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Recent position of surfaces of Holsteinian interglacial marine and limnic sediments, and of Saalian glacial river terraces (Explanatory notes to map 3)

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1. Vertical changes of the reference level during the chosen period

1.1 General remarks

The surface of the marine Holsteinian interglacial sediments proves the only reference plain formed since the beginning of Rupelian (Lower Oligocene) times, which is - with restrictions - suitable for calculation of the vertical tectonic displacements until the Recent. Only a small part of the area under investigation was covered by the Holsteinian interglacial sea. It is a favourable fact, that the sea bay along the lower Elbe river continued to the southeast via a series of basins filled with fresh water. Because of hydrographic communication their water level had been only a little above the sea level in the bay. Therefore, they can also be taken as reference level.

1.2 Areas of transgression and marine sedimentation

The Holsteinian interglacial sea ingressed into a glacial landscape whose main features were deep glacial channels Elsterian glacial in age. They have been totally infilled or for the most part in late Elsterian glacial to Holsteinian interglacial times. Several endogenic and exogenic factors had effects on the mainly glacioeustatic controlled transgression. At the end of Holsteinian interglacial, when the regression was acting, the relief must have been more smooth than beforethe beginning of the transgression had started. Therefore the differences in the reference level over the area under investigation may be neglected (LUDWIG 1995).

In northern Germany the reference level generally holds depths from -30 m to close to 0 m at present. In the German part of the North Sea and in Mecklenburg-Vorpommern it goes down to -70 m and -90 m b s. l. Single extremely deep positions probably have been caused by additional tectonical movements (see below) especially in the NE. In western Mecklenburg the deepest positions significantly correspond with salt structures, not shown in the map. The spread of the sediments left by the marine transgression in some areas became reduced by later exaration and erosion.
The marine (inclusive brackish) deposits are only few metres, rarely several ten metres, and in the extreme 56 m thick (LINKE 1993). They are often intercalated with limnic and fluvial sequences and appear in the palynological zones III b, IV, and V of the profiles (KNUDSEN 1993, LINKE & HALLIK 1993). Redeposition of fossils from earlier Pleistocene sediments into the marine Holsteinian can be excluded because there are only scarce indications to a Pleistocene transgression before Elsterian glaciation.
Merely stratigraphically exactly determined undisturbed Holsteinian and Eemian deposits were used for the construction of the map. It is supported by faunal (micro- and macrofaunas) and floral evidences (KNUDSEN 1993, LINKE 1993) and by their intercalation between Elsterian and Saalian glacial deposits respectively above the latter, or the two interglacial marine beds (Holsteinian and Eemien) are separated by Saalian glacial deposits.
The shown contours of the Holsteinian interglacial sea outline the total area from which marine sediments in situ are recorded, marginal brackish areas included. All over this area land and sea were close interwoven with each other. In the Schleswig-Holstein area the map shows locations of boreholes with recent depth of the reference level on the background of the main elements of the channel network. For the Mecklenburg-Vorpommern province an attempt was made to construct isobathes of the reference level on the base of numerous boreholes (U. MÜLLER 1994, RÜHBERG et al. 1995). In the western portion of that region the marine beds are close related to the system of glacial channels as it is real in Schleswig-Holstein, and besides that, to a NW-SE oriented zone of subsidence running in right angle to those. This zone had already stood out during the preceding period (Neogene - early Pleistocene).

The numerous locations of marine sediments in southern Mecklenburg-Vorpommern suggest for a probably multiple branched out transgression across that region, having formed a strongly embayed coast which extended to near the mouth of Odra river (RÜHBERG et al. 1995). After Dr. DOBRACKI, Szczecin (oral comm.) a borehole southeast of Szczecin pierced an interglacial sequence including a foraminiferal fauna presumably of Holsteinian age. The marine beds go down to depths similar to that in the neighbouring Vorpommern. If the Holsteinian age of these sediments can be firmed, there are indications that the low laying area around the mouth of Odra river was flooded by the Holsteinian sea. The eastern directed transgression as far as to northeastern Poland and the Baltic states could have used a way more to the north

around the Rügen island also. Another way of transgression across central Sweden cannot be excluded (Ludwig 1999).

1.3 Areas of limnic and fluvial sedimentation

In northwestern Germany the stratigraphic position of the limnic sediments is proved by their interfingering with marine Holsteinian deposits, dominantly by their floral and faunistic contents, and further to the southeast by the covering with glaciofluvial gravels and tills of Saalian age. If the uppermost parts of the sedimentary column have not been removed, the surface of the limnic-fluvial deposits is somewhat younger than that of the marine beds; for the interglacial regression ended earlier than the sedimentation in the lakes. The used reference level therefore means late Holsteinian interglacial until early Saalian glacial.

The limnic and fluvial sediments are 15 to 30 m thick, with a maximum of 75 m. The data from numerous boreholes establish the picture of a glacial lowlands flooded by fresh water, and subdivided by many islands as well as peninsulas (contours simplified in the map). The distribution of the lacustrine deposits also shows relations to the trends of the Elsterian glacial channels (Lippstreu 1993, Ziermann 1993).
The lacustrine basins (large lakes) worked as a receiving stream to the rivers which drained the waters from the highlands in the south into the bay in the north. In northwestern Germany, west of the Elbe river large limnic basins are lacking on account of generally higher position of the pre-Holsteinian surface.
The river terrace gravels are well investigated. Their stratigraphical classification is based on numerous gravel analyses and morphological features as well as geological criteria (e. g. Eissmann 1994, Knoth 1995, Wolf, Alexowsky et al. 1994).
In the lake area upstream the river deltas, the early Saalian glacial terrace gravels are recorded only in small rests. That is why later on the rivers have again cut into their terraces down to a few ten metres, often already as for as the levels of their recent valley bottom (e. g. Harz mountains and northern foreland). This process was supported by lasting uplift of the highlands in the south. The rivers then were already restricted to their present valleys (Eissmann 1994, Wolf, Alexowsky et al. 1994). Therefore the terrace surfaces rise in south direction. After the Saalian glaciation the rivers Elbe, Freiberger Mulde and Weisse Elster changed their courses at the northern foreland of the highlands in a westerly direction due to the morphologic effects of the Saalian glacial deposits.

1.4 Remarks on marine Eemian interglacial deposits

The contour lines of the Eemian sea are closer to the coastline of the recent Baltic Sea. Only in river flats the sea ingressed the land to the south (Meyer 1991, U. Müller 1994). The mainly near-shore marine Eemian deposits at the North Sea coast have been outside the glaciated area in Weichselian times, but along the coast of the Baltic Sea they occur between Saalian and Weichselian tills. Their thickness ranges from several metres to 28 m at maximum. The transgression was restricted to the time span of the climatic optimum with short-termed marine precursors, similar to the development during the Holsteinian interglacial period (Strahl et al. 1994).
The connection of the Eemian Sea in the east Baltic region with that in the North Sea region, for a long time missed, has probably existed across southern Jutland peninsula (Kosack & Lange 1985). At the German North Sea coast the surface of the marine Eemian is observed recently in -7 to -12 (-17) m b. s. l. (Sindowski 1970), and at the Baltic Sea coast between -15 and -30 (-40) m b. s. l. (Strahl et al. 1994). In all the coastal areas the Eemian deposits are in a higher position than the marine Holsteinian deposits.

2. Tectonical development since the end of Holsteinian interglacial

Strong local changes in depth of present position of the reference level point to important non-tectonic influences, to its deformation and have been eliminated. Further on the glacioisostatic processes have triggered differentiated movements at pre-existing joints in the block mosaic of the Earth´s crust. But there are no criteria enough to separate these exogenous induced vertical displacements from the tectonical generated.
Mainly, neotectonical interpretation of the available data is restricted to qualitative and relative statements (uplift, subsidence) as well as rough quantitative assessments. It is impossible up to now to construct isolines of amplitudes of the vertical movements.
The powerful movements of the crust, accompanied by intense block tectonics which lasted from the Pliocene until the early mid Pleistocene times were followed by a tectonical more quiet period since the late Holsteinian times. Only a few faults respective parts of them have been active up to the Recent. The previous intense volcanism was restricted to small events in the Rhenish massif, and in the western part of the Ohregraben (seismicity, thermal and mineral springs).
Since the end of theHolsteinian Interglacial all vertical displacements caused by fault tectonics as well by non-rupturral processes amounted to a few dekametres at maximum. Above all, these processes continued the movement trends of the pre-existing structures. The morphostructures built up during the Neogene period and developed further on in the early Quaternary times are reflected in the main features of the recent surface relief as well as the base of Quaternary (map 2) (Schwab & Ludwig 1996). Characteristic of both reliefs is their general dip to north.
The North Sea coastal area subsided basin-shaped to 20 m deep (in offshore direction increasingly deeper) without remarkable fault tectonics, and the uplift in the highlands kept themselves within the same limits. For the Rhenish massif uplift have been ascertained to about 75 m throughout all the entire Quaternary times (Zöller 1983).
The most striking tectonical element during Holsteinian interglacial was a flat deep zone extending NW-SE from the mouth of Elbe river as far as to southeast Brandenburg (Hamburg-Cottbus depression in the following). It corresponds with the distribution of the areas with marine and the adjacent

areas with limnic Holsteinian sediments. This zone was the dominant drainage vain throughout all the Quaternary times. It follows the axis of the Central European Subsidence Zone. A swell with uplift tendencies extends from the Rügen island as far as to the Danish islands and SW Skane, separating the Mecklenburg Bay in the west from the Arkona basin in the east. The swell may have hindered or restricted the transgressions into the east Baltic region to a relative small passage (Ludwig 1999). The lower Odra river follows a meridional zone of slight subsidence in the field of a meridional fault zone.

Two other N-S arranged relatively deep zones of probably lasting subsidence meet the Hamburg-Cottbus depression from the south. The western one, comprising the area of the Leipzig Tieflandsbucht (lowland bay), already existed in the Palaeogene and has concentrated the drainage of the waters of the Thuringian and west Saxonian highlands and passed on to the north since the transition Neogene/early Quaternary. The west flank of the meridional depressed area has been uplifted in post-Middle Miocene times yet. Evidences for post-Holsteinian vertical movements are lacking, but persistent slight subsidence is indicated by the recent hydrography.

3. Additional remarks on block fault tectonics

Most active block fault tectonics occurred in the Roer-Lower Rhine graben region. The displacements have summed up to 175 m subsidence at maximum during all Quaternary times. At the marginal fault of Peel horst 30 m vertical displacement still occurred during this time span (Ahorner 1983, Müller & Lipps 1983). Vertical displacements of post-Holsteinian deposits to about some metres have been observed in the Lower Lusatian lignite district (Thiem 1989).

The nearly total absence of active faults in the North German lowland on the map is not real; for, the small block displacements which we can be expect will have been seldom significantly transmitted up to the surface through the thick cover with its voluminous salt beds and loose rocks.

The unusual deep position of marine Holsteinian deposits near Anklam (Vorpommern) seems to indicate late tectonic movements - perhaps supported by tectonically stimulated subrosion - in the graben of Möckow-Dargibell, which already had been active earlier in post-Rupelien times (oral comm. J. Haupt, Schwerin). However, the area of the deep situated marine Holsteinian sediments is extended across the graben.

4. Remarks on the Quaternary base (map 2)

The base of Quaternary is outside the glacial channels in the lowland quite smooth, and generally flat tilted to north (Schwab & Ludwig 1996). In the coastal areas of North Sea and Baltic Sea it approximately holds the same level. South of the about +100 m isohypse the rising of the Quaternary base becomes stronger, that means at the transition to the highlands. The Quaternary base reflects simplified the pattern of the tectonic structures and especially their neotectonical development. This similarly applies to the relief of the recent surface with some modifications caused by the cover of dominantly glacial Quaternary deposits. Therefore, characteristically of the Quaternary base is a slight undulation with NW-SE axes in northeastern Germany. A narrow flat depression corresponds with the Hamburg-Cottbus depression of Holsteinian age.

The distribution of the glacial channels in northeast Germany approximately corresponds with the Hamburg-Cottbus depression, but the channels are arranged crosswise to it (NE-SW). West of the Lower Elbe river the channels turn into N-S direction, and parallel to the there existing block fault pattern as well as the orientation of the long salt structures in northwest Germany. In this part of the lowland the area with glacial channels is restricted to the southern termination of the region with N-S striking fault structures, following the southern rim of the Pompeckij block.

5. Conclusions

The surface of marine and adjacent limnic sequences of Holsteinian interglacial and early Saalian glacial forms in north Germany a reference plain which is in a limited degree usable to establish tendencies of vertical movements since the end of Holsteinian interglacial. A map with isolines of vertical movements cannot be drawn, but it was possible to make a subdivision into areas with tendencies of uplift and others of subsidence. In the pattern of vertical movements, the NW-SE and meridional arranged tectonical elements are the dominant ones, especially the Roer-Lower Rhine graben and the Hamburg-Cottbus zone.

The vertical uplift and subsidence movements (non-ruptural and ruptural) amount to a few metres, seldom 20 m and more with the average up or down rate in the order of 0,1mm/y. The total amplitude of uplift and subsidence from the coastal areas up to the highlands reaches about 50 m.

In southern part of Baltic region the area flooded by the sea was shifted to the north. This may be, above all, due to stronger glacial exaration especially in the north, and stronger accumulation, especially in the south, but it has been supported by tectonical movements. More significant neotectonic subsidences since the Holsteinian interglacial which essentially contributed to form the Baltic Sea basin have been restricted to the part east of the Tornquist-Teisseyre Zone, preferentially to the central part of the basins (Garetsky et al. 1999).

The tectonics generally acting since the Holsteinian interglacial have continued the vertical movements of the earlier span of the neotectonic period. The relief of the Quaternary base reflects in a simplified form the pattern of the neotectonic structures and trends of the vertical movements, though this plain was not synchronously generated.

Summary

The amplitudes of vertical movements are estimated regarding the top of marine Holsteinian interglacial sediments and the top of contemporaneous lacustrine sediments at nearly the same level as a reference level. Without non-tectonic influences the ruptural and non-ruptural vertical displacements of the reference level amount to a few dekametres

subsidence as well as uplift at maximum. All vertical movements since the end of Holsteinian interglacial times continued the movement trends of earlier neotectonic and partly pre-neotectonic structures: mainly subsidences in the northern part of the map area and uplifts in the highland region in the south. Relations to the Emian marine deposits and to the pre-Quaternary surface are discussed.

Zusammenfassung

Bezogen auf die Oberfläche der marinen Sedimente des Holstein-Interglazials und äquivalenter limnischer Sedimente in nahezu gleicher Höhenlage werden die Amplituden der vertikalen Krustenbewegungen seit dem Ende des Holstein-Interglazials abgeschätzt. Nach Ausschluss atektonischer Effekte belaufen sich die rupturellen und nicht rupturellen Vertikalverschiebungen auf maximal wenige Dekameter Senkung oder Hebung. Sie setzen die Bewegungstrends vorausgegangener neotektonischer, vielfach auch präneotektonischer Strukturentwicklungen fort. Vorwiegend Senkungen treten im Nordteil des Kartengebiets auf, im Südteil, dem Mittelgebirgsraum, dagegen Hebungen. Die Beziehungen zu marinen Eem-Ablagerungen und zur Quartärbasisfläche werden diskutiert.

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