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Vertical movements since the beginning of Rupelian stage (map 1)

Neogeodynamica Baltica IGCP-Project 346

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1. Conception of the map and methodical remarks

The map covers parts of the following previous developed geotectonic units:

the Fennoscandian craton (Fennoscandia)
the Precambrian East European Platform (EEP)
the Carpathian orogen and its foredeep
the Palaeozoic West European Platform (WEP)

The dimensions and magnitudes of the neotectonic vertical movements of the Earth´s crust as well as the distribution of the intensities are shown in the map. Except for the non-ruptural regional deformations (isolines of the vertical movements) the faults and active flexures during the neotectonic period are demonstrated, and also the frontal overthrust of the Carpathians. Indications of horizontal shear movements are also regarded.
The used reference level for determination of the vertical movements changes from the west to the east to younger stratigraphical horizons. That means, it is a somewhat diachronous plane (see 2. and Fig. 1). Younger reference levels with extension over large areas, and useful for better understanding the chronological course of the vertical movements are scarcely available because of the important primary and secondary gaps in the sedimentary record concerning the Neogene to early Quaternary times (see 3.3).

Fig. 1.
Recent areas of the sediments used for calculation of the vertical neotectonic movements - base of the Rupelian, top of the Kharkov beds, base of Miocene deposits

As to the East Baltic region and the adjacent area of the Central Baltic Sea the base of Quaternary has been accepted as the main reference level to establish the neotectonic movements since Tertiary deposits are absent there. Also, the recent relief and the geological structure of Quaternary cover were of use. The Application of research work adapted to the geological and working conditions specific to this region (offshore and onshore areas) provided indications which can be assigned to preglacial shares of the neotectonic movements. Regarding to the other regions of East Europe without or with minor relics of the Tertiary cover the presented results are based on a similar step by step retrospective morphostructural and tectonical analysis (Garetsky et al. 1999).
In the North German Lowland the movements of the fault structures are only evidenced up to the middle Miocene sequence showing the youngest seismical determinable horizon. Post middle Miocene sediments, found in top grabens above salt structures indicate later tectonical activities (oral comm. F. Kockel, Hannover). The areas containing neotectonical active salt structures are also outlined to point to probable block tectonics in the basement. An individual presentation of these structures would have overloaded the map.
The short-term glacioeustatic sea-level changes were compared with the long-term tectonoeustatic ones getting a significant amount already before the Pleistocene glaciations (accumulation of the antarctic ice sheet, temporary isolations of the Mediterranean Sea from the ocean). They essentially contributed to the repeated facies changes due to the trans- and regressions in the area under investigation.

Therefore the ingression of the Miocene sea which started from the North Sea area and the Carpathian foredeep as far as to the Polish lowland (Dyjor 1986) cannot just like that be explained by tectonics because - likely in the main - they may also have been originated from glacio- and tectonoeustatically controlled sea-level changes.
The glacioisostatic vertical movements which occurred during the Quaternary and Neogene times were climatically controlled in the same way. They have superimposed the tectonical movements. Separation of the effects of both forces from one another is possible only to a very limited degree up to now. It works better for northern Europe, the region stron-

ger affected by glacioisostatic movements. The same is true for the glaciated area in the Carpathians.

For the Holocene times itself it is not certain whether the glacioisostatic rebound has terminated already some thousand years ago or whether it is still in action (Mörner 1990, Riis 1992). There is no doubt that due to the glacioisostatic process many pre-existing faults have been reactivated for displacements up to 30 m (Lagerbäck 1990, Fredén 1994). In the Ukrainian part of EEP (small cover of glacial sediments) glacioisostatic movements are also indicated (Palienko & Matoshko 1995).

The map shows only the cumulative effects of the vertical movements. Changes of sign (up - down or vice versa) remain concealed. From the isolines of the vertical displacements of the reference level one cannot infer immediately to the same mobility of the different structures. More about these problem you will find in the regional contributions of the complete version of the explanations to the map set (in press), while here are presented only some general comments.

The neovolcanism, close connected with the fault tectonics, was restricted to the Central European Uplift zone in the northern foreland of the Alpine-Carpathian orogen. Due to the chosen scale of the map only an outline of the area with volcanic effusions is demonstrated. Only the two largest volcanoes, the Vogelsberg in the Hesse graben and the Dupovske Mountains in the Ohre graben, are individually shown.

2. Character and course of the neotectonic movements

2.1 General remarks

From the investigations result, that the neotectonic movements were largely controlled by the former structural development and that the geotectonic units moved accordingly differentiated. In the WEP they generally continued the vertical movements of the epirogenic and ruptural structures, with and without rupturing, temporarily strengthened and with regionally changing sign. Besides that single new structures developed. The North Sea and the neotectonic Central European subsidence zone repeated approximately the North German Polish depression originated at the end of the Variscan orogeny. The like is true for the EEP related to their older fundament and cover structures. In this point both platforms, the older and the younger one, resemble each other while in the detail significant differences in mobility do exist, due to their differentiated tectonic development throughout the Phanerozoic. In view of the WEP the movements resulted in more significant strengthening of the relief in the uplifted zone and in forming of morphostructures of dimensions scarcely arrived at the Permian times. With it for long time latent structures could have been reactivated and appeared to be new tectonic elements. On account of this fact interpretation had to consider the development far back in time. In the EEP region morphostructures with smaller amplitudes formed. The complex relationships between the structures of the fundament, the sedimentary cover, and on the other side the neotectonic structures are characteristic of large parts in the EEP and not restricted to areas with thick salt layers in the cover. They reflect repeated transformations of the structural plan during the neotectonic stage (Garetsky et al. in prep.).

Further on the EEP contrasts with the WEP by its striking net of widely extended active faults, which are often combined with lateral shearings but they are without volcanism. In the lowland of the WEP faults are underrepresented on account of the slow down effects on tectonic impulses caused by the thick late Palaeozoic and Mesozoic layers of salt as well as the unconsolidated Tertiary and Quaternary rocks in the cover. Such layers are mostly thin or lacking in the part of EEP shown in the map. Moreover, these geological differences required the apply of different methodical procedures to each platform. In some regions the reference level is not exposed or not verifiable (e.g. sea area) so that indirect research methods must have been used. From point by point data taken from different disciplines and under consideration of pre-existing fault structures reactivations along total length of these fault structures are inferred.

In the East Baltic region neotectonically activated faults are often accentuated by recent and older river valleys as well as by glacial channels cut into the pre-Quaternary rocks (Šliaupa et al. 1995). In northern Europe such movements lasted until Holocene times. It suggests to glacioisostatic causes (Lagerbäck 1990).

The map also reveals that the maximum subsidences and uplifts are of the same order, but in the WEP the amount are nearly one order more than in the EEP. There are subsidences in the Roer-Lower Rhine graben and the North Sea depression up to >1500 m, in the Central graben (outside the map area) to 2500 m, are in contrast to uplifts to >2000 m of the Norwegian mountains, and to >2500 m of the Carpathians, while only about 250 m subsidence have been reached in the Central Baltic Sea region, and up to about 350 m uplift in the EEP (Fig. 2).

The average rates of the vertical movements show regionally significant increases from the Neogene to the Quaternary (Fig. 3). This does not express the actually reached velocities because of the temporary accelerations of the movements and their changes in sign, and since the average rates calculated for the Quaternary are related only to a comparatively short period.

In the WEP block fault tectonics above all was of tensional nature with W - E direction except for the WSW - ENE striking Ohre graben. This corresponds to a crosswise tensional effect in relation to the general NNW - SSE oriented stress. All active fault directions in pre-neotectonic times were more or less temporarily alternating reactivated.

Compressive movements have been observed apart from the Carpathian orogen only at the northern rims of NW - SE directed blocks in the WEP. These fault structures remained closed and without volcanic events, corresponding to the controlling stress. Endogenous folding was restricted to the Carpathian orogen.

The most rapid vertical movements occurred at the transition from Oligocene to Miocene times, during the Miocene and from late Pliocene to early Quaternary times in the WEP, and in the EEP at approximately the same times.

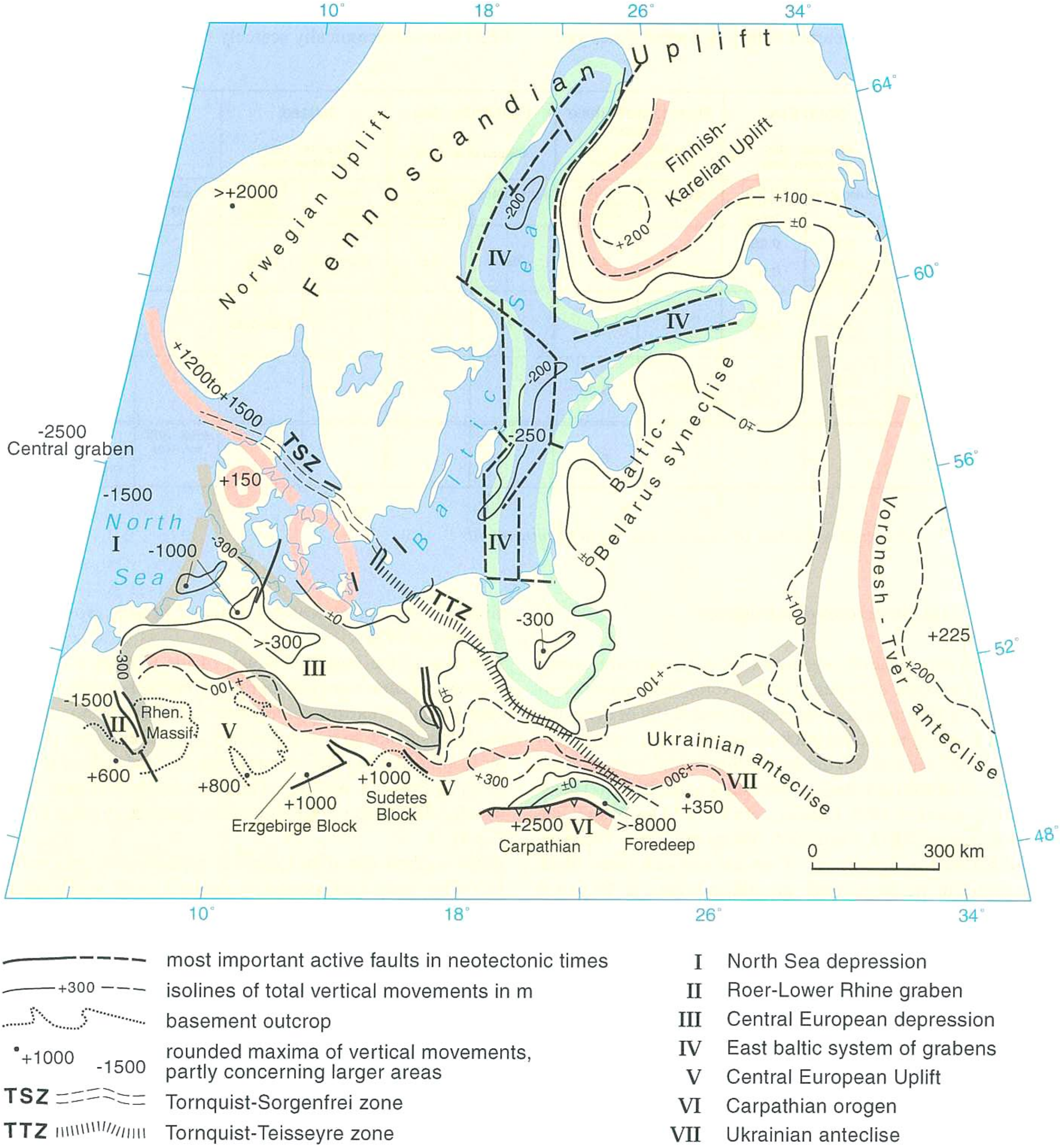

Fig. 2
Most important areas of neotectonic subsidence/uplift, maximum vertical displacements used map no. 1 and data from JENSEN *and* SCHMIDT *(1993).*

On top of it inversions of the movements occurred since Oligocene times with culminations in the Miocene and with increases during the transition to the Quaternary. These changes also took place almost contemporaneously in the affected regions shown in the map. The most important tectonic inversion apart the Carpathian orogen was realized by the strong, nearly non-ruptural uplift of the eastern rim of the North Sea depression since the Oligocene times (see below). A decrease of the neotectonical activities during the Quaternary times cannot be derived from these data. The floor of the North Sea has subsided to about 1000 m in the Quaternary and the base of Quaternary in the Central graben area shows vertical displacements to 100 m (CAMERON et al. 1987). In the Roer-Lower Rhine graben and in the Podolian plate block fault tectonics occurred during Holocene times yet.

Upper Cretaceous times. In contrary, the Tornquist-Teisseyre Zone, following to the southeast (the western rim of the EEP) was neotectonically scarcely reactivated - apart from

	North Sea Pedersen 1995 Michelsen 1996		Roer-Lower-Rhine Graben Ahorner 1962, 1983 Klostermann 1995		East Baltic Sea Šliaupa et al. 1995		Jutland Pedersen 1995 Michelsen 1996		Fennoscandia Freden 1994	
	Subsidence (m)	Rate of Subsidence (mm/a)	Subsidence (m)	Rate of Subsidence (mm/a)	Subsidence (m)	Rate of Subsidence (mm/a)	Uplift (m)	Rate of Uplift (mm/a)	Uplift (m)	Rate of Uplift (mm/a)
Quaternary	500 1000 (Centr. Graben)	**0.25** 0.50	175	**0.1**	250	0.6	100-150	**0.06**		
Oligocene-Pliocene	1000	**0.03**	-	-	?	?		**0.02-0.03**		
Post-Eocene	1500 (2000)	0.04 0.055	1500	**0.04**						
Holocene				0.3					max. 285 last 9500a	30.0 max. 9.2 recent

Fig. 3 Average velocities of neotectonic vertical movements

2.2 Main structures of subsidence

Most recent research revealed that the generally saucer shaped Cenozoic subsidence of the North Sea region occurred very differentiated in space and time: shifts of the depocentres, strong increased thicknesses of several members of the Tertiary sequence in the area of the Central graben, different rates of sedimentation on both sides of the graben (BJORSLEV NIELSEN et al. 1986, CAMERON et al. 1987, DORE 1992, JENSEN & SCHMIDT 1993, JORDT 1995, MICHELSEN 1996). Therefore and because of activations of several salt structures, block tectonics in the deeper underground must have taken part in the basin´s subsidence. But only some of the activated faults were transferred to the uppermost parts of the Cenozoic sedimentary cover.

At the eastern rim of the North Sea depression subsidence was followed by strong uplift since Oligocene times. The elevation occurred nearly without fault tectonics but with changing velocities. Culminations appeared in the Miocene and from the Late Pliocene to the Early Quaternary. One of the main discordances formed at the Quaternary base. Towards the basin´s centre continuous sedimentation produced up to about 1000 m Quaternary deposits. The elevation was linked with the strong uplift of the Norwegian Mountains which largely followed the Palaeozoic Caledonian orogen and formed part of a circum Atlantic uplift zone (DORE 1992, RIIS 1992, JENSEN & SCHMIDT 1993). Central Jutland was also affected by post-Oligocene uplift but to a less degree. The present coastline was fixed not before the transition from Miocene to Pliocene times (JORDT 1995).

The vertical uplift movement´s high intensity in the offshore and onshore areas of southern Norway may depend on a combination with late movements in the Tornquist-Sorgenfrei Zone, which tectonic inversion started as early as in

minor movements at nearly meridional striking cross faults (OSTAFICZUK 1995).

The rims to the north and south of the Central European subsidence zone were also uplifted (relatively) but to a less degree. Only a narrow central strip of the depression continued subsidence in the Quaternary. Its present deep position is indicated by backswamp areas and river flood plains developed during interglacial and Holocene times as well as by a flat depression in the base of the Quaternary (map 2 and Fig. 4).

At the northern rim of the Central European subsidence zone, following early Oligocene subsidence a swell was formed running from the Ruegen to the Zealand island and a more elevation came into existence in part of the Ringkobing-Fyn high area. Probably these uplifting continued until Quaternary times. The swell follows different older structures, but without congruence.

The unusual deep downwarping of the two troughs (1000 m, halokinetic effects excluded) at the mouth of Elbe river points to fault tectonic activities in the basement. These structures developed above and near the flanks of the Glückstadt graben which was created in the late Palaeozoic. Probably an old WNW - ESE striking cross fault structure was reactivated - at least in parts - by which some meridional arranged salt structures and the western of both troughs were shifted somewhat to the west while the eastern trough terminates at this fault zone. Both troughs dip to the south towards this fault structure and have reached there maximum subsidence.

The southern portion of the Central Baltic Sea depression is situated above the transition zone from the EEP to the Fennoscandian uplift and to the north it gets into the uplifted region. The depression corresponds with Palaeozoic negative structures. Its neotectonic subsidence appears to have

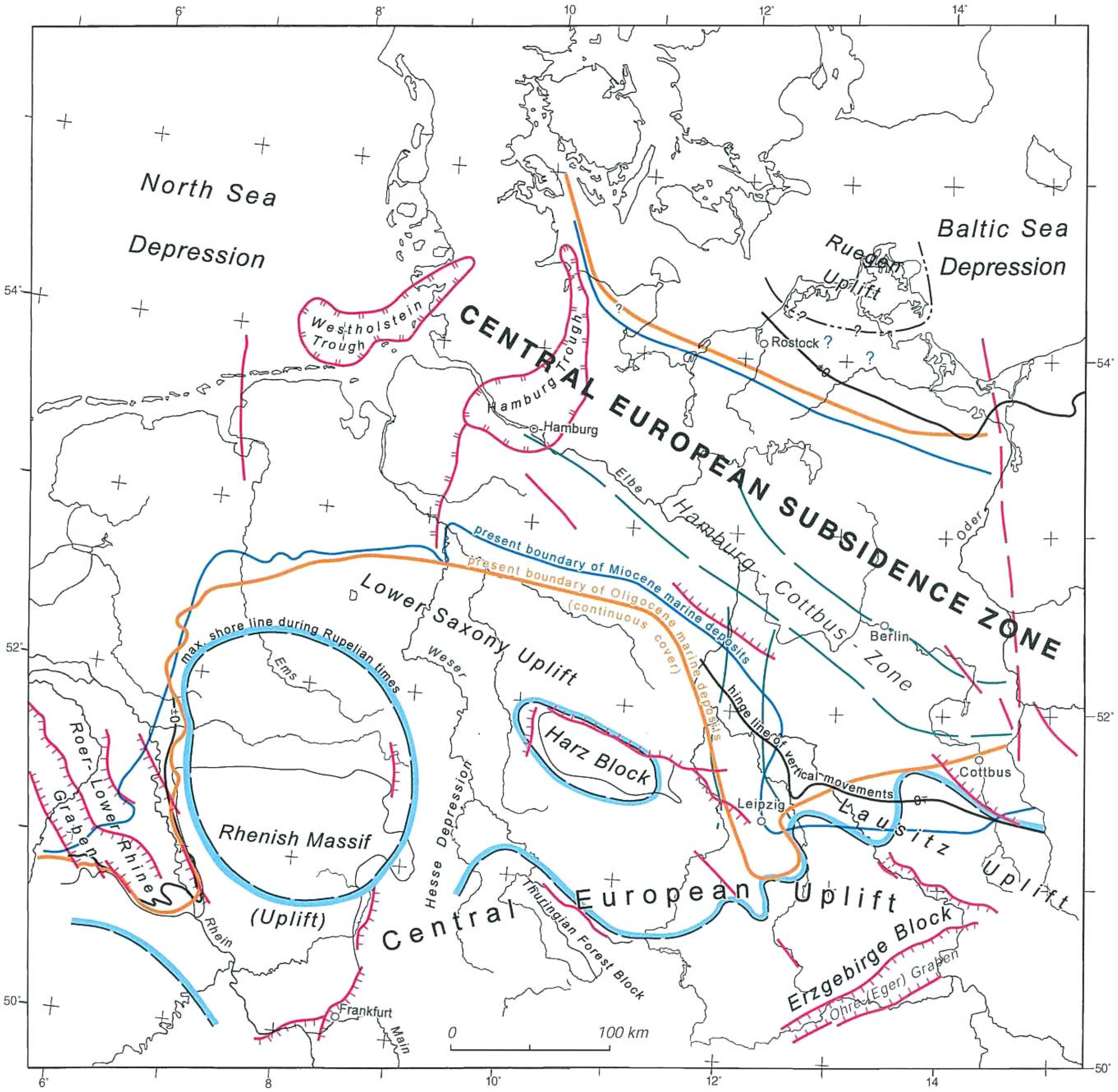

Fig. 4
Recent areas of the Rupelian and Miocene beds in the Central European depression compared with the shoreline of the Rupelian sea.

been accompanied by graben tectonics with meridional orientation. By this movements new morphostructures have been formed (Karabanov et al. 1994).
Connected with this development the dip of the northwestern parts of the EEP towards the Central Baltic Sea depression (the Lithuanian-Estonian monocline) was established and the drainage system formed, focussed to the depression centre. The uplift of single structures in the East Baltic region (Lithuania, Latvia, Estonia), probably also on the opposite side in Scandinavia, was accompanied by reactivation of fault structures, but in contrast to the sea area diagoal faults have been here the most active (Šliaupa et al. 1995).
The beginning of the neotectonic subsidence of the young Baltic Sea depression cannot be dated exactly up to now. By the ingression of the Holsteinian interglacial sea it is indicated for the first time (Karabanov et al. 1994). Probably the subsidence has started earlier. If it is right that the glacial channels in the base of the Quaternary in this region are glacially reworked river valleys (Šliaupa et al. 1995) then subsidence of the Central Baltic Sea region must have started already in preglacial (pre-Elsterian) times (Ludwig 1999).

2.3 Main structures of uplift

Reconstruction of the vertical movements´ development for the uplifted areas is essentially more difficult because of the erosion of the sediments needed for dating. Therefore the changes of the landforms and the kind of sedimentation in adjacent depressions serve as base for establishing phases of accelerated or slowed down vertical movements. But it is to consider that the observed geomorphic and sedimentary changes could also be caused by climatic changes. Therefore close temporal relations between the controlling endogenic and exogenic processes cannot be assumed a priori.

Most important uplifted region apart from the above mentioned Norwegian Mountains is the Central European Uplift zone. It surrounds in a large belt the Alpine-Carpathian arc in the northern foreland. The compression as well was transferred from the orogen to neighbouring parts of the EEP but with minor effects there and without volcanism. In this way the initial subsidence in this area was changed into uplift in Neogene times and was given rise to strengthening of the movements´ intensities at the transition from the Pliocene to the Pleistocene.

In the WEP the uplift was linked with stretching above mantle updomings as well as corresponding rupturing, forming of grabens, and neovolcanism. The latter was also arranged in a W - E running belt which turned to southeast into the Sudetes. The effusions mainly followed NNW - SSE oriented fault structures. That is also valid for the volcanism belonging to the Ohre graben structure, though the WSW - ENE extension of the volcanic area follows the graben´s strike. Volcanic collapses occurred too, e. g. in the Ohre graben and the Zittau basin (East Saxony). The neovolcanic climaxes were connected with that of the block tectonics at the transition from the Palaeogene to the Neogene times and in the Miocene, while only minor volcanic events have accompanied the strengthened block movements during the late Pliocene to early Quaternary times.

The tensional faults und graben structures indicate for the WEP predominantly stretching in W - E direction, cross to the neotectonical stress direction in NNW - SSE. Most active structures were the Roer - Lower Rhine graben, the Ohre graben, both following Variscan cross respectively longitudinal structures, as well as the NW - SE faults of the Sudetes. The Ohre graben forms a tensional structure perpendicular to the main stress direction.

Tendencies of posthumous reverse faulting are established for the northern rims of NW - SE extended blocks in Central Germany, as well as at the southern rim and within the Rhenish Massif. These movements produced block tilting into opposite directions (Thuringian Forest, Harz to the southwest, Erzgebirge Mountains to the northwest).

The uplift occurred strongly differentiated. In the WEP single blocks were exceptionally uplifted above the regional level. Common to both platforms (WEP and EEP) are accelerations of the uplifts in Miocene times, partly following previous subsidence, and renewed strengthening at the transition from Pliocene to Quaternary times. Important tangential shortening (about 50%) supported by folding and overthrusting was restricted to the Carpathian orogen.

In the EEP, southeastern part of the map, inversional movements created the Voronesh-Tver and the Ukrainian anteclise, where crystalline Basement reaches up to 280 m a. s. l. The stepwise uplifts, which total amplitude has not exceeded 380 m, started at the transition from late Oligocene to early Miocene times and lasted until the Recent. During Middle Miocene times the areas of the West Ukrainian anteclise and of the before extremely subsided Carpathian foredeep have been increasingly involved in the far spaced permanent uplifts. These were accompanied by differentiated block tectonics (developing grabens and horsts) and resulted only in moderate vertical displacements. Block boundaries and other important faults were activated then (GARETSKY et al. 1999).

The Dnieper syneclise was involved in the uplift to a lesser degree and with shift of its axis. Reactivations of the marginal faults of the Dnieper-Donets graben are indicated by halokinetic effects. Seismic events in the southern marginal zone reveal lasting activities.

The postinversion movements have determined the fundamental features of the EEP. Here are closer relations between the neotectonic structures, especially their active boundary faults, and the glacial structures as well as the landforms can be observed in the WEP. The Neogene tendencies of the vertical movements have been inherited until the Quaternary times. Here the glacigenous structural inventory and the glacial landforms (push moraines, glacigenous diapirs and injection structures) often indicate neotectonic activities, but it is difficult to make a distinction between glacioeuostatic and glacioisostatical triggered movements.

During the neotectonic uplift all fault directions of the preneotectonic period have been reactivated, partly contemporaneously, partly at different times. In the WEP the NNW - SSE striking ruptures then have been dominant for the first time. Frequently they were occupied by volcanism.

2.4 Important meridional structures

The most important N - S striking structures in the WEP have existed since early Permian times, probably already earlier. In the neotectonic period they were reactivated with different intensities and with tendencies of subsidence due to tensional forces. That is true for the Central graben in the North Sea depression and for the Hesse depression as described above. In the Hesse depression the northern border of the neovolcanic belt extends far to the north. Moreover, on account of a flexural activation of the eastward following meridional structure, the Magdeburg - Vogtland fault zone, the northern boundary of the Central European Uplift zone was moved far to the south (Fig. 4). East of it the Rupelian beds are preserved far to the south, while they are removed from the uplifted westerside apart from small remnants.

Indications of neotectonic reactivations are, at least in parts, the old fault zone running from Cesky Brod across the Zittau basin to the mouth of Oder river, the collapse of the Zittau basin, the extension of the neovolcanic area from the Ohre graben far to the north following this zone, the changes of the direction and the depth of the glacial channels at the Quaternary base in this zone, and other Quaternary features. Whether the neotectonic development of the significant approximately N - S striking graben zone on the Polish territory may also be related to older fault structures remains open. But this is true for the Central Baltic Sea depression as mentioned above.

All these significant zones of weakness and graben structures were always involved into the regional uplift or subsidence. Within the depressions they were ahead of the subsiding movements and within the uplift areas they lagged behind the elevation. As to the Hesse depression its initial subsidence was changed into uplift during the neotectonic times.
North of the Central European uplift zone the meridional zones were not affected by neovolcanism in spite of their tensional tectonic regime.

Summary

Methodical aspects of the map construction are explained, and the amplitudes of vertical movements are documented. There are significant differences between the East and the West European platforms (EEP, WEP), concerning development of the neotectonic structures, their relation to pre-neotectonic structures, and the character of the movements with and without ruptures. The total amplitude outside the Carpathian region amounts to < 4,5 km (subsidence + uplift). The development of the main structures with negative and with positive trends of movements are described. They have been mainly controlled by earlier analogous structures, especially in the WEP, while in the southeastern part of EEP Ukrainian shield was created by inversional movements the. Besides that single new structures were developed. The importance of neotectonic activities of meridional structures is emphasized. Neovolcanism was restricted to the WEP. It occured there in close connection with the block tectonics.

Zusammenfassung

Die Konstruktion der Karte wird erläutert, die ermittelten Amplituden der Vertikalbewegungen im Kartengebiet des Oligozäns werden ausgewertet. Die West- und die Osteuropäische Plattform haben sich neotektonisch strukturell wie morphostrukturell unterschiedlich entwickelt. Ebenso hinsichtlich ihrer Beziehungen zu präneotektonischen Strukturen und des Charakters der rupturellen und nicht rupturellen Bewegungen (Bewegungsintensitäten, Dimensionen, Dichte des Netzes). Die Gesamtamplitude beläuft sich außerhalb des jungen Karpatenorogens auf < 4,5 km (Senkung und Hebung). Die Entwicklung der positiven und negativen Hauptstrukturen und ihre Bewegungstrends werden umrissen. Besonders in der Westeuropäischen Plattform sind diese hauptsächlich von analogen früheren Strukturen kontrolliert worden, während im SE-Teil der Osteuropäischen Plattform inversive Bewegungen den Ukrainischen Schild geformt haben. Seltener erscheinen in der neotektonischen Epoche neue Strukturen. Wichtige meridionale Strukturen erfuhren eine signifikante Reaktivierung. Der Neovulkanismus blieb auf die Westeuropäische Plattform beschränkt. Er stand in enger Verbindung zur Bruchschollentektonik.

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