Geopotential Deutsche Nordsee

Relative sea-level change in northwest Europe and the southern North Sea during the Holocene: Determination of isostatic and (neo)tectonic subsidence in the German Bight

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1. Unresolved questions

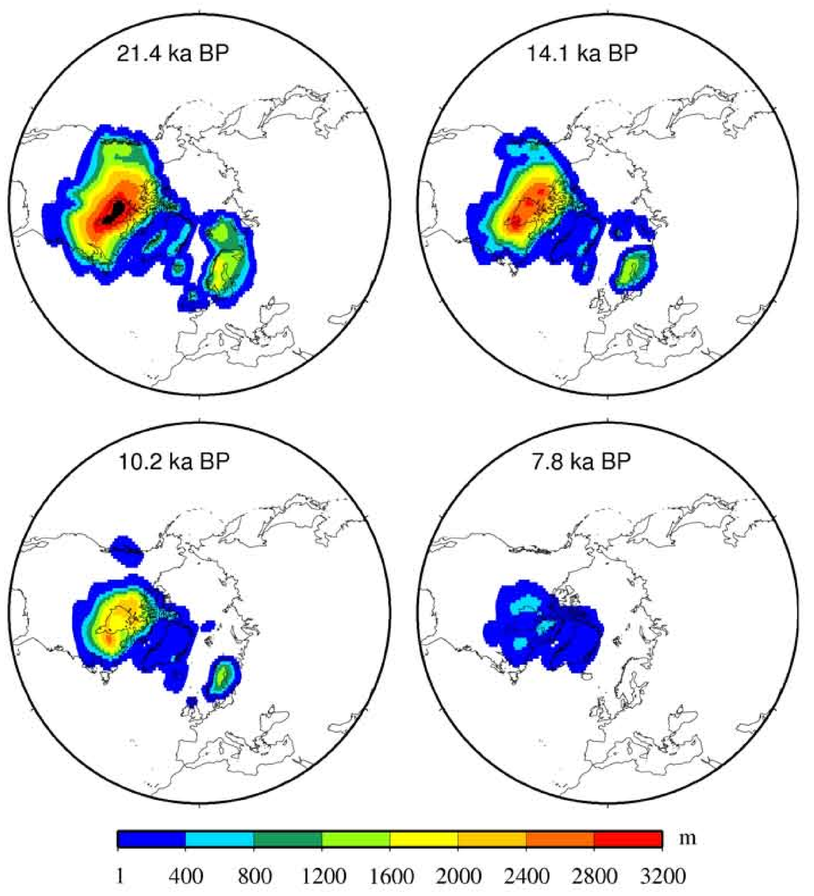


***Figure 1:** Ice distribution and thickness over the northern hemisphere during the last glacial maximum and deglaciation period (ice model RSES; Kurt Lambeck, Research School of Earth Sciences, Canberra, Australia).*

The weight of the Fennoscandian ice sheet of the Last Glacial Maximum (LGM) forced the crust to sink into the visco-elastic mantle, causing a surface depression of hundreds of meters and, most likely, an uplift in its peripheral areas (the "Glacial Forebulge"). During the following deglaciation, this process of Glacial Isostatic Adjustment (GIA) reversed, with Fennoscandian rebound still occurring today.

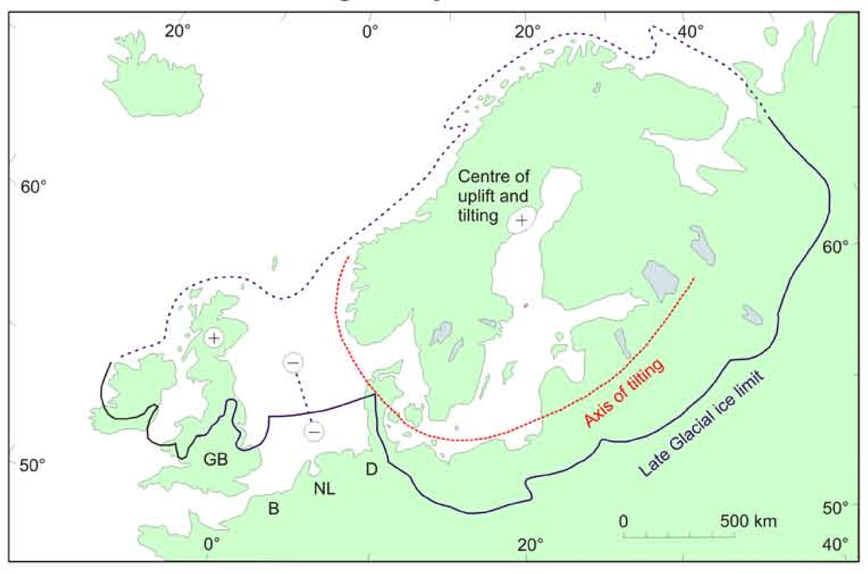


***Figure 2:** Last Glacial ice limit in Europe and approximate axis of tilting between post-glacial isostatic Fennoscandian uplift (+) and North Sea Basin subsidence (-) (after Mörner, 1980).*

As NW Europe was not completely covered by the glacial ice sheet and lies relatively far off from the axis of tilting, the following questions remain: **To what extent was/is NW Europe affected by (differential) post-glacial isostatic subsidence related to Fennoscandian uplift? Can we determine a (neo)tectonic subsidence component in the German Bight?**

2. Sea-level index points as an answer

The nature of relative sea-level movement in any area is determined by crustal movement in addition to the climatically-induced eustatic increase in ocean water volume. A comprehensive observational database of Holocene relative sea-level index points (mainly deriving from basal peats) from NW Europe (Fig. 3) shows that relative mean sea-level (MSL) rise varies locally in magnitude and form (Fig. 5), revealing a complex pattern of differential crustal movement related mainly to a combination of tectonic and post-glacial glacio- and hydro-isostatic processes. Our research aims at identifying and, where possible, quantifying these movements based on (i) the direct comparison of observational/geological data (Figs. 5 and 9); and (ii) geodynamic Earth and ice modelling procedures (Figs. 6-8).

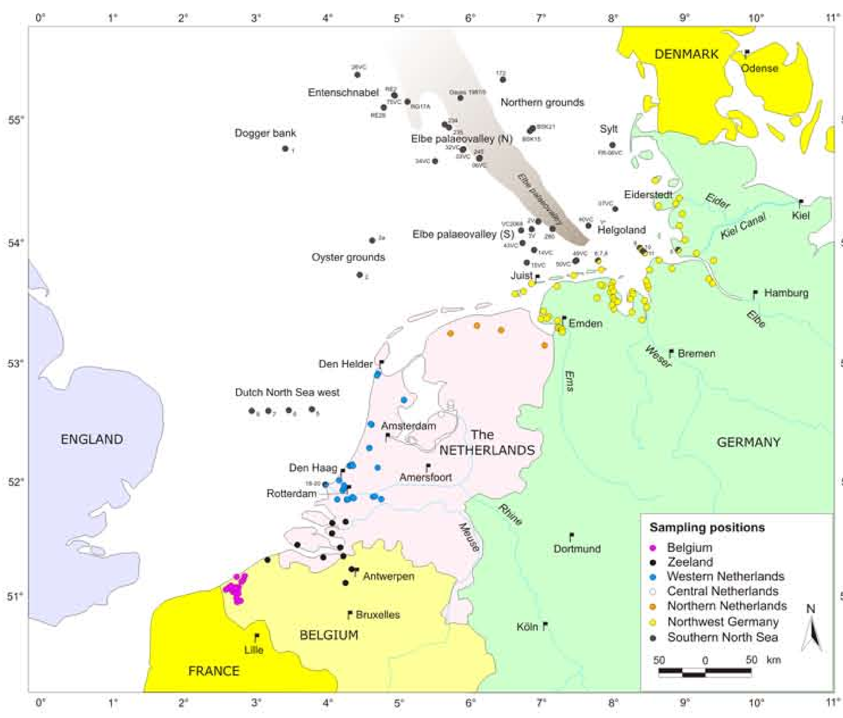


***Figure 3:** Locations of SL index points (mainly basal peats) used for the determination of NW European / southern North Sea Holocene relative sea-level rise.*

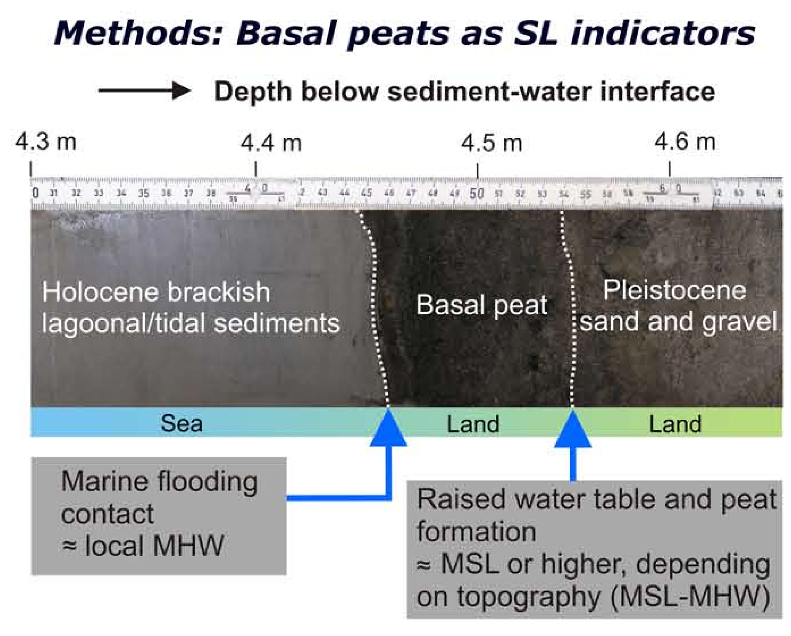


***Figure 4:** Example of Holocene basal peat from a North Sea core, showing sedimentary changes as a direct result of rising sea level. The indicative meaning of both the base and the top of the peat is indicated. MHW = Mean high water level; MSL = mean sea level.*

3. Differential subsidence in NW Europe

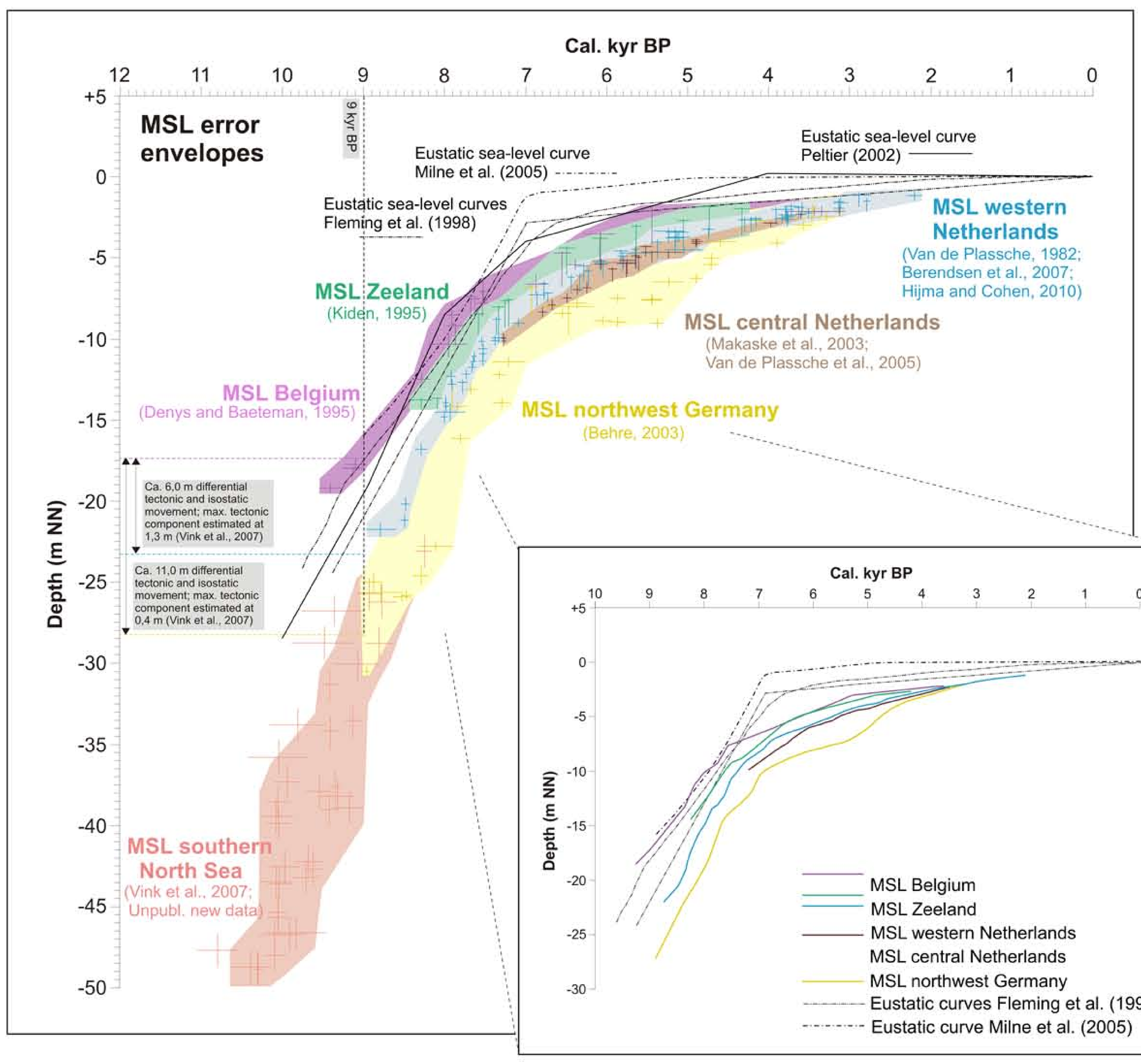


***Figure 5:** Time-depth distribution and error bands of sea-level index points (corrected to mean sea level; MSL) in comparison with several eustatic/global sea-level curves. The MSL curves in the inset represent the mid-lines of the respective MSL error bands.*

The altitudinal differences between the MSL curves of NW Germany, the southern North Sea, the western Netherlands and Belgium provide insight into the relative subsidence/uplift rates between these regions (Fig. 5). Using the present depths of Eemian sea-level highstand data, we can roughly estimate long-term linear tectonic subsidence rates since 125 kyr BP in the different coastal regions and subtract this component from the total differential subsidence. A slowly decaying isostatic subsidence component in comparison to Belgium emerges which for NW Germany amounts to >10 m during the last 9 kyr (Fig. 5). Assuming that Belgium has also undergone some isostatic subsidence (Fig. 5), absolute isostatic subsidence may even be somewhat higher.

4. Geodynamic modelling and mantle structure

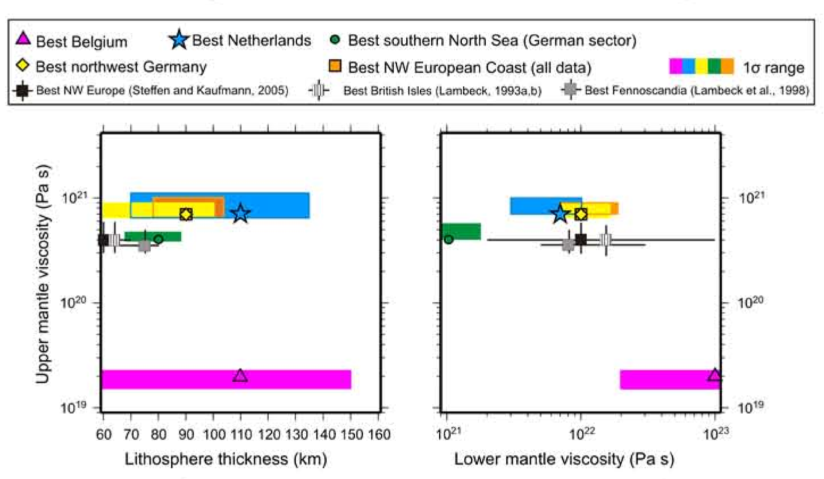
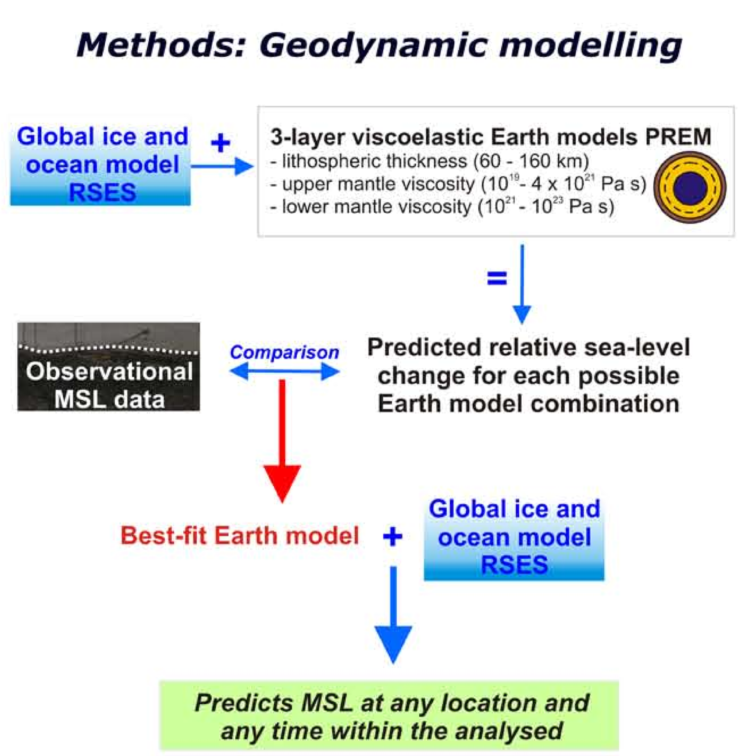


***Figure 6:** Inferred radial viscosity structure of the Earth's mantle: Best regional three-layer Earth models and their confidence regions using the ice model RSES. A broad range of Earth parameters fit the Belgian MSL data, suggesting only a minor effect of GIA in that area. In contrast, a narrow range of Earth parameters define the southern North Sea region, reflecting the greater influence of GIA on these deeper/older index points.*



5. Modelled isostatic subsidence

Modelled MSL curves for the region show that the amount of isostatic subsidence increases strongly in a north-easterly direction and with time (Fig. 7). The centre of the Glacial Forebulge, which was subject to the largest amount of Holocene subsidence, is approximately constrained by the models to have passed through the German sector of the North Sea and the coastal areas of the German state of Lower Saxony.

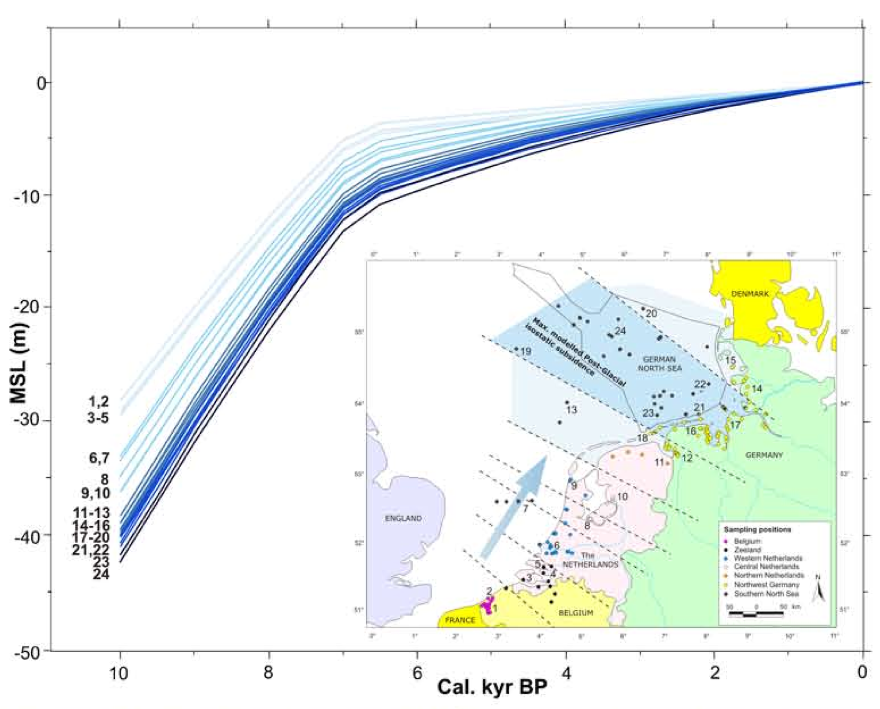


***Figure 7:** Predicted smooth MSL curves based on regional best-fit Earth models. The approximate zone of maximum post-glacial crustal isostatic subsidence due to Fennoscandian uplift is identified.*

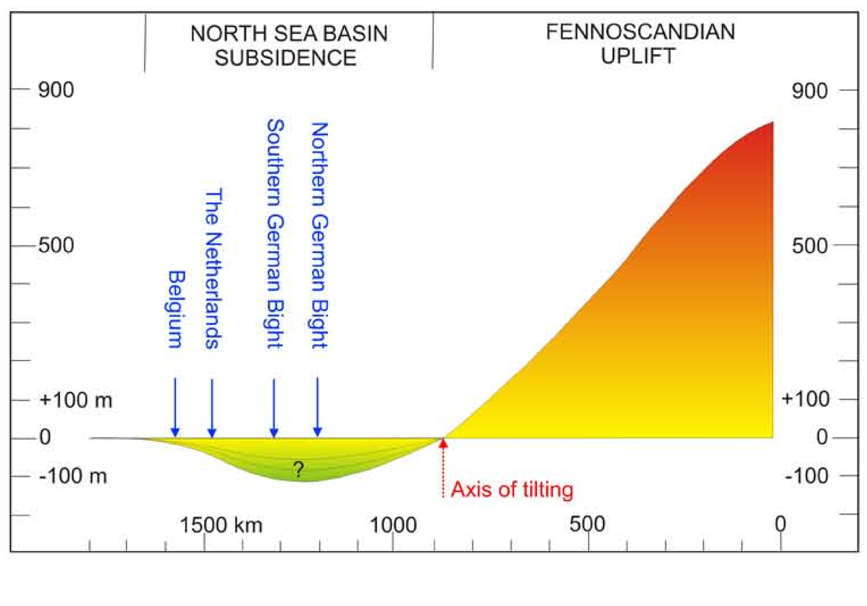


***Figure 8:** Geographic distribution of isostatic subsidence since the LGM based on the model predictions of Fig. 7 (modified after Mörner, 1980).*

5. (Neo)tectonic subsidence in the German Bight

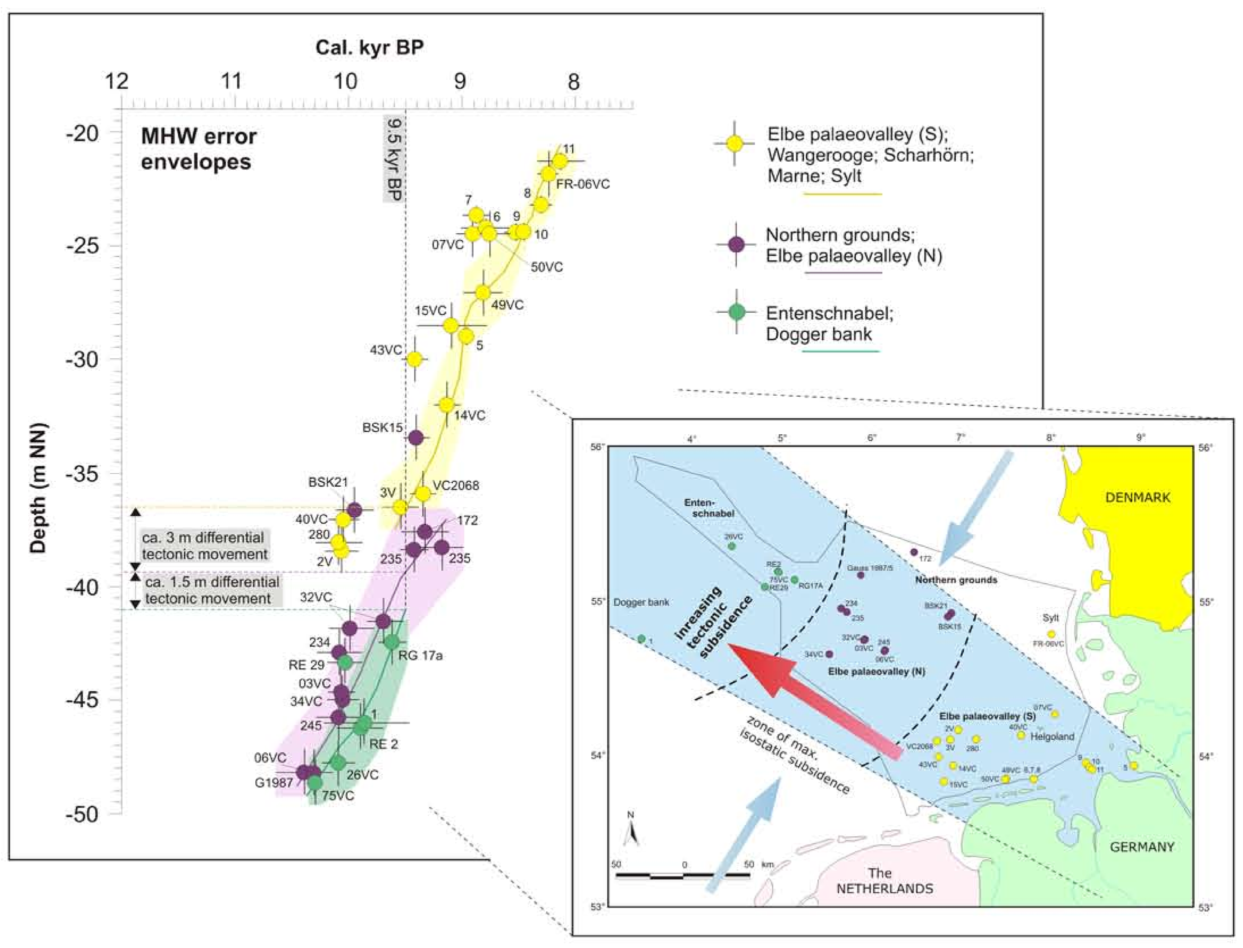


***Figure 9:** Time-depth distribution and error bands of sea-level index points (MHW) in different regions of the German Bight (coastal, middle and outer region, see inset).*

Within the zone of maximum glacio-isostatic subsidence, sea-level index points further offshore lie deeper than those close to the coast (Fig. 9), showing that (neo)tectonic subsidence has occurred in a direction approximately perpendicular to that of isostatic subsidence during the last 10 kyr BP (i.e. in a NW-SE direction). We assume the effects of hydro-isostatic subsidence to be small concidering the shallow water depths of the area. Eemian sea-level highstand data and levelling activities suggest that the linear tectonic subsidence component along the NW German coast is very small at <0,05 m/kyr. Observational and modelled RSL data suggest that linear (neo)tectonic subsidence increases to ca. **0,37 m/kyr** in the central region of the German North Sea sector, and to ca. **0,53 m/kyr** in the Dogger bank/ outer region (Fig. 9).

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