Glaciation, salt and the present landscape

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4.5.1 Introduction

The modern topography of the Central European Basin System (CEBS) is not only caused by the morphological shape of glacial landforms, e.g., moraines and ice-marginal valleys, and subsequent fluvial erosion, but clearly also reflects the pattern of the tectonic structures at depth, indicated by the preferred orientation of coastlines and rivers with three major tectonic strike directions: NW-SE, NNE-SSW and NE-SW (Fig. 4.5.1). Most likely, these pre-existing tectonic fault zones have fragmented the crust and lithosphere of the CEBS into distinct fault-bounded blocks. These block boundaries serve as discontinuities reactivated during times of isostatic adjustment in the major phases of the waxing and waning of Pleistocene ice sheets in the CEBS area. The effects of the isostatic rebound from the last (Weichselian) glaciation and subsequent crustal relaxation are still ongoing in Scandinavia and the southern Baltic and affect parts of the CEBS: Scandinavia is rising and most of the southern Baltic is actively subsiding. The loading/deloading processes must have been active also at the end of the earlier glaciations (Elsterian and Saalian) with maximum ice sheet extent over the CEBS.

The frequent occurrence of pronounced lineaments in the modern topography indicates that unconsolidated Quaternary sediments only blanket the fault blocks. Expression of neotectonically active faults between blocks and along the major graben borders and salt diapirs are reconstructed from so-called fault-surface-penetration-points that are locally active still today and cause depressions (sink holes) with highest subsidence rates, partly leading to ground failures.

Several interconnected processes between salt and ice have shaped the glacial surface topography. The advancing ice sheets eroded the sediments and sedimentary rocks of the CEBS and interacted with salt diapirs at depth. Diapirs probably acted temporarily as barriers at which the glaciers stopped, depositing extensive meltwater sediments that subsequently became compressed by the advancing glacier, leading to the formation of large push moraines over the salt. Faults were locked under the ice cover, but the isostatic subsidence was compensated by a lithospheric forebulge in front of the ice sheet. Below the ice sheets deep tunnel valleys were formed by subglacial meltwater erosion.

The lithospheric forebulge formed in the periglacial regions, where permafrost reached depths of > 170 m. However, enhanced heat flow over the salt diapirs caused shallow permafrost depth compared to the surrounding sediments. Soils and unconsolidated Quaternary sediments of the subsurface were thus frozen into an irregular polygonal permafrost pattern with brittle (frozen) and plastic (unfrozen) patches with ice wedges, which must have provided a very inhomogeneous substrate for the advancing glaciers with implications for the abrasive power and stability of the ice sheet.

4.5.2 Modern topography and glacial isostasy

The modern topography of the CEBS landscape can be generalised into two major features in the digital elevation model (Fig. 4.5.1 a). The first is that of several arch-shaped moraine belts with a maximum elevation of more than 200 m stretching from western Poland to the North Sea and the Netherlands. These moraines are characterised by often laterally stacked thrust sheets and consist of unconsolidated till, glaciofluvial, glaciolacustrine and fluvial deposits. The base of the Quaternary deposits comprises mainly Tertiary clastic marine and coastal deposits. In eastern Germany extensive lignite deposits are intercalated in the sediments. In southern Lower Saxony push moraines partly overlie Cretaceous claystones, forming the basal detachment.

The other dominating features are linearly orientated structures (Fig. 4.5.1 a). These orientations led Sirocko (1998) to express the hypothesis that the pattern of the North German rivers dominantly reflects the tectonic patterns of NW-SE and NNE-SSW striking faults at depth in the CEBS. These directions become visible in the shorelines of the Baltic Sea, but also reflect the course of river valleys like the Elbe, Weser and their tributaries. There are, however, also other directions such as the ice-marginal valley of Baruth, the rivers Havel and Spree. The nearly circular trend of river Havel, for example, is caused

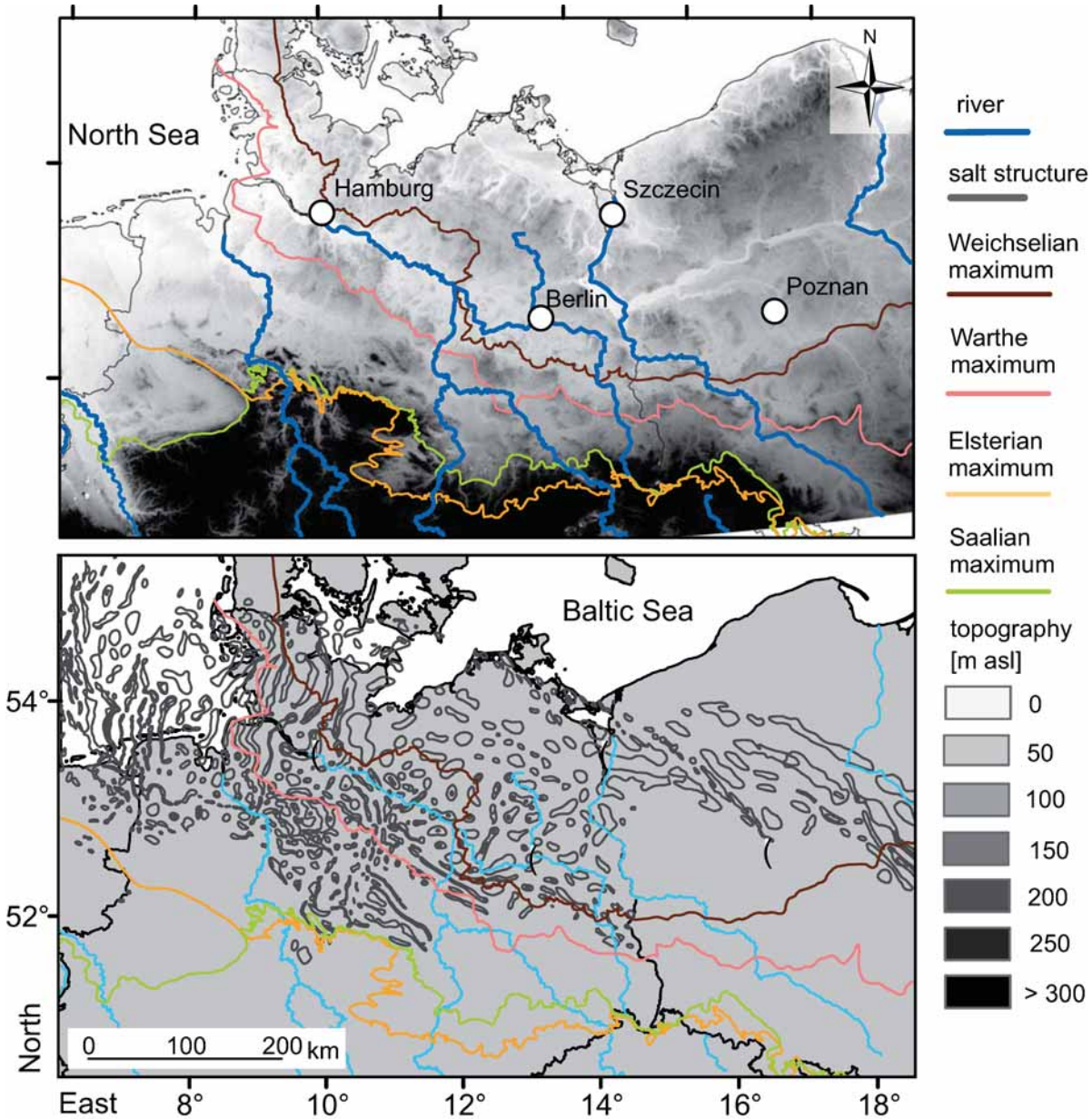


Figure 4.5.1.
a) Digital elevation model of Northern Germany and Poland (data from Jarvis et al. 2006) showing major rivers, the maximum extent of the Weichselian, Saalian and Elsterian glaciations, after Ehlers et al. (2004).
b) Salt diapirs and salt pillows of Northern Germany and Poland, after Lokhorst et al. (1998)

by a young subsiding block on top of the Elbe-lineament (Stackebrandt 2005). To explain the geodynamic cause of all these linear patterns it was necessary to quantify whether tectonic faults from the depth of the basin do indeed penetrate to the modern surface and/or if the position of the Quaternary inland glaciers was associated with tectonic units/structures at depth. This theory was proven by Reicherter et al. (2005), who showed by the evaluation of lineaments that basement faults in the supra-salt Rotliegend (Fig. 4.5.2) are clearly reflected in the present-day landscape. The drainage pattern and the distribution of lakes in northern Germany correspond exactly to block boundaries in the deep basement and, hence, mark zones of subsidence and uplift. Additionally, the fluvial system in the CEBS is more complicated because of the occurrence of salt diapirs (Fig. 4.5.1b) and their response to ice loading. To take this complexity even further, a part of the system reacts diachronically. The Fennoscandian

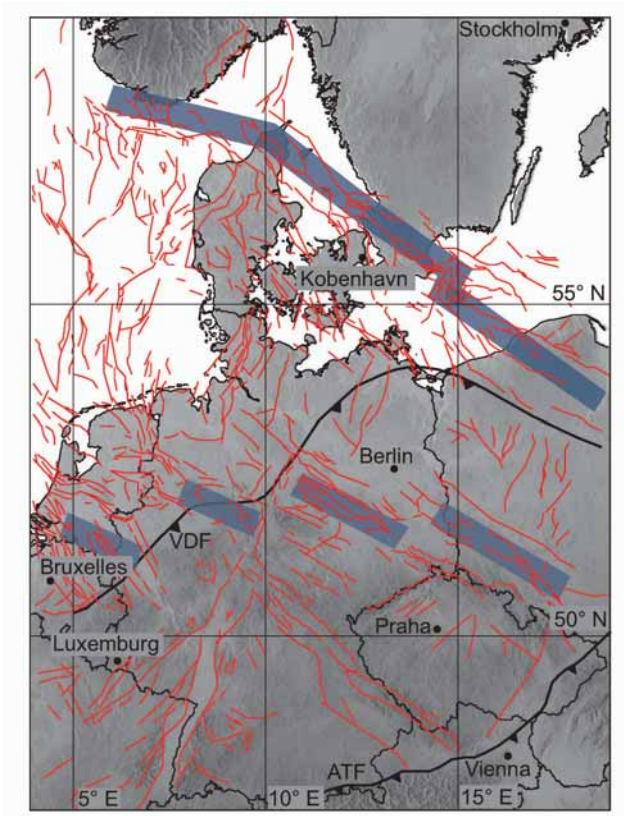


Figure 4.5.2. Topographic map of the North German Basin; boundaries are shown in *blue*, major basement fault systems are shown in *red*; *VDF* marks the Variscan deformation front (from Reicherter et al. 2008)

Ice Sheet in northern Germany during the last glaciation, the so-called Weichselian ice age some 20,000 years ago, reached a maximum ice thickness of 3000 m (Fig. 4.5.3), reconstructed from the mountain glaciation in Norway, isostatic rebound models and clay compaction of tills of the basal moraines (Piotrowski and Tulaczyk 1999). The load of the inland glaciers compressed the crust (or pressed the crust and lithosphere into the asthenospheric mantle), which after the retreat of the ice was unloaded and uplifted/expanded over several thousand years, attaining an isostatic equilibrium (Fig. 4.5.4). Accordingly, the prevailing regional tectonic stress caused by plate convergence in the Alps or spreading in the Central Atlantic is overprinted by glacial stresses (Roth and Fleckenstein 2001). The time of loading is considered to be long enough for a state of the isostatic equilibrium to be attained in the crust (Watts 2001). Elastic crustal flexure resulted in a circular depression below the centre, caused by radial outward flow of the asthenosphere (Daly 1934). The decay of the ice sheets must have changed the equilibrium situation in the crust and upper mantle. Important to note in this context is that the elastic response to fluctuating ice loads is regarded to be instantaneous, whereas the viscoelastic response of the mantle is much slower and must be active even thousands of years after the ice retreat (Stewart et al. 2000).

Faults and diapirs must have acted during this transition as discontinuities concentrating displacements with offsets of tens to hundreds of metres as observed during the Holocene in Scandinavia (Fig. 4.5.5). There is at the moment not even a common hypothesis for the current geodynamic regime including regional tectonics, salt dia-

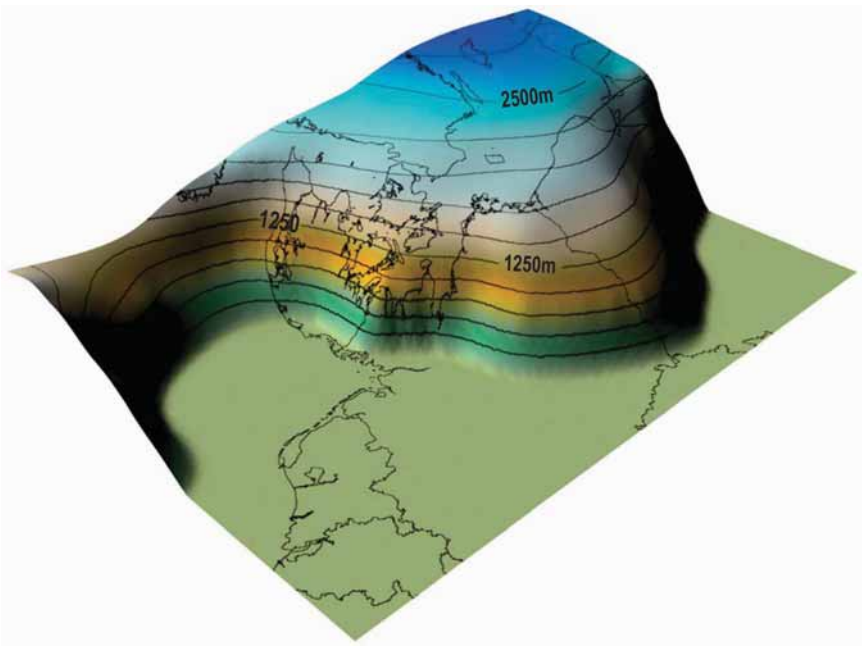


Figure 4.5.3.
3-D model of the Scandinavian ice sheet during the late Weichselian (*LGM*, last glacial maximum, approx. 20,000 years ago). The vertical scale is highly exaggerated. Data for model after Wu et al. (1999) and Siegert et al. (2001)

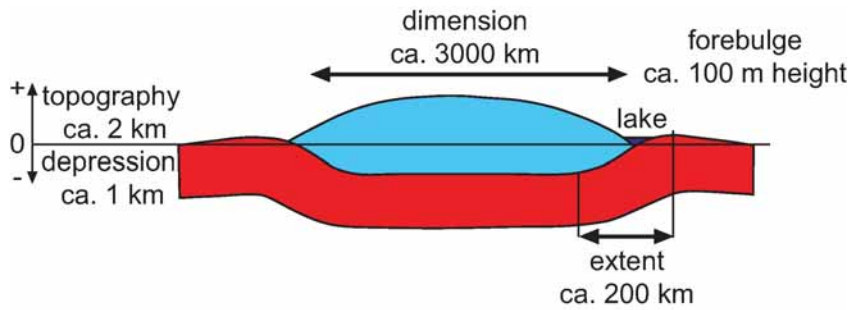


Figure 4.5.4.
Cross section model through the upper crust with a 3 km thick ice sheet in a quasi-isostatic equilibrium (modified after Mörner 2003)

pirism, glacial isostasy and modern landscape development for a reconstruction for the different glacial periods and interglacial periods of the past. This must remain a challenge for future dynamic modelling of the CEBS during the Quaternary. In the following chapter we will thus only present a few case studies to develop mechanistic model explanations.

4.5.3 Crustal movements, seismicity and landscape formation

The adjustment of the crust and lithosphere over the CEBS into an ice-free equilibrium state must have been accompanied by several geological phenomena, like seismicity and earthquakes (Fig. 4.5.5 a, after Gregersen and Voss 2008), with the formation of large faults and surface ruptures, slope failures and liquefaction as well as raising shorelines (Stewart et al. 2000; Mörner 2003). The isostatic uplift due to the postglacial rebound in Fennoscandia is also associated with moderate to major seismicity, which led to major earthquakes (Magnitude > 8) and surface ruptures in northern Sweden and Finland in the early phase of the uplift (Mörner 2003). The deloading accompanying geological effects in the peripheral areas during the Holocene were not as dramatic as in the centre of the ice load. However, differential subsidence and/or uplift must have been on the order of several mm per year and in the beginning with much higher rates.

The complex seismic strain-release patterns modified during the decay of the ice sheets have been termed "deglaciation seismotectonics" by Muir-Wood (2000). Measurable crustal deformation is still the consequence of the mantle response to deglaciation (Scherneck et al. 1998), accompanied by decelerating seismic activity (Mörner 2003). It has to be pointed out that it is generally very difficult to distinguish between ice-induced earthquakes and earthquakes resulting from plate tectonics in areas of repeated glaciation/deglaciation cycles.

The shorelines of the early Holocene Baltic Sea have been uplifted by at least 300 m since the deglaciation.

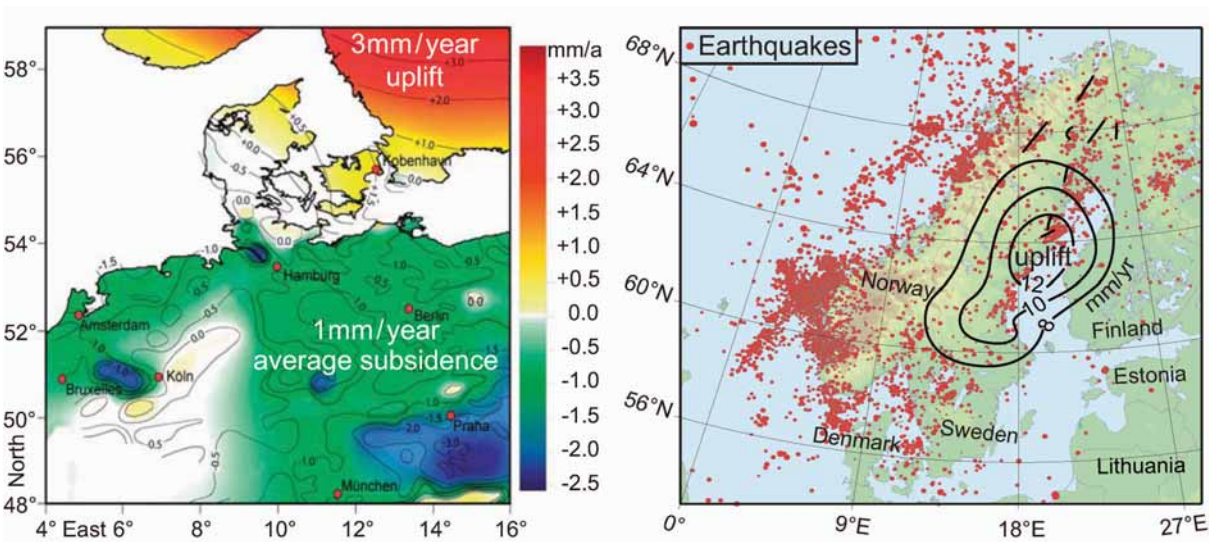
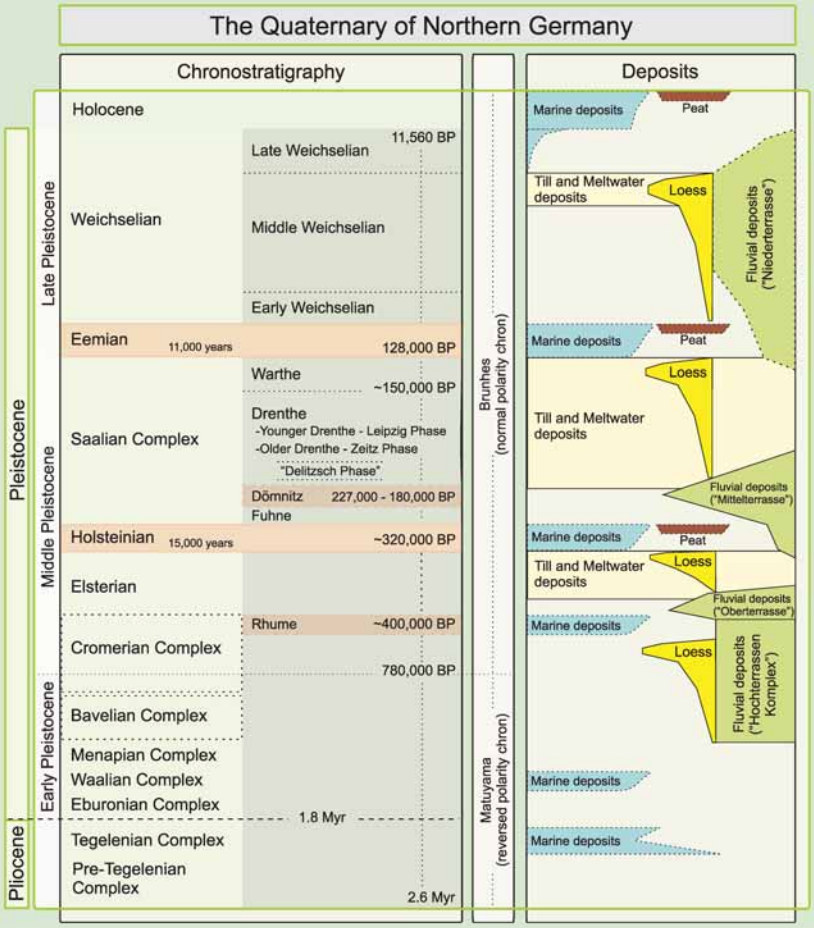


Figure 4.5.5.
a) Recent uplift and subsidence in the North German Basin area in mm/year (modified after Frischbutter et al. 2001)
b) Postglacial seismicity and active faults in Scandinavia (from Gregersen and Voss 2008)

Box 4.5.1. Glaciations

The Central European Basin was affected by 3 major glaciations during the Elsterian, Saalian and Weichselian periods. Figure 1 shows the very latest stratigraphic information, compiled by Litt et al. (2007). Sediments of the oldest Quaternary glaciation, the Cromerian Complex, are rarely known. Studies on the number and extent of ice sheets transgressing the Central European Basin are mainly based on the interpretation of glacial landforms and/or the distribution of glacial deposits (Ehlers et al. 2004). Tills are separated by glaciolacustrine and glaciofluvial deposits. In front of the ice sheets numerous large ice-marginal lakes formed capturing glacial meltwater and surficial water due to the blockage of natural drainage pathways to the north by ice sheets. Widespread fluvial erosion took place during interglacials and coastal areas became flooded due to rising sea-levels (e.g., Caspers et al. 1995; Eissmann 2002; Ehlers et al. 2004; Winsemann et al. 2007a,b).



Modern geodetic measurements still reveal uplift rates of up to 11 mm/year (Fig. 4.5.5a; James and Lambert 1993; Scherneck et al. 1998; Milne 2001). Lower Saxony and most of Schleswig-Holstein of Northern Germany are instead actively subsiding at rates of up to 1.5 mm/year (Fig. 4.5.5b). The reason for subsidence is asthenospheric back flow towards the centre of the former glaciation in Scandinavia and isostatic crustal re-adjustment in the CEBS area. Apparently, the regional tectonic stresses from the Alpine front and the Mid-Atlantic ridge push gain again more influence as pointed out by stress distribution modelling in the previous chapter.

Major basement faults in Northern Germany are oriented NW-SE, while minor faults trend NE-SW and NNE-SSW (Reicherter et al. 2005). The first indication that these orientations of structures in the deep crust are also expressed at the surface (Fig. 4.5.1) came from Hennig (1906). A similar interpretation of the orientation of rivers related to tectonic lineaments has been pointed out by Sirocko (1998) in particular for the river courses of the Oder, the Elbe (only the lower course from Magdeburg to the estuary near Hamburg) and the Weser, which either follow NW-SW or NNE-SSW directions. The location and trend of lineaments and faults correspond to old structures in the Variscan and pre-

Variscan basement (Fig. 4.5.2). The digital elevation model exhibits this observation, which can also be applied for other parts of the landscape forming (Fig. 4.5.1). In particular, the shorelines of the Baltic Sea are relatively linear, but mostly with SW-NE orientation which is the third major tectonic orientation of the CEBS. The river Oder between Germany and Poland marks a sharp change in the preferred orientation. The Polish rivers and shores are dominated by the SW-NE orientation, whereas in Germany, NW-SE or NNE-SSW orientation is dominating. These three directions dominate the surface topography of the entire CEBS. A strong indication that the modern landscape is at least partly a mirror of the basin history is the continuation of the Polish salt pillows at depth and the modern Baltic Sea coastline southwest of Rügen Island (Fig. 4.5.1b). However, it is unlikely that such surface lineaments are directly forced by processes from below (endogenic or halokinetic), but much more likely these lineaments represent block boundaries, activated by the repeated loading and unloading under the glacial ice masses. Modern rivers and shorelines still mark the boundaries between individual blocks.

Inland ice masses during previous glaciations had an even larger extent than during the Weichselian, when glaciers were restricted to the area north of the river Elbe. The Saalian and Elsterian glaciation (ice margins in Fig. 4.5.1, see Box "Glaciation" for chronology) reached further south up to the foot of the Harz Mountains and into the Netherlands. Maximum ice sheet thickness and, hence, ice load during these two earlier glaciations were higher over the CEBS area than during the Weichselian, leading to strong ice-isostatic effects. The model of the ice sheet – crust interaction (after Mörner 2003) indicates that under the conditions of the Elsterian or Saalian there was an enhanced ice loading of the CEBS sediments. This effect was accompanied by the development of a crustal forebulge extending up to several hundred kilometres distance from the ice front in the distal foreland (Fig. 4.5.4). Hence, the effects of isostatic rebound were not only limited to the former ice-covered areas, but also to the periglacial landscape in front of an ice sheet.

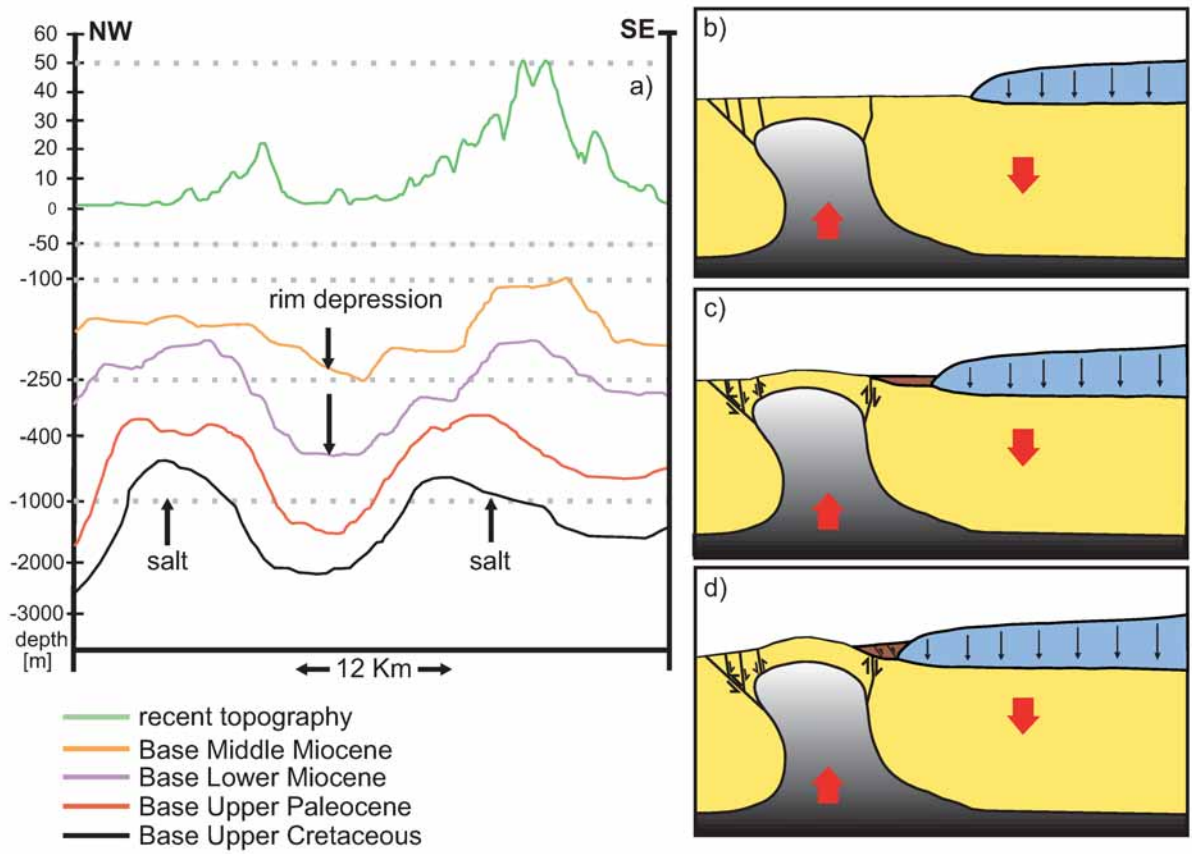


Figure 4.5.6.
a) Modern topography of the landscape around Rederstall (Schleswig Holstein) in parallel orientation to the geological strata below (Lehné and Sirocko 2007), data from Baldschuhn et al. (1996).
b) to d) Schematic sketch of a forward moving glacier with a salt diapir at subsurface

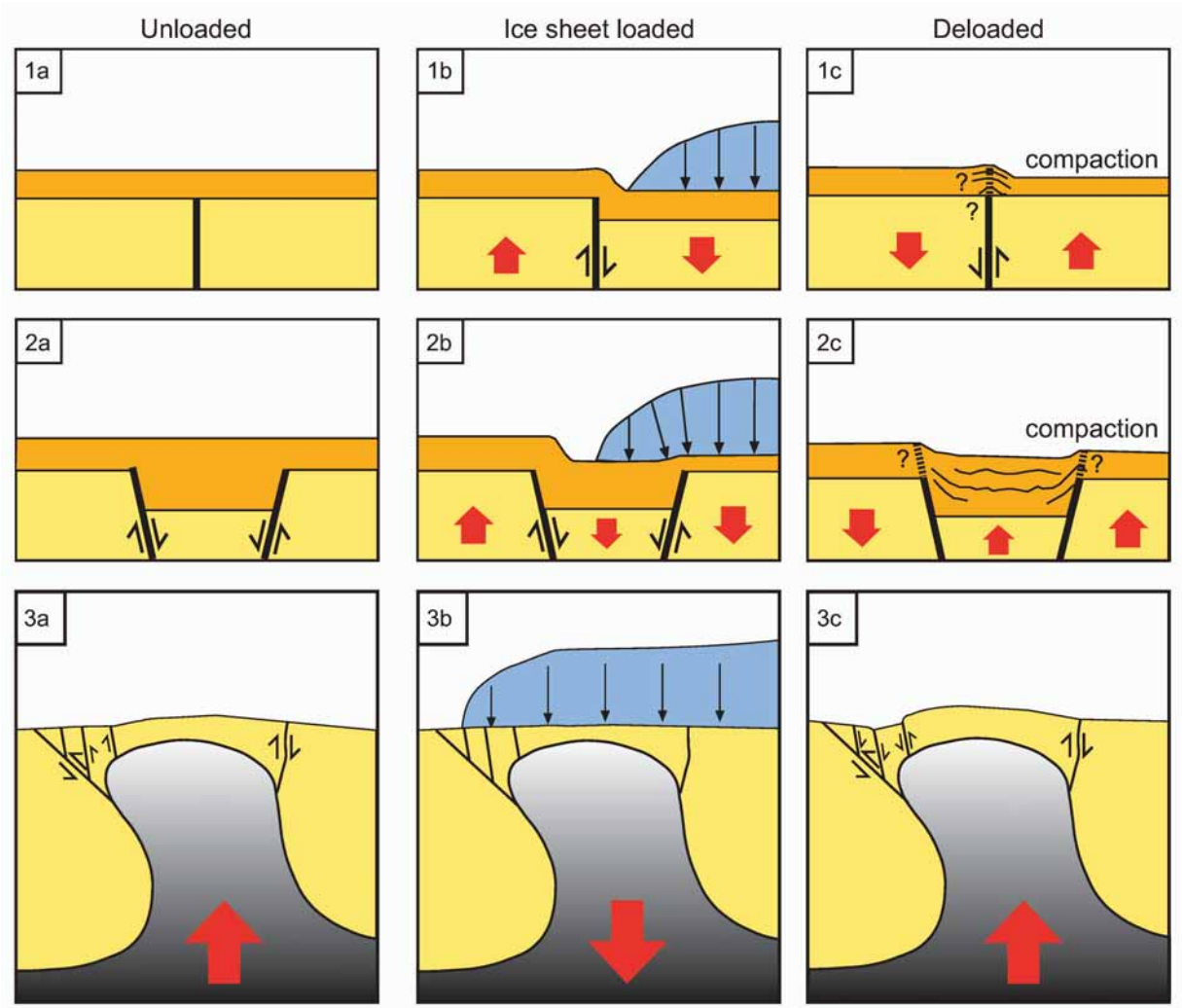


Figure 4.5.7.
Ice load induced tectonism (modified from Liszkowski 1993)
1a-c Influence of ice-loading/unloading on a normal fault with crustal failure and reactivation of inherited structures. *Red arrows* indicate relative crustal movements
2a-c Effects of ice-loading/unloading on a pre-existing graben system with conjugate faults
3a-c Consequences of ice-loading/unloading on faults and salt dynamics associated with a salt diapir, *red arrows* indicate relative diapiric movements (Liszkowski 1993)

4.5.3.1 Regional and case studies

Schirrmeister (1998) demonstrated that most Weichselian moraines in Mecklenburg-Vorpommern and Brandenburg are in direct contact with salt structures at depth. Lehné and Sirocko (2007) reported this relationship also for a section through the salt structures of Hennstedt and Tellingstedt south of Husum in Schleswig-Holstein (Fig. 4.5.6 a) where a parallel orientation of the salt structures with the geological strata above and the modern topography becomes evident. The Quaternary deposits along the section are of Saalian age, which would invoke an average continuous uplift of 0.3 mm/year if the surface structures would be caused by rising salt alone. However, the pattern of parallel topography and salt at depth could be explained also by another scenario, which starts with the glacier advancing towards a salt structure leading to an additional load on the subsurface, creating local accommodation space for meltwater deposits in front of the rising salt diapir. The meltwater deposits subsequently became compressed, leading to the formation of a push moraine. Such a model would help to explain why glacial push moraine belts are often (but not always) located immediately north of a salt diapir.

Other mechanistic models for salt – ice interaction have also been proposed (Fig. 4.5.7). An attendant and very important circumstance of ice loading is stabilisation of

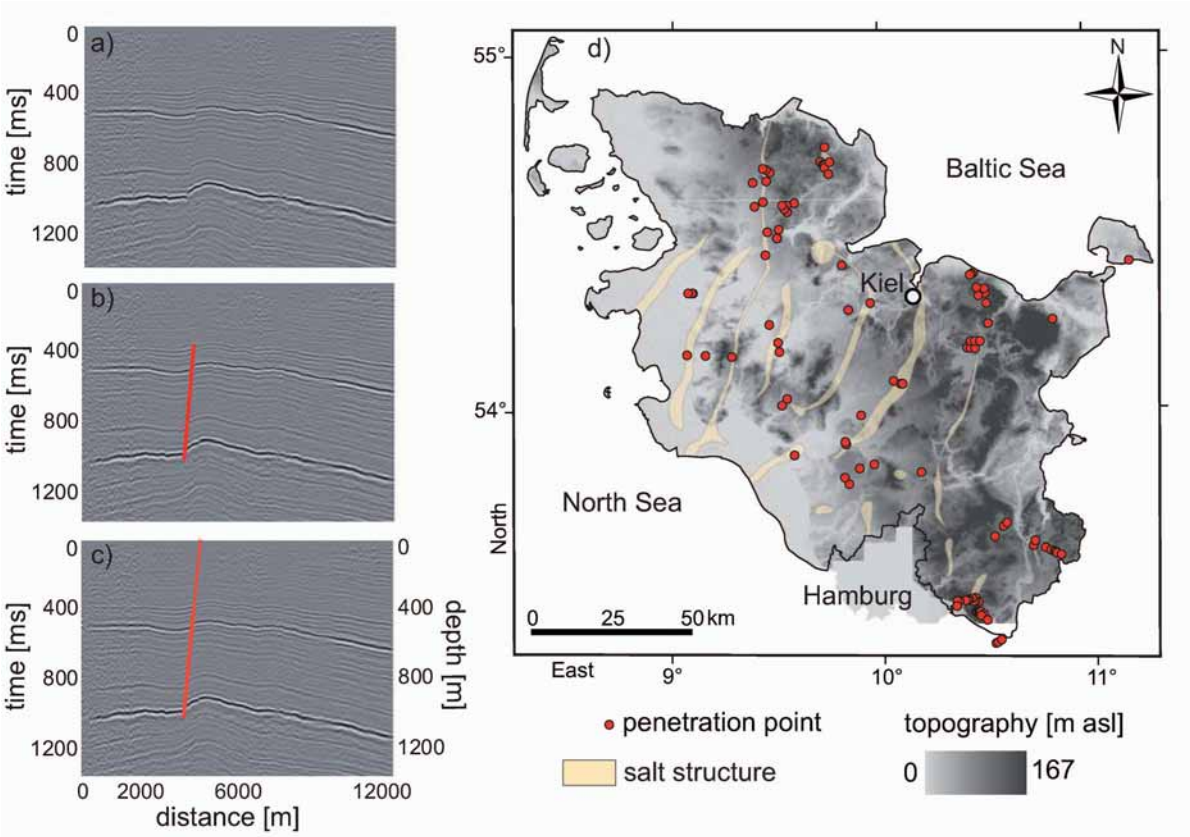


Figure 4.5.8. a-c) Seismic profile of a salt diapir with near surface faults and fault projection to the surface.
d) Map of Schleswig Holstein with fault penetration points, determined by evaluation of 454 seismic lines of the oil industry (from Lehné and Sirocko 2007)

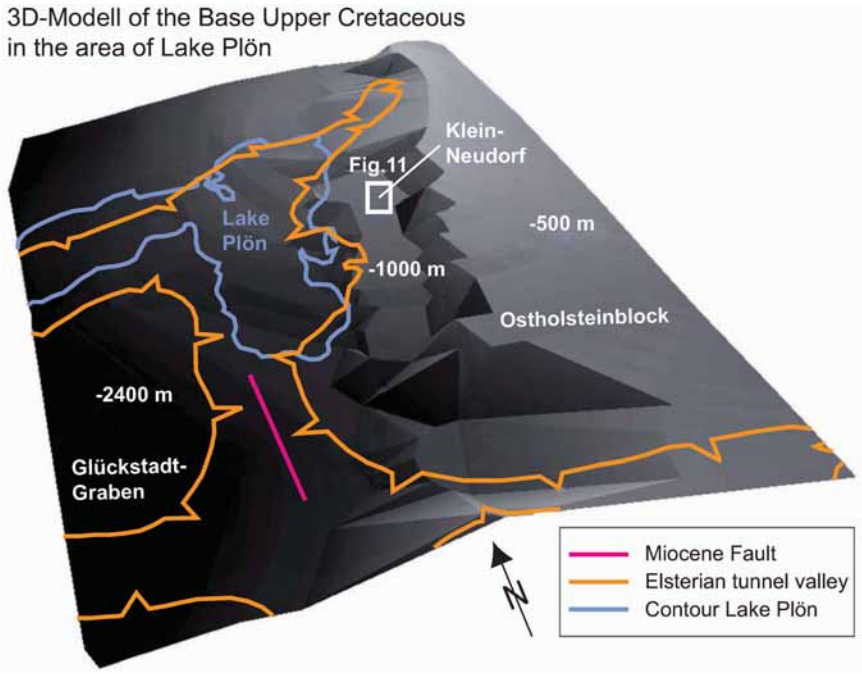
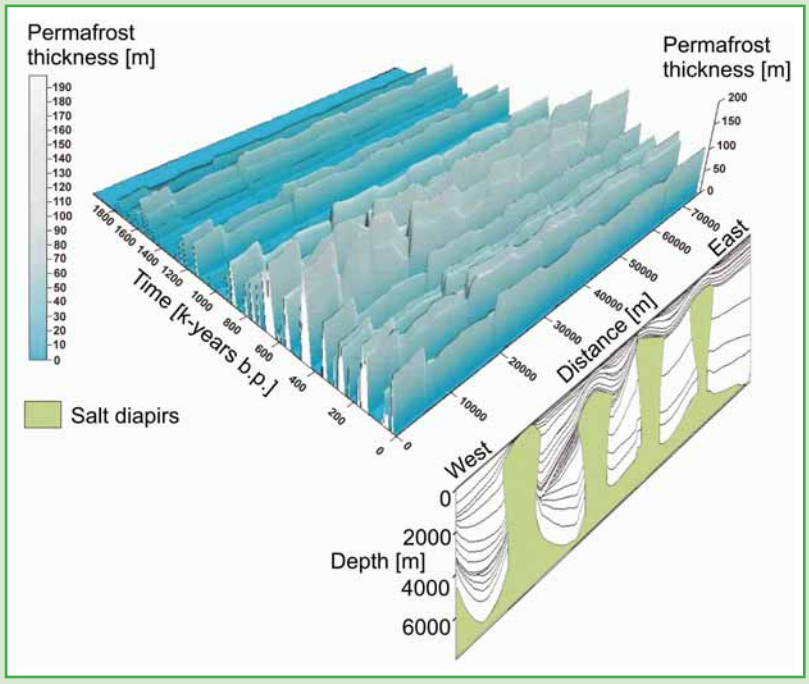


Figure 4.5.9.
3-D Plot of the base of Late Cretaceous in the lake Plön area, additional lines for faults of the eastern boundary of the Glückstadt Graben, position of an Elsterian tunnel valley and position of project area Klein Neudorf

Box 4.5.2. Permafrost

The presence of permafrost in central Europe during various glacial stages of the Pleistocene is indicated by relict ice-wedge structures, which have been frequently observed in excavations of lignite mining districts of East Germany (Eissmann 2002) and are observable even today in vegetation patterns, mimicking relict ice-wedge polygons in northern Germany (Delisle et al. 2007). However, no direct indication of the former permafrost depth is known from the sub-surface sedimentary record. Figure 1 shows the calculated variations in depth of permafrost along a 75 km long profile crossing several salt structures of the Glückstadt Graben. The permafrost reconstruction is based on the mean annual ground temperatures curve (MAGT) for north-central Europe, the marine proxy record of ODP-site 659, the average porosity of the sediments and the average thermal conductivity. The model predicts a maximum permafrost depth of about 170 m during the last million years. Above salt structures the depth of permafrost is reduced by up to 40 m. Higher thermal conductivity of rock salt results in enhanced heat flow through salt structures at the expense of the surrounding country rock. Therefore, enhanced heat flow over salt domes impeded the development of permafrost, and reduced heat flow in the adjacent country rock favoured deeper penetration of the lower permafrost boundary.

The interplay of salt diapirism and fault movements in the North German Basin is difficult to assess for several reasons: during permafrost times the groundwater was frozen and not able to dissolve or modify evaporites (e.g., anhydrite to gypsum); due to the ice load faults and rising diapirs were blocked: the effective stresses were the sum of the regional tectonic stresses and the ice-induced stresses.



faults under the ice, leading to the suppression of seismicity and a decrease in fault stability beyond the ice margin (Johnston 1987; Johnston et al. 1998). Ekström et al. (2003) detected dozens of previously unknown, moderate earthquakes beneath large glaciers. These are relatively "slow", because the driving mechanism is thought to be wave-like glacial movements they are termed "glacial earthquakes". However, loading by small ice sheets (radius approx. 300 km) causes an increase in stability of less than 1 MPa at shallow depth, but promotes instability at greater depths (Stewart et al. 2000). In contrast, unloading also decreases stability relative to the initial pre-glacial state (Fig. 4.5.7 1a-c). Repeated ice progression during interstadial and interglacial periods must have significant influence on the fault activity, i.e., faults get locked under the ice loads and are reactivated/initiated in front of the ice mass (Fig. 4.5.7 2a-c). The influence of underlying salt (which is regarded as incompressible) on fault activity in the vicinity of diapirs is shown in figure 4.5.7 3a-c. During glaciation the rise of the diapir is hindered, and faults are blocked. After the retreat of the ice sheets, faults are reactivated.

To verify or falsify these model assumptions we examined whether faults are capable to reach the surface even through unconsolidated Quaternary deposits of some-

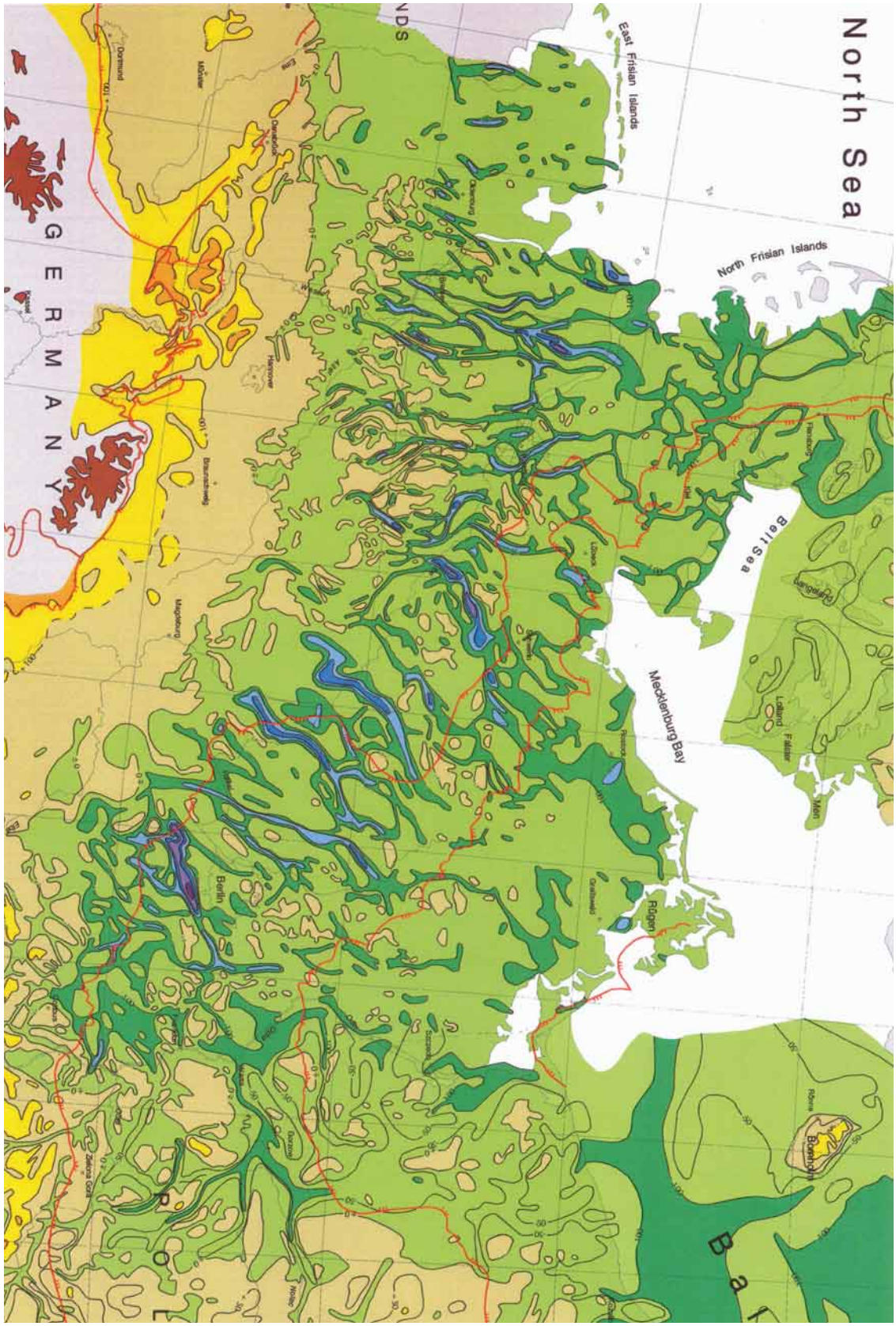


Figure 4.5.10. Base of Quaternary deposits (deepest sections depicting the tunnel valleys), reproduced from Stackebrandt et al. (2001)

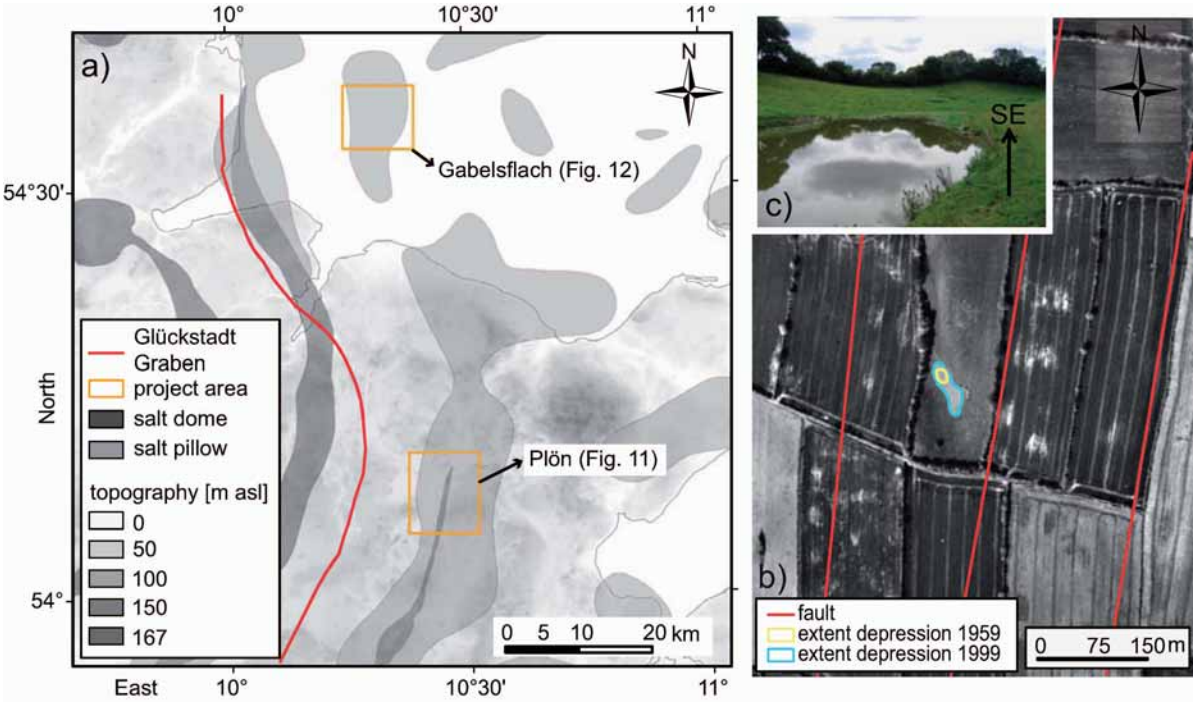


Figure 4.5.11.
a) Map of Ostholstein with salt diapirs and salt pillows and the two project areas of Lake Plön and the offshore Gabelsflach, both along the very eastern flank of the Glückstadt Graben.
b) and c) Photo of an actively sinking depression near Klein Neudorf, east of Lake Plön. Aerial picture of the enlarging depression in 1959 and 1999 (from Lehné and Sirocko 2007)

times several hundred meters thickness. The approach is based on the observation that an observed offset at depth multiplied by a factor of 20 approximates the minimal continuation of a fault (J. Urai, pers. comm.). The fault at 500 m depth in the example of figure 4.5.8 has an offset of 40 m and will continue for at least another 800 m. Accordingly it has the potential to reach the surface and cause a penetration point. This approach was used for a systematic mapping of all available seismic lines in Schleswig-Holstein and resulted in a map of penetration points (Fig. 4.5.8, from Lehné and Sirocko 2007), which shows that most penetrations points are associated with salt diapirs that have risen to depths of a few hundred meters below the surface. There are, however, also clusters of points in areas not associated with salt diapirism, for example north of the most eastward salt wall. This salt wall north of Bad Segeberg parallels the eastern flank of the Glückstadt Graben and is associated with deep reaching faults down to the base of the CEBS, in particular east of Lake Plön. A digital elevation model for the Lake Plön area reveals the base layer of the Late Cretaceous (data after Baldschuhn et al. 1996; Fig. 4.5.9). The eastern shoreline of the lake is above two parallel running faults striking in a SSW-NNE direction, associated with the deep Segeberg-Plön salt wall / pillow. Both faults are normal faults with a displacement of almost 2000 m with respect to the Glückstadt Graben. The orientation is remarkably parallel to the eastern shore of Lake Plön. The western shoreline of the lake is also straight and parallels a small Miocene graben. Accordingly, Lake Plön can be regarded as a tectonic lake and not only a basin formed by glacial erosion.

However, the shape of the modern Lake Plön matches also an Elsterian tunnel valley. These valleys of up to 500 m depth developed at the base of the Elsterian ice sheet. Figure 4.5.10 reproduces a compilation map of Stackebrandt et al. (2001) and Stackebrandt (2004). The orientation of the tunnel valleys is on average NE-SW and thus not fully identical to the NNW-SSE strike. The tunnel valleys were mainly formed by subglacial meltwater erosion (Piotrowski 1997; Huuse and Lykke-Andersen 2000; Jørgensen and Sandersen 2004) and the direction of tunnel valleys in general is thought to be perpendicular to the ice sheet margins, documenting the flow direction of the ice. It is discussed since long whether the subglacial drainage pattern could have partly followed old tectonic structures in the subsurface. The modern Lake Plön is thus most probably an inherited structure, which originated in the Miocene under intense tectonic stresses due to the Alpine orogeny and maximum uplift rates of salt diapirs in the CEBS, it would thus be an example for the model explanation of figure 4.5.7 case 2.

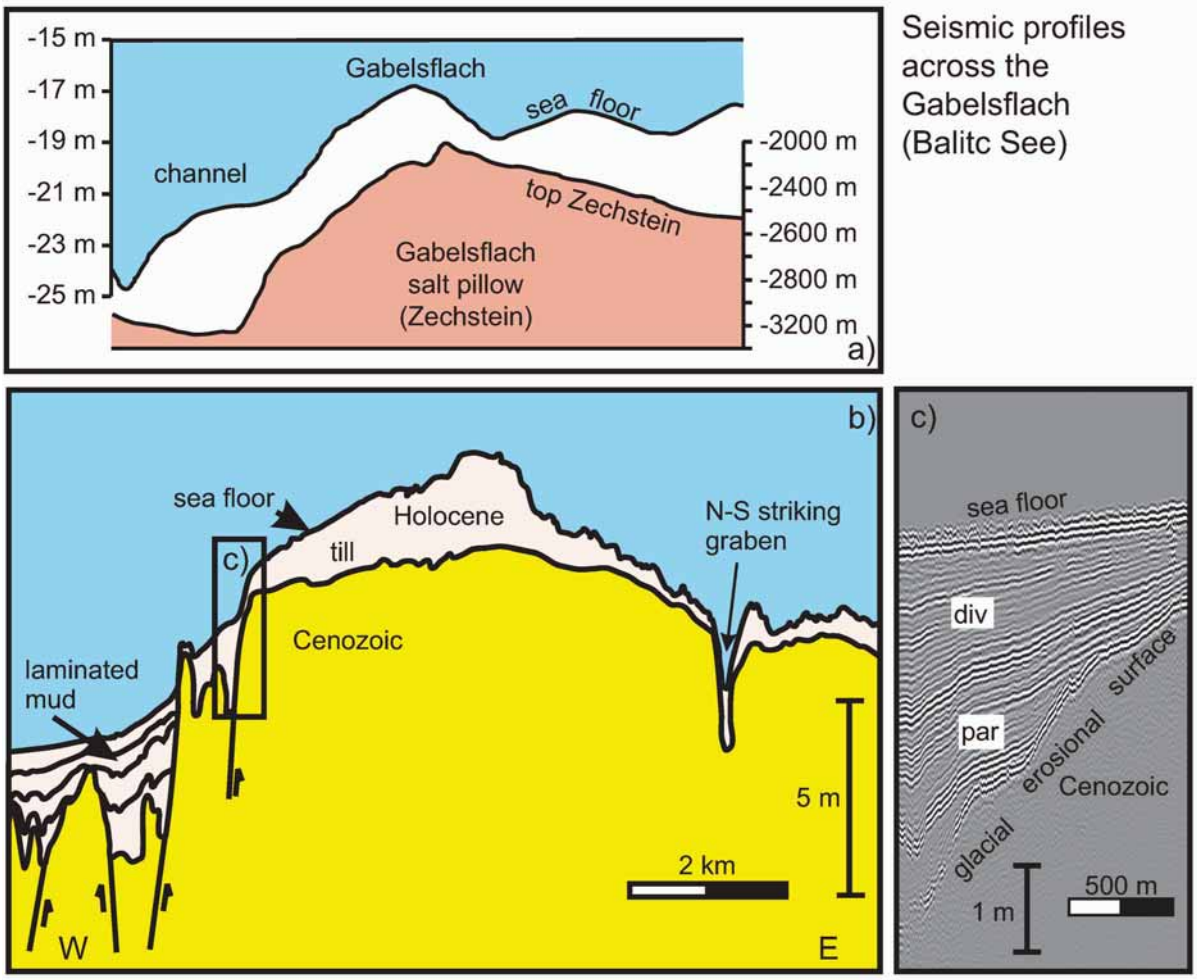
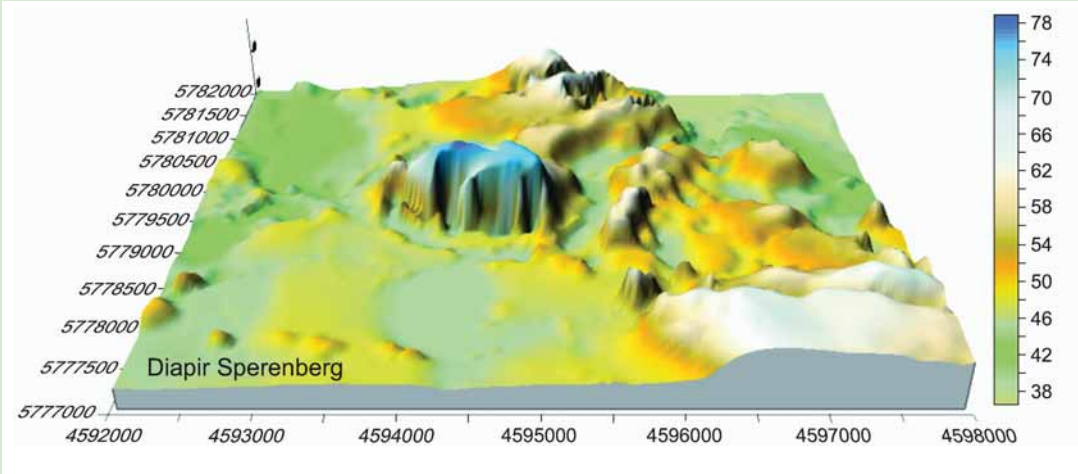


Figure 4.5.12.
a) Seismic profile along the Gabelsflach in the southwestern Baltic Sea (Fig. 4.5.1a) located above a salt structure.
b) Line drawing of parametric echosounder data (/Innomar SES system/) across the "Gabelsflach Heigh" with Holocene sediments superimposing an unconformity from glacial erosion.
c) Vertical succession of pre-tectonic (parallel) and syn-tectonic (divergent) Holocene sediments at the flanks

The larger Lake Plön area also provides evidence that these faults along the eastern flank of the Glückstadt Graben are still active today (Lehné and Sirocko 2005, 2007). This inference comes from a recently enlarging depression near Bosau/Klein Neudorf. The depression is located directly above the large faults, which offset the Late Cretaceous by some 2000 m (see location of depression in Fig. 4.5.9). The depression had a diameter of 15 metres in 1959 (Fig. 4.5.11, yellow line); in 1999, 40 years later, the diameter had enlarged to 65 metres (Fig. 4.5.11, blue line). The amount of subsidence was more than one metre in 50 years, thus on the order of several cm/year, which is much higher than the general basin subsidence of less than 1 mm/year. The high sinking rates require a geodynamic process operating on the order of cm/years. Such rates have been reported from local maxima of dissolution of salt in the subsurface or from compacting peat. A 65 m borehole into the depression, however, has neither revealed peat nor salt at depth, but only sand. This corroborates the very young nature of the depression, because if this had been a late Weichselian kettle hole, the depression would have been filled with Holocene gyttja and peat. Dissolution of salt in the subsurface is also impossible because the salt surface is at 2000 m depth where pore water is saturated with salt. The depression, however, lies exactly above steep faults with high slip rates at depth. If these faults are associated with extensional stress and a fault penetrates through unconsolidated sediments, a local sinking might well be the expression of a surface penetration point. This is the most likely interpretation for the depression at Klein Neudorf and for many other local depressions in the surface sediments of the tectonically active CEBS, today and

Box 4.5.3. Salt diapirs at the surface; the Sperenberg example

Salt diapirs have penetrated the modern surface at only three locations in the CEBS: at Bad Segeberg in Schleswig Holstein, Lüneburg in Lower Saxony, and Sperenberg, south of Berlin. Figure 1 shows an elevation model for Sperenberg (Stackebrandt 2005), which is situated on a NW-SE striking neotectonically active fault zone. The caprock consists of several tens of metres thick gypsum and anhydrite; the salt has been encountered 120 m below the surface. The Sperenberg diapir was only loaded by ice during Elsterian and Saalian glaciations. Thus, it has been ice-free for about 130.000 years. The Saalian tills, which cover the structure, were uplifted differentially. During the subsequent Weichselian ice age, Sperenberg formed a topographic high, possibly related to a Nunatak. The isostatic caused uplift of the diapir leads to salt solution in the sweet water reaching neck of the diapir characterised today by circular lakes, indicating active present-day landscape sculpturing processes.



also during the past, when isostatic movements must have affected fault activity in northern Germany, in particularly during the early deglaciation.

The paragraphs above describe examples of tectonic and halokinetic activity on land. The following section will now evaluate if these mechanisms also operate offshore. We studied in detail the Gabelsflach, which is a bathymetric high of less than 10 m water depth in the southwestern Bay of Kiel, located on the continuation of the Glückstadt Graben border from the area of Lake Plön to the north into the Baltic Sea (Fig. 4.5.11 a). Hübscher et al. (2004) describes marine seismic surveys, which reveal a deep salt diapir with pronounced bathymetric changes on the sea floor above (Fig. 4.5.12). The outcropping sediment on top of the salt diapir is a glacial till, whereas at the flanks we find laminated mud. The western flank of the uplifted sea bottom is subdivided into a parallel lower and a divergent upper succession. Parallel layers were deposited during tectonic quiescence, whereas divergent reflection points towards vertical movement, which confirms that the entire Gabelsflach structure was uplifted during the later Holocene. Thus, the salt diapir below the Gabelsflach structure was active during postglacial times. This fact proves that also halokinetic forces were active during the Holocene, not only isostatic processes.

The picture of an active landscape formation from endogenic-exogenic forces in the CEBS is based on GIS analysis of the topography, models of isostasy and rebound, reconstruction of fault activity and modern subsidence rates. A common interpretation of all observations highlights the role of the Quaternary glaciations, which flexured the crust and fractured it into blocks along existing faults at depth that reach deep into the basin. Salt diapirs were halokinetically rising mainly during the Tertiary, but are still active during the Holocene. Today, even after the decay of the ice sheets, ongoing subsidence still reflects the long-lasting isostatic adjustment of the crust and lithosphere in the CEBS, a process which had shaped the modern landscape in particular during the final phase of the last glaciation.