars. The lines show the profiles, which were studied before new cores were collected.

3 Methodical and experimental details

From several Southern North Sea coast studies (e.g. Reineck & Singh 1980; Streif 2004) it is known that at the Southern North Sea coast retrogradational sequences are generally represented by a sequence of peat covered by brackish and marine deposits. Progradational sequences are generally represented by a sequence of marine and brackish deposits covered by peat. Based on this knowledge a detailed sedimentological analysis on the NLfB core data was conducted to recognise these retrogradational and progradational sequences in the sedimentary record. Subsequently, a suitable site was chosen, where at least one transgressive and one regressive phase were documented within the siliciclastic sedimentary record. At this site (Fig. 1) new cores were taken using a STITZ corer with 5 cm diameter (Merkt & Streif 1970). In order to collect sufficient sample material for optical dating three cores were taken at each of the three sites with a maximal distance of 2 m. The cores were subsequently squeezed out of the tubes into light-tide bags and stored at 8°C before laboratory processing started.

In the luminescence laboratory material gained from corresponding lithological units of the three cores of each site was taken as one sample. Optical differentiation of lithological units is almost impossible under subdued laboratory light. To correlate the individual layers for sampling purposes sediment properties like grain size, molluscs and plant and carbonate content were utilised.

For optical dating samples were treated under subdued laboratory light (589 nm) applying the conventional preparation procedures for silt-sized samples (Mauz et al. 2002). Subsequently, samples were etched in diluted hydrofluoric acid (5%, 10%) for several tens of minutes to obtain a pure quartz sample. The single aliquot regeneration protocol (SAR; Murray & Wintle 2000) was adopted on around 30-70 aliquots of each sample. All measurements were conducted with an automated Risø TL/OSL DA-15 reader using blue diodes (470Δ20 nm) for stimulation and UV transmitting optical filters for detection. The external β- and γ-dose rate was calculated using radionuclide concentration derived from neutron activation analysis. A mean water content was assumed for each sample using the measured field moisture and allowing for little fluctuations.

From the core BLB2 three samples from the peat layers were collected for radiocarbon dating. The resulting AMS ages were calibrated with Calib rev 4.3 after Stuiver & Reimer (1993).

4 Results

The AMS ages of BLB2 date the peat between 1290 BC to 1025 BC. This time range is consistent with 14C-ages obtained from the Upper Peat (Behre 2004). In each core two transgressive hemicycles and at least one regressive hemicyle were identified and hence, enabled correlation between the coring sites (Fig. 2).

A time framework for the recognised oscillations is postulated: the first transgressive phase started before about 400 AD and lasted until 800 AD. The regressive phase occurred from ca 800 to ca 1220 AD and the second transgressive phase occurred from ca 1220 to not long after ca 1400 AD. A second regressive phase cannot be proved by sedimentological data at the moment.

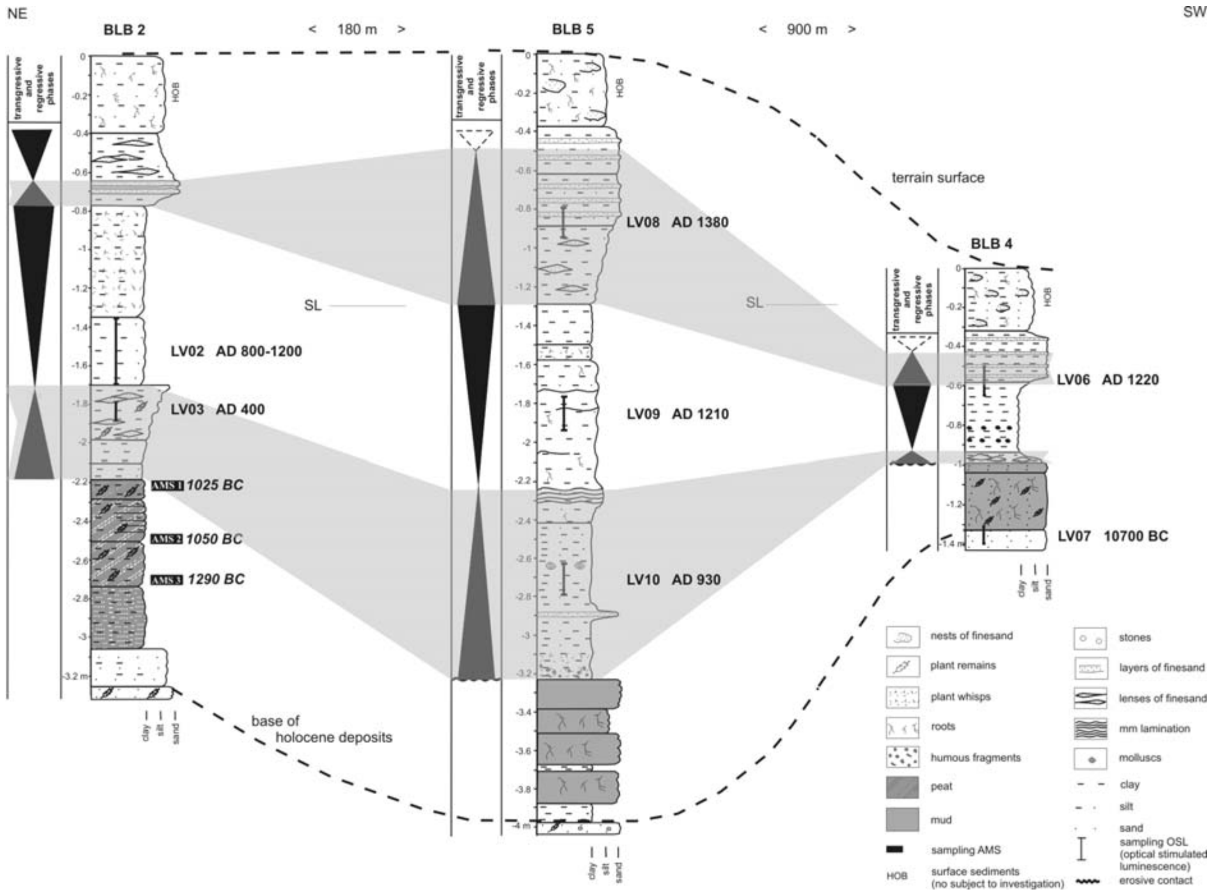

Fig. 2: The sedimentary record of the sites investigated. The base of the Holocene is indicated by a dashed line. The wells refer to sea level (SL). The sequence stratigraphic interpretation of the cores in terms of base level cyclicity is shown by triangles according to Cross & Lessenger (1998). The stratigraphic correlation of the transgressive hemicycles are shown by grey patches. To facilitate reading radiocarbon and optical ages are given with reference to AD/BC.

5 Discussion

Transgressive and regressive hemicyles could be recognised in the siliciclastic core record of the coastal Holocene of the East Frisian coast, indicating, that a sequence stratigraphic approach is applicable to a small scale and short-term sedimentary record. This provides the opportunity to study a sedimentary record independently from the presence of peat layers. In addition, optical dating provides the chance of higher resolution in establishing a curve of 'coastal onlap' of the coastal sediments of the Southern North Sea.

According to the investigations of ancient dikes (Lengen 1978), the difference of 1 m terrain height between BLB4 (being located furthest away from the coastline) and the other wells (Fig. 1 and 2) cannot be explained by the coring sites situated on different polders (Behre 2004). But in contrast to the coring sites of BLB5 and BLB2, the BLB4-site is drained. This could explain a reinforced shrinkage generating height differences between adjacent terrains.

For optical dating the fine-silt quartz approach was chosen. As this approach needs a large quantitiy of sample material, several centimetres of core material were collected covering a relatively long period of time. On the other hand, this allowed sampling of layers, which were deposited from suspension. More importantly, the content of organic matter in the sediment and the proximity to peat layers require a specific modelling approach to determine the annual dose rate. Work on this model is in progress.

According to the sea level curve for the late Holocene of the North Sea coastal region of Germany established by Behre (2004) four transgressions occurred after the formation of the Upper Peat. This number of transgressions is not confirmed in the present study, neither by the sedimentary record nor by the optical ages. Considering the dynamic depositional processes characterising the Holocene sediment body, we assume that not all strata after the Upper Peat formation are recognisable in our cores. One reason could be that the resolution of sedimentological analysis is not sufficient to recognise these processes. Another reason could be erosion of sediments by small-scale transgressions or by storm tide events, but erosional features were identified in one core only. In the core BLB2, in contrast, a non-erosive transition from peat to siliciclastic sediment is evident.

The timing of the late Holocene sea level oscillations resulting from optical ages is concordant with the sea level curve established by Behre (2004) who analysed the sea level change during the late Holocene using dominantly archaeological data. We recognise a regressive phase from 800 BC to 1220 BC at the East Frisian coast of Langeoog. Behre (2004) reports a regression from 850 cal. BC to 1100 cal. BC significant for the area or the Southern North Sea. The second transgression last probably not much longer than 1400 AD and this time constraint is also consistent with the regression until 1450 reported by Behre (2004).

6 Conclusions

Oscillations of Holocene sea level rise at the East Frisian coast of the Southern North Sea are recorded by the formation of peat layers and by facies changes within the siliciclastic sedimentary record. Whereas the timing of peat formation is well-known from a large number of radiocarbon ages, the time constraints of further sea level changes require a different approach. In this study, we combined higher-order sequence stratigraphy with optical dating to constrain the timing of late Holocene sea level oscillations. The sequence stratigraphic approach provided the identification and correlation of transgressive and regressive phases. The optical ages provided a reasonable time framework for the chronostratigraphic classification of the analysed coastal sediments.

The technique of optical dating of silt-sized quartzes in siliciclastical tidal deposits needs to be improved if organic matter is incorporated.

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