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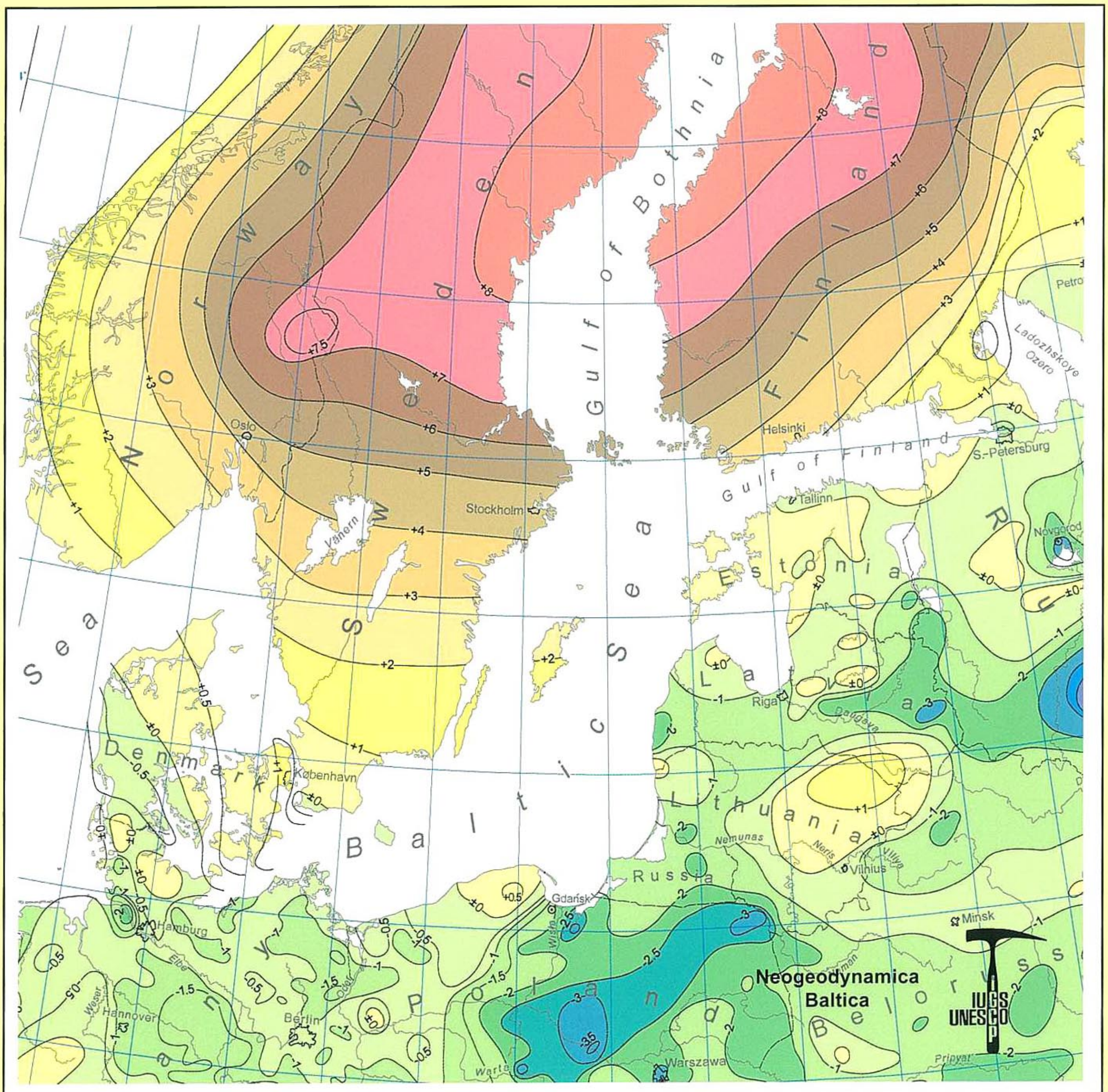

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Titelbild:
Ausschnitt aus der Karte der rezenten vertikalen Bewegungen (Karte 4)
Part of map 4: Recent vertical movements

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NEOGEODYNAMICS OF THE BALTIC SEA DEPRESSION AND ADJACENT AREAS

Results of IGCP project 346

Abridged version

(Guest-) Editors and Scientific Board

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Content

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Introduction

The study of young geodynamic processes is of great interest. This is motivated by its importance for forecasting of hazards like earthquakes, the siting of large engineering constructions (nuclear power stations, coast protection and coastal engineering, water-storage reservoirs, etc.). However, detailed geodynamic investigations were mainly performed within mobile seismoactive areas. Neogeodynamic phenomena observed within rather stable intraplate regions have not been adequately studied yet.

The genesis of the Baltic Sea depression is still one of the debatable problems in the geology of Europe. Therefore, investigations concerning the neogeodynamic status of the Baltic Sea Depression and adjacent areas was the main aim of IGCP-Project Nr. 346 (Neogeodynamica Baltica). Guided by R. G. GARETSKY, E. A. LEVKOV † (Belarus) und G. SCHWAB †, W. STACKEBRANDT (Germany) an international group of geoscientists [1] from Denmark, Germany, Poland, Belarus, Latvia, Lithuania, Russia, and Ukraine was engaged in 1994 to 1998 with clarifying either the endogen (neotectonic) or exogen (glaciogenic and erosional) genesis of the Baltic Sea depression.

The results of this neogeodynamic project were figured in a set of eight maps (see enclosures) characterising the neotectonic status of the Baltic Sea depression and its southern surrounding (northern Central Europe and western East Europe). Three of the maps were compiled on a scale 1 : 1 500 000 (showing the amplitudes of the vertical movements of the neotectonic stage, the base of Quaternary deposits, and the recent position of the surface of marine Holsteinian beds), and five maps on a scale of 1 : 5 000 000 (showing recent vertical movements, stresses, epicentres of earthquakes, Moho discontinuity and neotectonic zoning):

Main maps (scale 1 : 1 500 000):

(1) Vertical movements since the beginning of Rupelian stage (map 1)
Coordination: KARABANOV, LUDWIG, SCHWAB
(2) Base of Quaternary deposits of the Baltic Sea depression and adjacent areas (map 2)
Coordination: KARABANOV, LUDWIG, SCHWAB
(3) Recent position of surfaces of Holsteinian interglacial marine and limnic sediments, and of Saalian glacial river terraces (map 3)
Coordination: LUDWIG

Additional maps (scale 1 : 5 000 000):

(4) Recent vertical movements (map 4)
Coordination: FRISCHBUTTER, SCHWAB, STROMEYER, LEMGO
(5) Direction of recent maximal stress (map 5)
Coordination: GRÜNTHAL
(6) Epicenter map of tectonic earthquakes (maps 6)
Coordination: GRÜNTHAL
(7) Depth of Mohorovicic discontiniuty (map 7)
Coordination: AIZBERG, GARETSKY, KARATAEV, SCHWAB
(8) Neotectonic Subdivision (map 8)
Coordination: AIZBERG, GARETSKY, KARABANOV, KOCKEL, LEVKOV, LUDWIG, LYKKE-ANDERSEN, OSTAFICZUK, PALIJENKO, SCHWAB, ŠLIAUPA, STACKEBRANDT

The neogeodynamic activity has been derived from **reference horizons**. For map one the base of Early Oligocene deposits (Rupelian and other correlated layers) has been selected as the main reference horizon mostly widespread and reliably identified in the section. No younger Tertiary plain meets these criteria. The duration of the neotectonic stage (Early Oligocene until the Recent) is estimated at 35 - 37 million years. Marine Rupelian sediments are preserved over most territories of northern Central Europe investigated in the project, but in the other parts they lacked primary or were removed by subsequent erosion respectively exaration. In the Danish sector of the North Sea and in the central part of the Jutland Peninsula the base of the Viborg formation (37 million years), correlated with Rupelian deposits, was taken as a reference horizon to determine the amplitudes of the neotectonic movements, and south of the Danish basin the base of the Branden clay formation (Upper Oligocene) above partly eroded Eocene, is a nearly contemporaneous reference horizon.

In the eastern part of the region the top of the Kharkov suite of marine Lower Oligocene deposits (see Fig. 1 in LUDWIG, this volume) was selected for neogeodynamic reconstructions.

All the mentioned reference horizons are not strictly synchronous, however, the time differences can be ignored because of the week relief, low tectonic activity in the Early Oligocene and a small thickness of Lower Oligocene sediments in the eastern part of the studied area. In the Carpathian foredeep the sedimentation started only in the Miocene, following the compression in the Carpathian orogenic belt and combined with uplifting of the Carpathians. As to areas without Oligocene and Neogene sediments the amplitudes of neogeodynamic activities were judged by indirect evidences.

The reference level for map two is the base of Quaternary sediments although there are some limitations in the accuracy and because of its strong exogenic reworking (see Stackebrandt et al., this volume).

Generally, the amplitudes of the vertical movements, that means the differences between the original position of the reference plains and their recent position both related to the present sea level, were established with elimination of atectonic factors (e. g. salt diapirism, subrosion, glaciogenic disturbances a. s. o.) respectively with corrections made for lowering of the original surface due to erosion, exaration and other atectonic factors.

Regions with a high neogeodynamic activity are for example the movements in the southwestern part of Scandinavia, the grabens in the central part of the Baltic Sea, and the more or less fault controlled Central European Subsidence Zone of northern Central Europe.

In the following manuscripts only brief descriptions of the main features of the eight maps and the most important results of the investigations of the international group are presented. A more complete explanation to the set of maps showing the detailed regional data, and the conclusions fom them will be published by the Polish partners (Garetzky et al.). All institutes and specialists of the states incorporated into the project - Belarus, Denmark, Germany, Latvia, Lithuania, Poland, Russia and Ukraine – are listed on the maps. Parallel to this publication in the Brandenburgische Geowissenschaftliche Beiträge this abridged explanation together with the neogeodynamic set of maps likewise will be published in volume **35** (NF) 2001 of the Abhandlungen des Naturwissenschaftlichen Vereins Hamburg.

During the project realization some new questions arose as to the activity of older intraplate block structures and some aspects to interactions of endogenic and exogenic processes were found. They remain open for further investigations.

Werner Stackebrandt Radim G. Garetzki Alfred O. Ludwig

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

Neogeodynamica Baltica IGCP-Project 346

ALFRED O. LUDWIG

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).

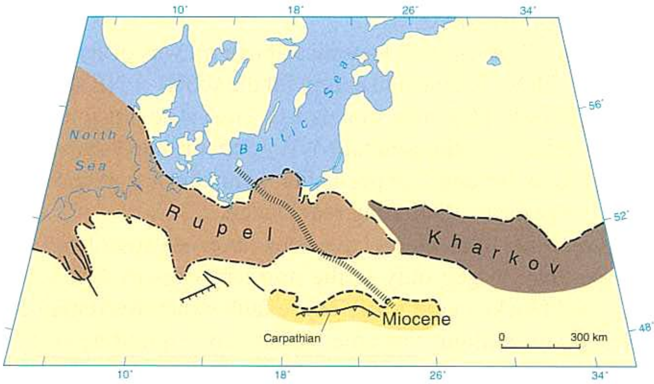


Fig. 1.
Recent areas of the sediments used for calculation of the vertical neotectonic movements - base of the Rupelian, top of the Kharkov beds, base of Miocene deposits

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).

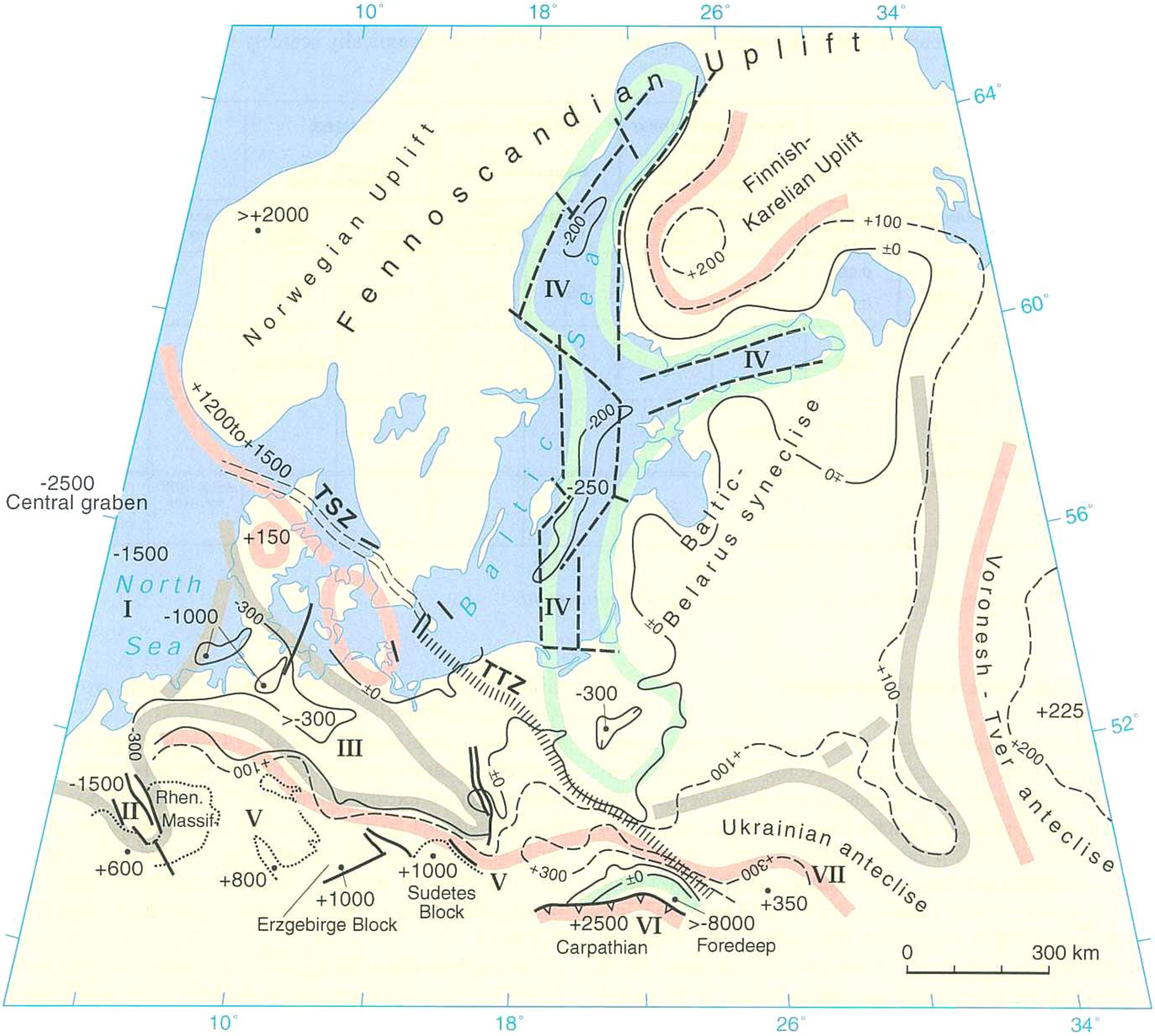
The map also reveals that the maximum subsidences and uplifts are of the same order, but in the WEP the amount are nearly one order more than in the EEP. There are subsidences in the Roer-Lower Rhine graben and the North Sea depression up to >1500 m, in the Central graben (outside the map area) to 2500 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.



most important active faults in neotectonic times
+300 isolines of total vertical movements in m
basement outcrop
+1000 -1500 rounded maxima of vertical movements, partly concerning larger areas
TSZ Tornquist-Sorgenfrei zone
TTZ Tornquist-Teisseyre zone

I North Sea depression
II Roer-Lower Rhine graben
III Central European depression
IV East baltic system of grabens
V Central European Uplift
VI Carpathian orogen
VII Ukrainian anteclise

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

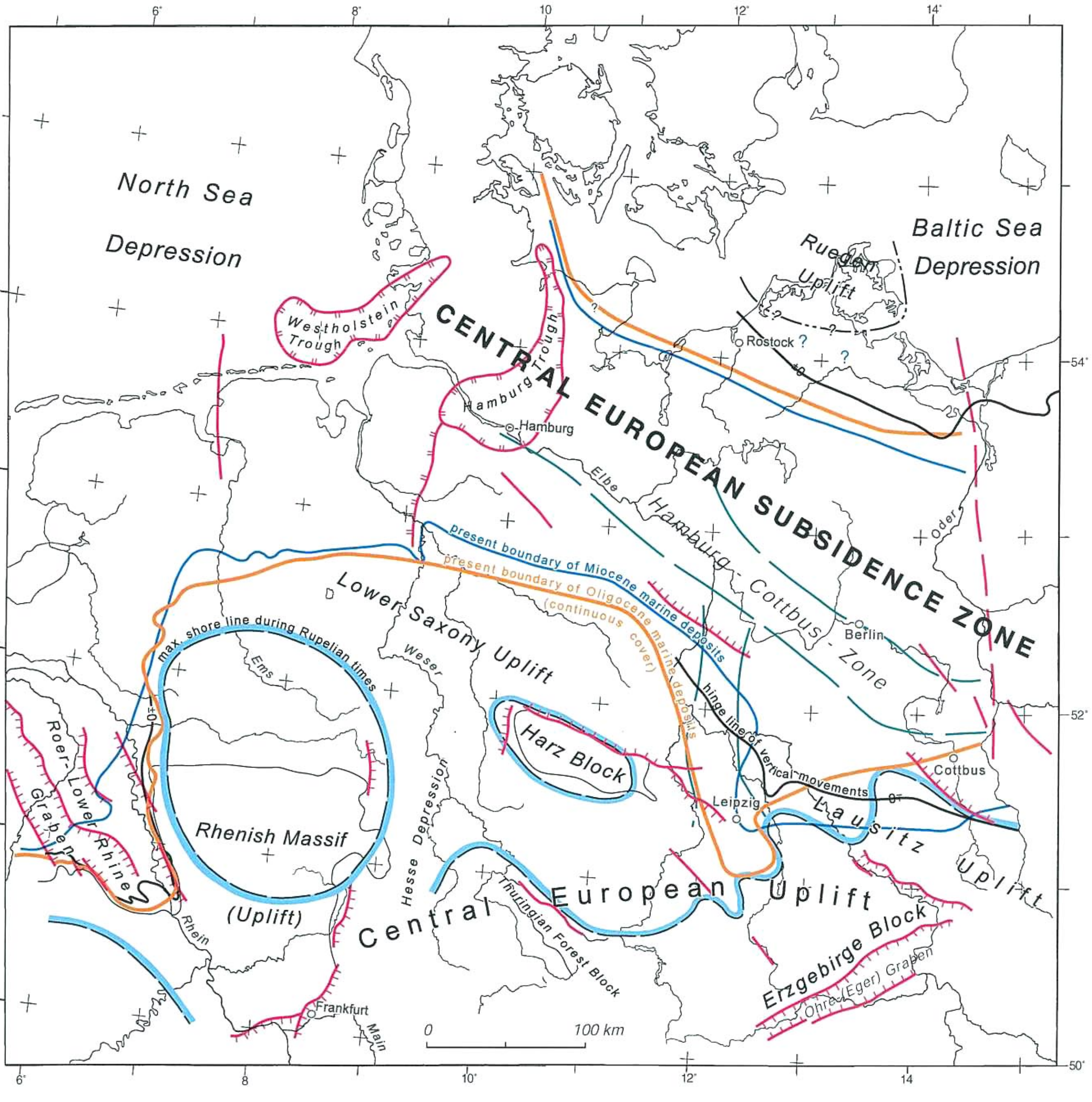


Fig. 4
Recent areas of the Rupelian and Miocene beds in the Central European depression compared with the shoreline of the Rupelian sea.

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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Base of Quaternary deposits of the Baltic Sea depression and adjacent areas (map 2)

Neogeodynamica Baltica IGCP-Project 346

WERNER STACKEBRANDT, ALFRED O. LUDWIG[1] & STANISLAW OSTAFICZUK

1. Introduction

This brief description of Map 2 "Base of Quaternary deposits of the Baltic Sea depression and adjacent areas" summarizes regional reports of all authors listed on the map. Information from individual areas of the map concerning the elevation of the Quaternary base have already been published (e.g. SCHWAB & LUDWIG 1996; OSTAFICZUK 1999, and other publications listed in the references). The results of IGCP project 346 Neogeodynamica Baltica will be published to the full by GARETZKY et al. (in prep.).

The base of the Quaternary is of only limited use as a neotectonic reference horizon, because

- there is no horizon at or near the base of the Quaternary that can be used for stratigraphic and time correlation, i.e. the base of the Quaternary has no definite stratigraphic position;
- the relief of the Quaternary base provides only an indirect picture of the range of vertical movement since the beginning of the Quaternary;
- the specific sedimentation conditions caused in many areas a veil-like filling of the pre-Quaternary relief, i.e. there is only limited evidence on which can base a neogeodynamic interpretation;
- endogenic and exogenic processes were acting with quite a different intensity on regional and local scales in shaping the contours of the Quaternary base.

Despite these limitations in the accuracy and because of the strong exogenic reworking of the depth position of the Quaternary base, the relief of the Quaternary base shows a significant relationship to the regional pre-Quaternary geology of the studied area. Therefore, it is still possible to reconstruct the neotectonic history of the region for the short timespan since the beginning of the Quaternary. In parts of the region the tectonic history can be worked out by considering the interaction of endogenic and exogenic landscape-forming processes.

Unique features of the Quaternary base are developed in the following areas:

(1) the central Baltic Sea region including the Gulf of Bothnia (not shown on the map) and the Gulf of Finland;
(2) the area of the North Sea (only marginally touched);
(3) the northern part of Central Europe, especially the North German Lowlands and the adjacent lowland of western Poland (paleotectonically the post-Variscan part of the North German Basin);
(4) the southern border zone as transition to the southeast and central European mountain regions;
(5) the area of the East European craton.

2. Interpretation of the depth of the Quaternary base

In the research area, the relief of the Quaternary base varies by more than 1100 m (ranging from ≥ 500 m above sea level [a. s. l.] down to ≥ 600 m below sea level [b. s. l.]; not considered are the elevated top positions of the central and southeastern mountain chains). The areas with relatively specific development of the Quaternary base, listed above from (1) to (5), are partly characterized by a prominent depth-level or they are marked by strong devious gradients within the actual region. In the map, deep channels (tunnel valleys by Quaternary erosion) are a specific feature in northern central Europe. They are deeply cut into pre-Quaternary strata. East of the research area, where the Quaternary base relief is smoother, they are less deep.

The description of regions (1) to (5) in sections 2.1 to 2.5 is based both on the different levels of the Quaternary base and on their specific features. The five regional units can be further subdivided. OSTAFICZUK (1999) recognised 13 regional units in the research area, which are at least partly bounded by fault zones. A detailed description of all these areas will be given in the planned comprehensive publication (GARETSKY et al. in prep.).

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[1]The authors dedicate this contribution to Dr. habil. Günter Schwab (†), Scientific Board member and German project leader of IGCP project 346. With his conceptional ideas on the central European neogeodynamics and his scientific results, Günter Schwab provided the essential basis for these investigations. We hope that this brief description of „his" map would meet with his full approval.

2.1 The central Baltic Sea area

In the central Baltic Sea, the Quaternary base lies on average at about 100 m b. s. l.; in more central areas it can descend to 150 m b. s. l., locally down to 200 m below sea level. It can be assumed that the NNE-SSW striking longitudinal axis of the trough-like to tongue-like depression in the Quaternary base is due to the activity of the Scandinavian continental ice sheet. The ice might have followed a pre-existing deep and exaratively and erosively deepened and broadened it. The younger ice streams also exarated older Quaternary sediments, resulting in a basal layer of younger Quaternary sediments and leading to a secondary „rejuvenescence" of the Quaternary basal deposits.
On the map, areas in the Baltic Sea coloured in dark green give an impression of the approximate width of these main ice streams, which extended to 100 m b. s. l. and were between > 60 and 120 km wide.

2.2 The North Sea area

In the eastern North Sea only local data about the depth of the Quaternary base were available during the period of study. Therefore the description is quite limited. But the continuous slope of the Quaternary base from 100 m b.s.l. to more than 300 m b. s. l. and the similar slope of the Rupelian base (shown on Map 1; more than 1300 m b. s. l. deep), allow us to conclude that continuous tectonically induced sinking took place during the Quaternary. The almost similar nearly N-S orientation of the isobaths in both maps and the thickness distribution of the Quaternary pile of sediments support this interpretation.
A summary of recent results on the Quaternary in the southern North Sea has been published by Streif (1996). Included is a report on the continuation of the channel structures (SCHWARZ 1996). Numerous seismic profiles show that the channel structures were mostly oriented N-S.

2.3 Northern Central Europe – North German Lowland, western Poland

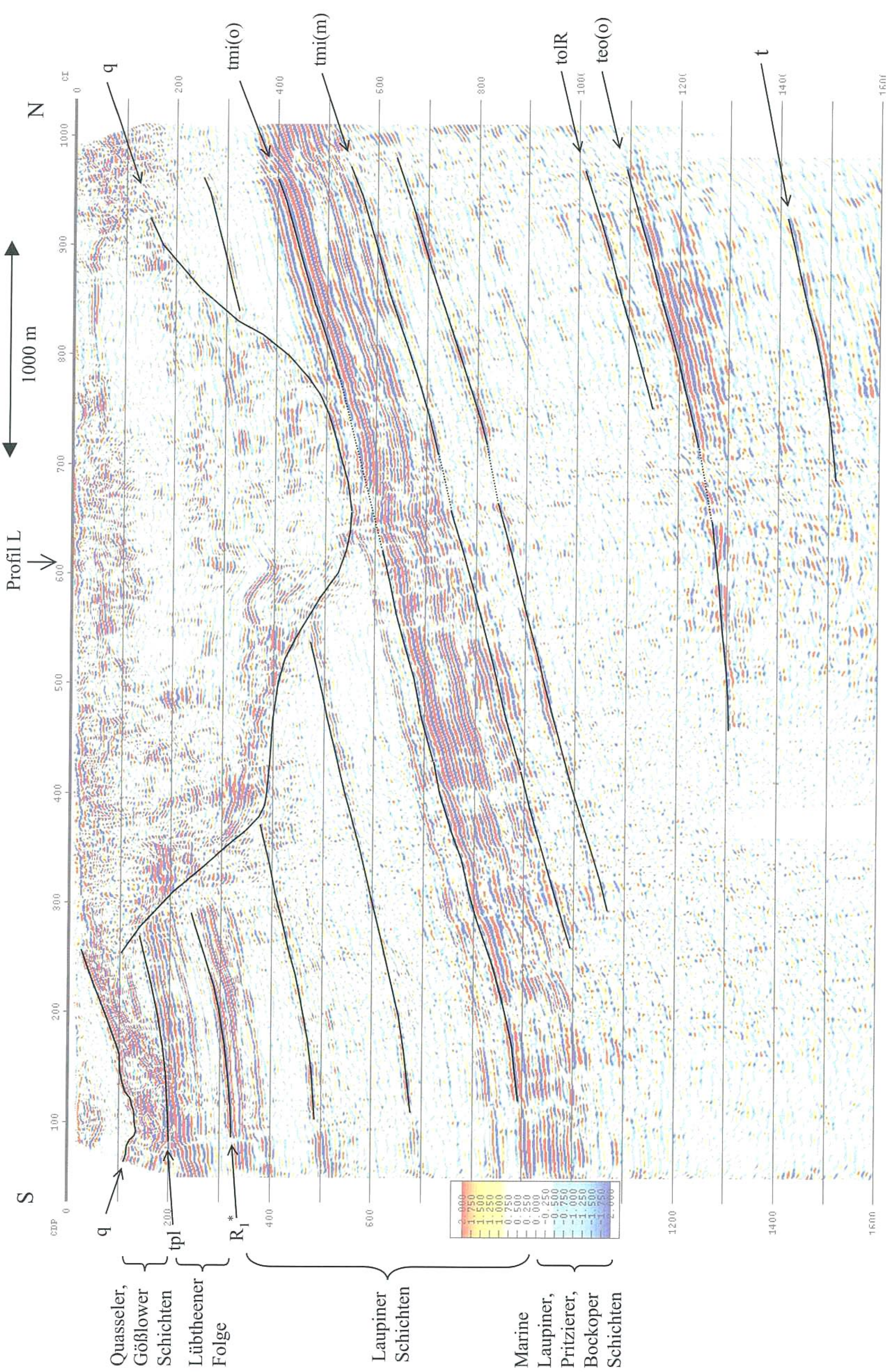
In northern Central Europe and especially in the North German Lowland, a very special feature are the (older) Quaternary tunnel valleys (channels), incised by the first Pleistocene continental ice sheet, which presumably left a prominent imprint here. They are unique as for their extent and their smaller-scale features, which are not met with in other parts of the research area. Since their discovery as a complex phenomenon characterizing of the North German Lowland (GRUBE 1979, HINSCH 1979, KUSTER & MEYER 1979, HÖNEMANN et al. 1995), their origin has been widely discussed (e.g. EHLERS et al. 1984, VON BÜLOW 1990, 2000, EHLERS 1990, LIPPSTREU 1995, HABBE 1996, SCHWAB & LUDWIG 1996[2], EISSMANN 1997, LIPPSTREU et al. 1997, SMED 1998).

The deep channels described here were mainly not only eroded during the Elsterian ice age but mostly also refilled then. Younger channels cut in later Quaternary deposits are not considered here, although they are mainly related to the Quaternary base too. Detailed maps of the surface geology and morphology as well as cross-sections through the Quaternary strata of North Germany give an idea of the relatively shallow depth, the orientation and occurrence of the channels (LIPPSTREU et al. 1997). The North German Quaternary base displays a relatively monotonous level area at about 100 m b.s.l. (light green) cut by the Elsterian longitudinal channels. These channels are quite narrow with a mean width of only a few kilometers but locally more than 500 m deep. By correlating the former depth of the Quaternary base in the North German Lowland above all the channels, a NW-SE regular isobath system shows up crossing the channels and increasing in depth „inwards", the deepest lying approximately in the central part of the Central European zone of subsidence (see LUDWIG, this volume).

However, in longitudinal profiles of the channels, the Quaternary base displays numerous depth steps, locally in opposite directions, which may be the result of subglacial cavities (evorsion). High resolution seismic profiling across the channels reveals a prominent secondary broadening and flattening of the originally steeper channels due to gravitational sliding of the material on the flanks. As an example, Figure 1, taken from BUNESS & WIEDERHOLD (1999), shows the originally much steeper flanks of a channel.

The Elsterian channels shown at the map are deeply cut into the pre-Quaternary strata. In eastern North Germany they show an unsual NNE-SSW trend, but a more N-S trend in the adjacent areas to the west. The deep channels can be followed over more than 100 km, locally up to 150 km. Concerning the origin of the channels and the reconstruction of the interacting endogenic and exogenic landscape-forming processes, the more or less simultaneous beginning of the channels in the north and similarly their termination in the south is remarkable (see STACKEBRANDT et al. 2001). This suggests that former tectonic structures were reactivated. Moreover, the different trends of the channels in eastern and western North Germany may be due to different ice stream directions. Since the pattern and orientation of the subglacial erosional phases correspond to the ice-flow movement, i.e. the general ice dynamics, the ice can be inferred to have flowed from the NNE or NE in eastern North Germany, and from the north in western North Germany. VON BÜLOW (1990) suggests that the extremely deep downcutting of the Elsterian channels took place in a temporary marginal uplift or swell of the Earth's crust caused by glaci-isostasy, which was then cut into sub-

[2] This publication of some of the results of the IGCP project 346 includes a detailed description of the relief of the Quaternary base in North Germany, which was in fact Günter Schwab's last contribution on this topic. Numerous references are given to the work of the individual authors who dealt with the different parts of the thematic map.



*) R_1: Basis der Lübtheener Folge (= Diatomeenkohle - Bergton Komplex)

Fig. 1
Profile across a deep Elsterian channel (Hagenow channel, from Buness & Wiederhold 1999); notice the secondary widening of the channel by gravitational gliding of material on the flanks

aquatically by the ice streams. But most authors postulate that the channels were formed subglacially under glaci-hydromechanical conditions. The channelling might have partly followed similarly oriented valleys already in existence in the pre-glacial fluvial systems. Nontheless, it remains problematic that the bottoms of the deepest channels are locally cut down much deeper than the plausible depth of the erosional base level at that time would allow one to assume.

Following Ehlers' (1983) suggestion of a clockwise rotating ice flow during glaciation and deglaciation, the differing orientation of the channels in eastern and western North Germany could reflect different phases of the ice flow. For Northwest Germany this would mean that the channels were cut during an early phase of the ice flow, whereas in Northeast Germany a later phase during the retreat of the Elsterian ice sheet is documented. This idea is supported by several findings, taking into account the general trend of the contours on the Quaternary base (see Map 2):

- the western Scandinavian provenance of the detritus in Elsterian moraines in Schleswig-Holstein (Stephan 1995),
- the upward change in younger Elsterian moraines of Lower Saxony from a western Scandinavian provenance to a more Baltic one (Woldstedt und Duphorn 1974, Hoffmann und Meyer 1997),
- the movement directions of the Elsterian ice sheet (Ehlers 1990).

To the east, the area is characterized by an irregular but relatively smooth relief of the Quaternary base. Around longitude 16°E, the Quaternary base rises above sea level, but drops again in the vicinity of the Bight of Danzig. This zone of culmination of the Quaternary base is cut diagonally by the NW-SE striking Tornquist-Teisseyre Zone (TTZ). In the northwestern part of the area the shape of the Quaternary base is not influenced by the TTZ, but it is in the southeastern part (see section 2.4).

2.4 The southern marginal border as transition zone to the southeastern and central European mountain regions

In central and southeast Central Europe, south of the eye-catching coloured areas where the Quaternary base lies below sea level, there is a narrow, E-W trending area where the Quaternary base shows numerous small-scale features and rises to between 100 and >500 m above sea level. The rise of the Quaternary base to this higher level is irregular and step-like, the contours on the map having a saw-tooth appearance. The contours on this high Quaternary base area document a close genetic connection with the well-known regional NW-SE faults, as well as with the cross-features (e. g. Tornquist-Teisseyre zone, Oder lineament, major fault system of the Central German area, Elbe zone, and Osning fault system). The contours on the Quaternary base suggest that these earlier fault systems underwent recent reactivation.

The marginal border described here – on Map 8 called the „Central European uplift zone“ – passes southwards into the mountain belt of the Alps and Carpathians. The high degree of neotectonic activity of this complex, roughly E-W trending mountain range had (together with the opening of the North Atlantic) great influence on our research area. However, the mountain belt was not covered by the present project.

2.5 The East European craton

East of the research area the relief of the Quaternary base is quite gentle. Two levels can be distinguished, clearly shown up as broad areas by the colouring on the map. The area of the Baltic republics including extensive areas of Russia, Belorussia and the Ukraine is characterized by an elevation of between 0 and 100 m a. s. l., only interrupted by a step-like rise of the Quaternary base to 200 m a.s.l., trending in a NW direction from the territories of Russia, Belorussia and the Ukraine into southern Estonia. To the south and east this step-like rise of the Quaternary base broadens and rises to elevations of between 100 and 200 m a. s. l., in some areas up to > 200 m above sea level.

Of higher significance is the deep Quaternary base in the direct prolongation of the central Baltic Sea basin to the south (Bight of Danzig, Königsberg region, western Lithuania). Here, the Quaternary base is at a depth of 0 to 100 m b. s. l., in the central zone down to 200 m below sea level. The contours and position of this zone allow a direct genetic correlation with a south-directed Elsterian ice stream. From the present-day coastline of the Baltic Sea this deepening of the Quaternary base can be traced for about 150 km into eastern Poland. There seems to be no connection between this area of a deep Quaternary base and the parallel, NW-SE trending Tornquist-Teisseyre zone on the southwestern margin. To the west, the Quaternary base rises to moderate elevations of 0 to 100 m a. s. l., until in western Poland the Quaternary base begins to descend to the deep level that it occupies beneath northeastern Germany.

In an overall E-W cross-section the general outline of the Quaternary base looks like a sine curve. This shape is a reflection of the ice dynamics in the region; however, the channels at the margin of the East European craton are strongly influenced by the crystalline rocks of the craton. These narrow erosional channels have a mean depth range of a few tens of meters; they are less pronounced than the channels in the North German region. There are also large differences in the orientation of the channels. In North Germany the deep Elsterian channels trend clearly N-S or NNE-SSW and show a very high degree of regularity, but on the East European craton the orientation of the channels is unclear; often they appear to show a dendritic pattern.

3. Conclusions on the neogeodynamics of the Baltic area from Map 2

Conclusions about the intensity, nature, regional extent and possible reasons for neotectonic activity can only be deduced from Maps 1 to 8 together. Therefore, an overall interpretation of the neogeodynamic crustal state of the peri-Baltic

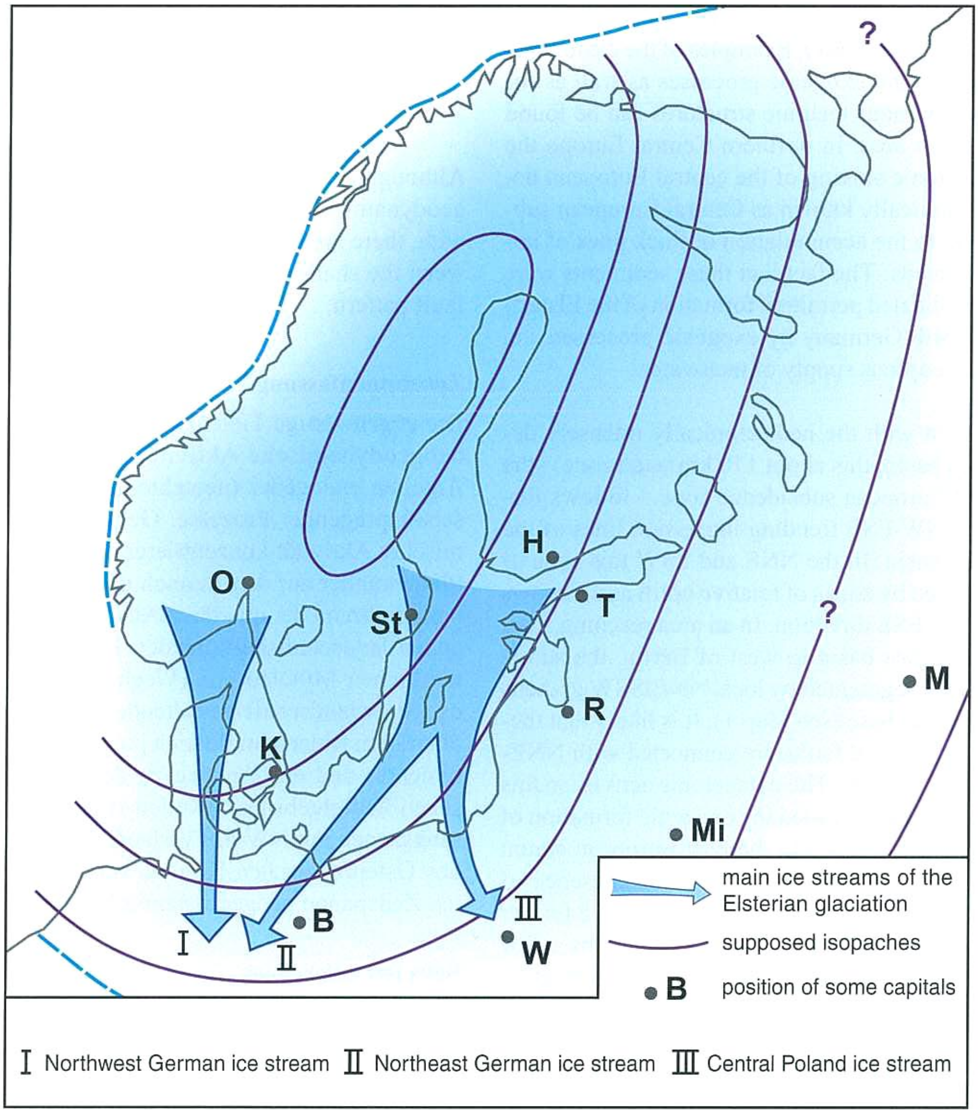


Fig.2 Subdivision of main ice streams of the Elsterian glaciation in northern Central Europe

region will be given in the comprehensive paper by GARETSKY et al. (this volume). However, in this chapter some observations will be made on certain aspects of neogeodynamic activity, as deduced from the hypsometric map „Base of Quaternary deposits of the Baltic Sea depression and adjacent areas".

Conclusions on the main Elsterian ice streams (i.e. NW German ice stream, NE German ice stream and central Poland ice stream):

The intense shaping of the landscape and formation of relief by the Scandinavian continental ice sheet moving along preferred paths permits specific information about the conditions of flow and extent of the Elsterian ice to be derived from the depth and relief of the Quaternary base. In contrast, information about the pre-glacial Quaternary sediments is poor. In the glacial and fluvioglacial erosional areas the older Pleistocene sediments were presumably removed (ŠLIAUPA et al. 1995, LUDWIG 2001). The base of the Quaternary consequently follows these major trough-like erosional zones. Interpretation of the relief of the Quaternary base over the whole of the region studied allows three main ice streams to be differentiated for the first Elsterian glaciation in northern Central Europe. From W to E these are (see Fig. 2)

- the N-S oriented Northwest German ice stream,
- the NE-SW oriented Northeast German ice stream, and
- the N-S to NW-SE oriented central-Poland ice stream.

This differentiation into several main ice streams is also confirmed by the correlation between channel orientation and main ice-flow directions, as well as by the change in provenance of the detritus mentioned in section 2.3.

Conclusions on the effectiveness of endogenic and exogenic processes for landscape generation, and on the possible posthumous relationships between old and young geologic and tectonic structures in the research area:

The possible relations between endogenic and exogenic landscape-forming processes and the origin of the deep Quaternary channels have already been mentioned, for example by Ludwig & Schwab (1995), von Bülow (1990, 2000) and Stackebrandt (1999, 2001). Examples of the close association of endogenic and exogenic processes as well as for reactivated or posthumous tectonic structures can be found all over the research area. In northern Central Europe the continuous neotectonic sinking of the central European depression – neotectonically known as Central European subsidence zone – led to the accumulation of thick piles of unconsolidated sediments. The fact that these sediments were only slightly consolidated permitted formation of the Elsterian channels in North Germany by exogenic processes, i.e. glacial flow and a copious supply of meltwater.

Starting in the west with the neotectonically intensely deepened North Sea basin, this about 170 km wide zone – the so-called Central European subsidence zone – follows former NW-SE to WNW-ESE trending ingression lines of the Central European basin. In the NNE and SSW this zone of subsidence is flanked by zones of relative uplift and narrows telescope-like in an ESE direction. In an area reaching from the southern North Sea basin to west of Berlin, the subsidence zone has been segmented by local NNE-SSW grabens affecting the Rupelian base (see Map 1). It is likely that these neotectonically induced faults are connected with NNE-SSW faults in the basement. The neotectonic activity in this region therefore indirectly caused the exogenic formation of very deep Elsterian channels. On the East European craton deep channels were not formed owing to the presence of crystalline rocks near the surface. Here, apparently a former network of valleys was only somewhat deepened by a few tens of meters, forming trough-like channels (Šliaupa et al. 1985).

The shaping of the overdeepened channels can be taken as an example of the interaction of endogenic and exogenic landscape-forming processes, whereas the steep slopes and high relief of the Quaternary base in the vicinity of NW-SE striking regional fault zones at the northern margin of the central and east European mountains are prominent examples of posthumous neotectonic movement on and/or reactivation of pre-existing geological structures.

Summary

It is possible to distinguish areas that differ with respect to the average elevation of the Quaternary base. These areas tend to correlate with differing regional geologic structures. The abrasional ice streams and the meltwaters did not eliminate the tectonic and neotectonic relief, but in many cases preserved it or modified it to correspond with the neotectonic pattern. The differences in the relief of the Quaternary base therefore permit to recognize areas of neogeodynamic activity with variable dominance of endogenic (neotectonic) and exogenic landscape-forming processes. Regions with relatively intense neogeodynamic activity occur on

- the area of the central Baltic Sea (dominance of exogenic, mainly erosive landscape-forming processes during the Quaternary),
- the area of northern Central Europe (formation of the overdeepened channels in the area of young, less compacted sediments), and
- the rise of the central and eastern European mountains (reactivated NW-SE regional fault zones).

Although large areas of the East European craton were neogeodynamically less active during the period being dealt with, there are very close relations in the eastern Baltic between the shallow channels, paleo-valleys and the fracture/fault pattern.

Zusammenfassung

Die gegenwärtige Tiefenlage der Basis des Quartärs belegt neogeodynamische Aktivitätsbereiche mit wechselnden Anteilen endogener (neotektonischer) und exogener landschaftsprägender Prozesse. Gebiete erhöhter neogeodynamischer Aktivität konzentrieren sich außerhalb der aktiven Plattenränder auf den Bereich der zentralen Ostsee (Dominanz während der quartären Ausgestaltungsetappe von exogenen landschaftsgestaltenden Prozessen), das Gebiet des nördlichen Mitteleuropa (Wechselwirkung endogener und exogener landschaftsgestaltender Prozesse, Ausbildung der übertiefen Rinnen im Bereich junger, unterkompaktierter Sedimente) und den Anstieg zu den mittel- und osteuropäischen Mittelgebirgsschwellen (reaktivierte regionale Störungszonen mit NW-SE-Verlauf). Dagegen sind weite Teile des Osteuropäischen Kratons während der hier behandelten Zeitspanne neogeodynamisch weniger intensiv aktiv.

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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)

Neogeodynamica Baltica IGCP-Project 346

ALFRED O. LUDWIG

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-ruptural 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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Recent vertical movements (map 4)

Neogeodynamica Baltica IGCP-Project 346

Alexander Frischbutter

Introduction

As a supplement to an atlas of several isopach maps, compiled to demonstrate the neotectonic evolution of the Earth's crust within the region around the Baltic Sea Depression (IGCP-project No. 346) the recently available data were collected for an area between 4° - 36° eastern longitude and 47° - 65° northern latitude. Although the available data basis is incomplete and of different quality over the area and above all not uniform regarding that used for single area's benchmarks, the map was compiled in the sense of a minimum variant, which was only possible to manage within the context of this project. On the other hand it seems to be impossible to dispense with any information concerning the state of knowledge regarding recent vertical crustal movements in discussing the neotectonic evolution of the Earth's crust within the region.

Methodology

The "Map of recent vertical crustal movements" is founded on published national and international, regional maps. The single sources used are:

(1) Vyskocil, P. (1990): Map of the horizontal gradients of recent vertical crustal movements of the territories of Bulgaria, Czech Republic, GDR, Hungary, Poland, Rumanian, USSR (European part of the country), 1 : 2 500 000.
benchmark: mean sea level (calculated from Baltic Sea, Black Sea, Asow Sea)

(2) Kaschina, L.A. (1989): Karta sovremennych vertikalnych dvizenij Zemnoj kory po geodeziceskim dannym po territoriju SSSR, 1 : 5 000 000.
benchmark: mean sea level

(3) Joo, I. (1992): Recent vertical surface movements in the Carpathian Basin.
Rumania, Hungary, Slowakia
benchmark: mean sea level (calculated from Baltic Sea, Black Sea, Adria)

(4) Höggerl, N. (1986): Report on Austrian efforts in the field of high precision levelling and recent crustal movements between 1983 and 1986 and future activities.
Austria (interpolated from a map of vertical movement velocities within first and second order junctions)
benchmark: Freistadt (N-Austria)

(5) Mälzer, H. (1990): DGK-Arbeitskreis für rezente Krustenbewegungen - Berechnungen von Höhenänderungen im Bayrischen Haupthöhennetz unter Verwendung unterschiedlicher Modelle.
SE-Bayern
benchmark: Schernfeld (Jurassic), Saldenburg (basement)

(6) Gubler, E., Arca, S., Kakkuri, J. & K. Zippelt (1992): Recent vertical crustal movement.
western Germany
benchmark: Wallenhorst (near Osnabrück), Wahlenau (Rheinland-Pfalz), Freudenstadt (Baden-Würtemberg), Schernfeld (Bayern)

(7) Pissart, A. & P. Lambot (1989): Les mouvements actuels du sol en Belgique; comparaison de deux nivellements IGN (1946-1948 et 1976-1980).
Belgien (calculated from a map of changes in altitude from 1948 to 1980 as a result of two levellings)
benchmark: Uccle (Brüssel)

(8) Lorenz, G. K. (1994): The first primary levelling in The Netherlands [1875-1885].
The Netherlands
benchmark: Normaal Amsterdam Peil (model 01)
Kooi, H., Johnston, P., Lambeck, K., Smither, C. & R. Molendijk (1998): Geological causes of recent (~100 yr) vertical land movement in the Netherlands. - Tectonophysics **299**, p 297-316, Amsterdam
underground benchmarks, founded in the upper reaches of Pleistocene sands.

(9) Leonhard, T. (1988): Zur Berechnung von Höhenänderungen in Norddeutschland - Modelldiskussion, Lösbarkeitsanalyse und numerische Ergebnisse.
N-Germany
benchmark: Wallenhorst (near Osnabrück)

(10) Andersen, N. (1992): The hydrostatic Levellings in Denmark.
Denmark
benchmark: mean sea level (Arhus, Kattegat)

(11) Gubler, E., Arca, S., Kakkuri, J. & K. Zippelt (1992): Recent vertical crustal movement
Scandinavia (Finland, Norway, Sweden)
benchmark: mean sea level

(12) Ihde, J., Steinberg, J., Ellenberg, J. & E. Bankwitz (1987): On recent vertical crustal movements derived from relevellings within the territory of the GDR.
E-Germany (for completion of (1) by original intermediate data)
benchmark: mean sea level (calculated from Baltic Sea, Black Sea, Asow Sea)

(13) Wyrzykowski, T. (1985): Map of the recent vertical movements of the surface of the Earth crust on the territory of Poland, 1 : 2 500 000.
Poland (for completion of (1) by original intermediate data)
benchmark: mean sea level (Baltic Sea)

(14) Forniguet, J. (1987): Géodynamique actuelle dans le Nord et el Nord-Est de la France.
Alsace-Lorraine
benchmark: related to the calculated difference of benchmark altitudes (mean sea level Marseille) used during two adjacent levelling

Data collection for the map was finished in 1995 (Frischbutter et al. 1995). Moreover, only data, geodetically determined by the interpretation of repeated triangulations (and no GPS-data) were used in order to avoid a data mix from different methods.
More than three quarters of the map are covered by data taken from only two different maps, each related to the benchmark "mean sea level": Eastern and middle Europe (1) and Scandinavia (11). The data from (1) are supplemented with additional values taken from the original, regional maps taken directly from the regional maps (e.g. (13) Wyrzykowsky for Poland, (12) Ihde et al. for eastern Germany) or are interpolated from point data for the territory of the former USSR (from (2) Kaschina). The resulting isolines (0,5 mm/a) are marked with a special signature in the "Map of the original data", which was published by Frischbutter et al. 1995.
Only for a small region around the Gulf of Finland the connection of isolines was "free hand interpolated" without any difficulties. Likewise, because of missing data the course of the 1 mm/a-isoline on the territories of Latvia and Estonia was without any problems "free hand extrapolated".
The data base for the western and southern parts of the map is extremely inhomogeneous. The least problems may exist concerning the connection of the data for the territories of Romania, Hungary and Slowakia after the map published by Joo (1992). But for the comparatively small part of western Europe the map have to be constructed from seven different regional maps. The connection between them is not only problematical because of the different used benchmarks, but also because of different nets of levelling.
The isolines for Austria were interpolated from velocity-data of vertical crustal movements within first and second order junctions (4) Höggerl (1986).
The course of isolines for the territory of Belgium was calculated from data of altitude changes within the junctions of the levels from 1946-1948 and 1976-1980 (7) Pissart & Lambot (1989).
For an area in Lower Saxony (Germany) stretched between Hamburg and Hannover were no data available up to the maps deadline. The region was closed by extrapolation.
For the territories of Poland, Slowakia, Czech Republic, Hungary and Austria it was also possible to resort to the "Catalogue of the annual velocities of vertical movements at the territory of CEI member countries" (ICRCM, Prag 1994). These data are not used, because the homogeneous base for eastern Europe after (1), which was the result of an intensive cooperation of all involved countries, would be additionally interrupted with the introduction of a further benchmark (Želešice, near Brno). Moreover, the catalogue did not consider the latest published data for eastern Germany. A strong E-W-gradient and different types of anomalies would follow on the borders between Germany, Poland and the Czech Republic.

An adjustment of isolines was calculated between the single regions based on the quoted original maps. As a quantity for correction was used the mean difference between isoline-

Tab. 1 Correction values for the fitting of the regional isoline planes

adjustment of	on	correction value
(4) Höggerl	(1)-(2)-(3)	- 0,8
(5) Mälzer	(1)-(2)-(3)-(4)	- 1.1
(6) Zippelt in Gubler	(1)-(2)-(3)-(4)-(5)	- 0,6
(7) Pissart	(1)-(2)-(3)-(4)-(5)-(6)	- 0,1
(8) Lorenz (Modell 16)	(1).............................-(7)	+ 0,2
(9) Leonhard	(1)..................................-(8)	+ 0,0(2)
(10) Andersen	(1).......................................-(9)	+ 0,7
(11) Kakkuri in Gubler	(1)..-(10)	+ 0,7
(14) Forniquet	(1)..-(11)	± 0

values along the borders of the single maps. The procedure started first with the basis map (1) Vyskocil et al. - in which were included already the completions from (2) Kaschina, (12) Ihde et al. and (13) Wyrzykowski - calculated together with (3) Joo. The combination of (1) and (3) by interpolation was without serious problems; - both maps are related to mean sea level. The quantity for correction became zero. The fit-procedure was continued towards west and north like it is demonstrated in the table 1, giving also the determined correction quantities.

The proportion of calculated, interpolated and extrapolated isolines was documented in the first published version of the map by different signatures (Frischbutter et al. 1995). This map show also the extrapolated region of missing data in Lower Saxony. The open area in France was later closed for the present map.
Above all the combinations between the southwestern, western and northern parts of the map (Austria, western Germany, Belgium to Denmark) is problematic not only regarding the adjustment of isolines, but also regarding the homogeneity of the resulting pattern of anomalies. Especially for these regions the map cannot comply with geodetic requirements in accuracy and have much more a hypothetical character.

Interpretation

An interpretation of the map is problematically not only because of the different used benchmarks for regional maps, but also because of differing configurations of the levelling nets. Already the first look at the map give the impression, that the degree of generalization of the isoline pattern depends directly on the territorial size of the regional maps. In this manner the anomaly pattern becomes more subtle in the sequence Fennoscandia - eastern Europe - Denmark and western Germany - Poland/eastern Germany/Czech Republic/Slowakia/Hungary - Belgium/the Netherlands.

In its northern part the map is dominated by the extensive, NE-SW - stretched uplift structure of Fennoscandia, which is certainly caused by glacial rebound of the crust. The maximum uplift values reach >8 mm/a (northern Bothnian Bay). Similar uplift values but of quite other reason occur in the studied area only within the Carpathians (> 6 mm/a). The Fennoscandian uplift is surrounded - most distinct between the Baltic States and northern Poland - by a zone of locally strong subsidence, which is subdivided by N-S -trending structures. Maximum subsidence up to 6 mm/a is observed within the depression around the Fennoscandian Block, especially where the zone is cutted by the N-S -trending Orscha- and Waldai-Depressions. The circo-Fennoscandian depression can be followed to the West, crossing the Polish-Lithuanian-Depression with moderate rates of subsidence (2,5 - 3 mm/a) up to the Tornquist-Teisseyre-Zone (TTZ). The depression was repeatedly discussed as a collapse structure of a ring-bulge of the Upper Mantle, which was formed as a reaction on the glacial-isostatic uplift of the Fennoscandian Block. The conditions for those combined uplift- and subsidence motions were estimated by Fjeldskaar (1994). He could show that the last glaciation of Scandinavia (15 000 b. p.) generated a ring-bulge of +60 m related to the equilibrium situation, which collapse takes place gradually without an appreciable lateral migration.

Ukrainian Massif, Voronesh Antecline, Dnepr-Donetsk-Depression, Pripyat-Trough and probably the Masurian-Belorussian Antecline also form a more or less subdivided unit of general subsidence (up to maximum values of -6 mm/a in the eastern Ukrainian Massif). The obvious N-S trending structure of the Archaean-Proterozoic basement of the Ukrainian Massif seems to be clearly reflected in the anomaly pattern of recent vertical crustal movements too and seems to be even not or only weakly influenced by processes in connection with the evolution of the Dnepr-Donetsk-Depression.

At its southern margin the map touches the Carpathians. An important uplift anomaly reaching values of >5 mm/a is formed where the TTZ leads into the Carpathian Foredeep or the Carpathian Front. Otherwise the western part of the Carpathian arc is characterized by only moderate recent vertical movements.

The Tornquist-Teisseyre-Zone is not reflected like an uniform structure in the pattern of recent vertical crustal movements. The TTZ is indicated between the Carpathians and the Baltic Sea by more or less strong gradients of different polarity. This corresponds to the structural pattern, which is characterized in this region by a line up of single, uplifted blocks (Westbaltic Range), accompanied with depressions (over relative uplifts of the Upper Mantle). The change from dominating NW-SE - direction of S_{max} in western Europe to N-S- and NNE-SSW-directions typical for the adjacent East European Platform is documented by around E-W trending direction within the range of the TTZ. Dextral strike slip is to be expect under those conditions on the TTZ (Sim et al. 1999).

West of the TTZ the isoline pattern of recent vertical crustal movements makes the impression of a much more complicated structure, which may partly caused by the original data, coming from several single, small area covering maps. On the other hand, this type of pattern may correspond also to the closer block structure of the West European Platform. The importance of N-S -directions for recent vertical crustal movements west of the TTZ was emphasized already by Ellenberg (1992). The Bohemian Massif forms an block of general subsidence, bordered not only by NE- and NW-, but also on E-W-trending isolines. Maximum subsidence (up to -3 mm/a) in the Bohemian Massif is observed over its Cretaceous Basins (e.g. Trebon- and Budejovice Basin).
Erzgebirge Mts. with Ohre Graben (young volcanism) and western Sudetes reflect at the northwestern flank of the Bohemian Massif an area of relative uplift in NE-SW. A zone of a steeper gradient follows the trend of the Danube-Marginal-Faults and the Franconian Line between the Alps and the Hessian Basin. Seismic activity around the Bohemian Massif is known above all on the southern flank of the Erzge-

birge Mts. (Vogtland), where the Ohře-Graben is intersected by sub-meridional structures, from the Elbezone and its continuation into the Northbohemian Cretaceous Basin and from the Moravosilesikum.
Upper Rhine Graben (NNE-SSW) and Lower Rhine Bay (NW-SE) are marked by well stretched structures of recent subsidence up to -2 mm/a. Probably the absolute values of subsidence in the Lower Rhine Bay may be partly anthropogenic influenced (opencast coal mining up to a depth of around 100 m). The middle Rhine region between them is characterized by a NE-SW-stretched anomaly of moderate uplifting. The entire Rhine Graben represents a zone of considerable seismic activity. Close inshore the North Sea moderate subsidence up to -2 mm/a dominate within a NE-SW - running pattern.
The isoline pattern of Denmark seems to be inserted between the TTZ and the frequently discussed Transeuropean Fault (TEF): The Danish type of anomalies is similar to that of Fennoscandia, superimposed by the denser structured pattern of anomalies (typical for central- and western Europe) south of the TEF.

Future Outlook

Substantial progress respecting the data base for recent vertical crustal movement representations are expected for the future from projects on the basis of the Global Positioning Systems (GPS). Results of an experiment covering all Fennoscandia (BIFROST-project, started in 8/93, Fig. 3) were published by Scherneck et al., 1998. The results demonstrated the general coincidence of data derived from triangulations and GPS concerning the position of anomalies. However, the GPS data indicate unrealistic high rates (uplifting twice as high as the values calculated from triangulations), but the maximum covers the same area - the northern Golf of Bothnia - and also higher rates of subsidence for the region south of the Baltic Sea. Additionally the anomaly pattern is much more generalized for Middle Europe. Nevertheless, the GPS-map demonstrate the importance of N-S-directed structures more explicit than the representation on the basis of geodetic triangulations. A longer duration of GPS-observation and further methodical corrections are expected to improve the results in future.
Further improvements are to expect from the all over Europe GPS-project EUVN (European Vertical GPS Reference Network), Ihde et al., 1999.

Summary

A "Map of recent vertical movements" is presented for the region around the Baltic Sea between 4° to 36° E and 47° to 65° N. The data base is made of published data, consisting especially for western Europe of presentations for national territories only. On the basis of a "Map of the original data" (Frischbutter et al. 1995) an isoline adjustment was calculated between the original maps, using the mean difference of isoline values along the border lines of the original maps. The resultant map reflects a minimum variant, which was possible to realize within the scope of IGCP-project 346 "Neogeodynamica Baltica".
Between the Fennoscandian Block, characterized by glacial-isostatic uplift and the uplift area of the Carpathians (N-drift of the African Plate) is situated an extensive region of recent subsidence, which may be less differentiated over the old East European Plate and which responds there in the main to an old created, reactivated structure of blocks. The southern margin of the uplifting Fennoscandian Block is followed by a belt of subsidence, which may be associated with a collapse structure within the Upper Mantle. The West European Plate is distinguished from the East European Plate by a more differentiated anomaly pattern of vertical recent crustal movement, possibly additionally influenced by the opening processes of the Atlantic. Nevertheless, NW-SE-trending structures seems to be more distinct developed than in NE-SW- direction. The Tornquist-Teisseyre-Zone (TTZ), the border between both plates is obviously of only slighter importance in recent vertical crustal movements. They are all together aseismic. N-S- to NNE-SSW-trending structures seem to be most important concerning recent vertical movements of the Earth's crust on both sides of the TTZ.

Zusammenfassung

Vorgestellt wird die Karte der rezenten vertikalen Krustenbewegungen für die Ostseeregion in den Grenzen 4° bis 36°E und 47° bis 65°N. Grundlage der Karte sind publizierte Daten, die speziell für das westliche Europa nur für nationale Territorien vorliegen. Auf der Grundlage einer Karte der Ausgangsdaten (Frischbutter et al. 1995) ist eine Isolinenangleichung unter den Originalkarten berechnet worden, wozu die mittlere Differenz entlang der Ausgangskarten benutzt wurde. Die abgeleitete Karte stellt die im Rahmen des IGCP-Projektes 346 "Neogeodynamica Baltica" realisierbare Minimalvariante dar.
Zwischen dem durch isostatischen Aufstieg gekennzeichneten Fennoscandischen Block und dem Hebungsgebiet der Karpaten (N-Drift der Afrikanischen Platte) liegt ein ausgedehntes Gebiet rezenter Senkung, welches über der alten Osteuropäischen Tafel möglicherweise weniger stark differenziert erscheint und stärker durch alt angelegte, reaktivierte Blockstrukturen charakterisiert ist. Dem südlichen Rand des aufsteigenden Fennoscandischen Blocks folgt eine Senkungszone, die auf eine Kollapsstruktur im Oberen Mantel zurückzuführen sein könnte. Die Westeuropäische Tafel unterscheidet sich von der Osteuropäischen durch ein differenzierteres Anomalienmuster, möglicherweise bedingt durch zusätzlichen Einfluß atlantischer Öffnungsprozesse. Generell scheinen NW-SE - streichende Strukturen stärker betont als NE-SW - streichende Richtungen. Die Tornquist-Teisseyre-Zone (TTZ), die Grenze zwischen beiden Tafeln, ist hinsichtlich rezenter vertikaler Bewegungen offensichtlich nur von geringer Bedeutung. All diese Elemente sind aseismisch. N-S- bis NNE-SSW-streichende Strukturen scheinen für die rezenten vertikalen Krustenbewegungen beiderseits der TTZ am Wichtigsten zu sein.

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Direction of recent maximal stress and epicenter map of tectonic earthquakes (maps 5 and 6)

Results of IGCP project 346

Gottfried Grünthal & Dietrich Stromeyer

1. Introduction

Recent crustal stress and seismicity data can provide valueable information about neotectonic processes within relatively stable continental blocks. For the study area of the IGCP-project "Neogeodynamica Baltica" the maps no. 5 and no. 6 present the state of the art of data compilation of both the direction of maximal horizontal compressive stress S_{Hmax} and the epicenters of earthquakes.

For the stress compilation the well known data base of the World Stress Map (WSM) project, a reinterpretation of the Fennoscandian stress field and a remarkable increase of stress data near and east of the Tornquist-Teisseyre Zone (TTZ) could be used. At first time this data set allows a comparable interpretation of the stress regime of the East European platform with the stress field of western Europe and Fennoscandia.

A homogeneous data set of seismicity is provided basing on earthquake data compiled in the last version of national earthquake catalogues for the study area. The data were collected and made homogeneous in the frame of the Global Seismic Hazard Assessment Program (GSHAP), the IDNDR demonstration project of the International Lithosphere Program ILP. The presented epicentre map seems to be one of the first where detailed data for Fennoscandia, for central Europe, and the scarce data for eastern Europe are combined.

2. Crustal stress data

The only stress parameter which is available with sufficient reliability and quantity is the direction of maximum horizontal stress S_{Hmax}. This parameter is exclusively dealt with for map no. 5. The compiled stress data are based on fault plane solution of earthquakes, in-situ stress measurements in boreholes and mines, geologic fault slip determinations and repeated precise geodetic triangulations as recommended by the WSM project (Zoback & Burke 1993). The methods and constraints of azimut determination of S_{Hmax} have been summerized by Zoback (1992) for the different techniques mentioned.

The presented data for the study area comprise the WSM-data base subset and the new stress indications discussed by Grünthal & Stromeyer (1994). Beyond that the data set for eastern Europe could be extended remarkably. For NE germany high quality breakout and hydrofrac data were recently presented by Palmer & Groß (1999). The breakout interpretations of Jarosinski (1994) for boreholes of the hydrocarbons industries fill a former gap in SE Poland and in the southern Baltic Sea. No stress data were available before the Geogeodynamica Baltica project for the Baltic countries (except one fault plane solution from the Ossmussaer earthquake 1976), NE Poland, Belorussia, and most western part of Russia. This figure could be changed completely by neotectonic stress indications which were derived from Sim et al. (1995) by analysis of secondary disturbances and geological-geomorphological features along recent faults. In a critical review of stress data for Fennoscandia Muir Wood (1993) referred to serious problems connected with fault plane parameters of mostly small earthquakes. Therefore, this map includes only those stress data of Fennoscandia which were recommended to be well-constrained.

To interpret the compiled stress data we have to distinguish between two primary categories of stresses in the upper, elastic part of the Earth's lithosphere. The first, usually called 'tectonic' stress is strongly related to broad-scale forces including plate boundary forces, large-scale flexure of the lithosphere owing to surface and subsurface loads, inhomogeneous density distributions, and thermoelastic forces in cooling oceanic lithosphere. The second category, the local or 'induced' stress, is connected with local effects of topography, anisotropy of strength or elastic properties, effects of erosion and man-made excavation (Zoback, 1992). In the study area there are indications for both, tectonic and induced stresses. The first order or large-scale behaviour of the direction of S_{Hmax} indicates NW-SE trending stress directions in western central Europe and most parts of Fennoscandia. This homogeneous stress field is coincident with a thin to medium lithosphere thickness (50-90 km). Finite element modellings provide clear constraints that Mid-Atlantic seafloor spreading and the northward directed motion of the African plate are compatible with this broad-scale observed stress field (Grünthal & Stromeyer 1992). Therefore, the observed data of this part of the Eurasian plate should mainly be controlled by forces that drive plate motion.

The second order S_{Hmax}-direction in Fennoscandia is not as consistent as in western Europe. Following smaller scaled areas of more or less similar directions can be found: dominating S_{Hmax}-direction NW-SE: offshore of central Norway, Denmark, SE-Norway, in the south of central Sweden as well as Finland; S_{Hmax}-directed N-S: S-Sweden; S_{Hmax}-directed E-W: central Sweden. Generally, one can conclude that the scatter is remarkable. A combination of plate boundary forces at the Mid-Atlantic ridge with flexual stresses from glacial rebound are the mostly discussed sources for the Fennoscandian stress province (BUNGUM & LINDHOLM 1996). Possible causes for the scattered tectonic stresses in Fennoscandia could reflect: (1) the shift of the Mid-Atlantic Ridge spreading axis at about 70°N by the Jan Mayen fracture zone, which may indicate an influence of lateral variation of plate boundary forces; (2) a local radial ridge push component due to the Iceland hot spot; and (3) the physical properties of the 110-170 km thick Fennoscandian lithosphere. It contributes to a reduction of the mean stress level of the lithosphere. This might cause local effects on the stress field due to the lateral density or strength inhomogeneities in the crust (MÜLLER et al. 1992, MUIR WOOD 1993).

The compressional stress regime on the East European Platform (EEP) seem to be significantly different from that in western central Europe and Fennoscandia. The broad-scale S_{Hmax}-orientation rotates to N-S when approaching to TTZ and is stable NE-SW in the southeast of the study area. Generally, stress data on the EEP are obviously subject of stronger fluctuations. This might be the result of the smaller stress magnitudes and/or due to the poor quality of stress information in that part of the study area in comparison with western central Europe. A possible interpretation of the generalized stress regime of the EEP could be a large scale transformation of northward directed push of the Arabian and Indian plate towards to the EEP, while the influence of the Mid-Atlantic spreading decreases.

The stress data for S-Karelia show obviously the same general NW-SE pattern as that in Finland derived from in situ measurements and fault plane solutions. Ridge push can be assumed as the predominat sources for this stress pattern (BUNGUM & LINDHOLM 1996).

No uniform stress pattern can be found for the area of the Baltic countries, the region of Kaliningrad and NE Poland. Most stress indications were derived from geological evidences and assessed as quality D. In the north the available data infer an E-W directed compression according to one fault plane solution, while the N-S orientated breakout of quality B dominates the border region of Poland and Lithuania. This Baltic region could be regarded as a transition zone between the stress province of the EEP and the Fennoscandian stress province. It seems to be influenced mainly by the regional effects as they were already discussed for Fennoscandia.

3. Seismicity data

One of the intentions of the IGCP-Project 346 "Neogeodynamica Baltica" is to compare the neotectonic features with the earthquake epicentres in order to derive conclusions which of the neogeodynamic processes have their expression in the occurrence of earthquake phenomena. All known earthquake epicentres have been compiled for this task and made homogeneous especially at the state boundaries. This procedure is described in GRÜNTHAL et al. (1999) as a part of the Global Seismic Hazard Assessment Program (GSHAP), the initiative of the ILP (International Lithosphere Program) to the IDNDR (International Decade for Natural Disaster Reduction).

The following, mostly national catalogues or data-files were elaborated to create a joint and homogeneous seismicity-file for the study area of Neogeodynamica Baltica: Austria (LENHARDT 1994) Belorussia and Pribaltica (BOBORIKIN et al. 1993), Belgium and Luxembourg (VERBEIREN et al. 1994), Czech Republic (SCHENKOVÁ 1989), Estonia (NIKONOV 1991; NIKONOV & SILDVEE 1992), Fennoscandia (AHJOS & USKI 1992), France (part of the SIRENE data-file, LAMBERT & LEVRET 1996), Germany (LEYDECKER 1986, GRÜNTHAL 1988), Hungary and adjacent territories (ZSIROS et al. 1991), The Netherlands (HOUTGAST 1990), Poland (PAGACZEWSKI, 1972 - added by data elaborated by GUTERCH 1995 as well as own studies), and data of the earthquake catalogue of the former Soviet Union (KONDORSKAYA & SHEBALIN 1977).

The earthquake strength parameter depicted in the map no. 6 is the local magnitude ML with values equal or greater 2.5. Most of the catalogues contained several non-instrumental data (i. e. historical earthquakes) given by their intensity (macroseismically felt effects). These data were transformed into ML in the frame of the above mentioned GSHAP activities. It proved to be necessary to elaborate separate empirical relations for each catalogue to convert the epicentral intensity, the felt area and, if available, the focal depth into ML. The seismicity data for the Baltic Republics, for Belorussia and the Ukraine are too scarce to get a reliable separate empirical conversion relation. Because of similarities in the crustal structure and seismicity pattern with those in Finland the relations used there were applied to the large region south of Finland in cases where the original catalogues include solely the intensity as earthquake strength parameter.

For studying the seismicity pattern with respect to tectonic features it is essential to consider different aspects of the data quality. First of all, the localization accuracy of earthquakes has to be taken into account for a detailed analyses. A sufficient high precision of the localization can be guaranteed for these events recorded by dense seismic networks. Large localization errors are frequently typical for historical events. Therefore, the intention of this contribution can solely be to discuss the appearance of seismicity in an areal extent.

The knowledge of the temporal completeness of data is essential for any further conclusion. It is obvious that the temporal completeness shows large differences in the study area. While southwestern parts show rather long lasting data completeness back into history, the data are less complete when approaching to the east (GRÜNTHAL et al. 1999). The clusters of events in the southwestern part of the study area belong to the well known areas of increased seismic activity of the Upper Rhine graben, the middle Rhine zone and the Lower Rhine embayment (AHORNER 1975), the Hohenzollerngraben (SCHNEIDER 1980, 1992) and to the saxothuringian seismotectonic province with the prominent swarm quake region of

the Vogtland. The seismotectonics of this region is described by GRÜNTHAL et al. (1990).
Another concentration of seismic activity is connected with the northern rim of the Carpathians as well as with the northern border of the Bohemian massif (border region of Czech Republic and Poland). The seismotectonic provinces of the eastern part of the West European Platform were derived and at least tentatively connected with tectonic elements by GRÜNTHAL et al. (1985).
The seismicity of the Lower Rhine embayment is in most cases connected with normal faulting, while the seismic activity of the Upper Rhine, of the Hohenzollerngraben and of the Vogtland is the result of dominant strike slip movements, the latter two along nearly N-S directed faults, which are at the surface of secondary order. The first order, mostly NW-SE directed faults, are obviously aseismic. But in seismically active regions they can obviously provide zones of weakness. In general, they are not the localizations of the earthquake hypocentres itself. For the other regions mentioned above, there are not so clear constraints and the seismotectonic interpretations can be tentative only.
The seismicity of Fennoscandia (as it is part of the study area) concentrates mainly in three areas: (1) at the coast of western Norway, (2) in a region between the Oslo-graben, the lake Vänern and the lake Vättern as well as (3) at the Swedish coast of the Gulf of Bothnia. The remaining parts of Norway, Sweden, Finland and northern Denmark, including the Skagerak, show a certain level of background activity except the Baltic Sea, where the seismicity is almost lacking. This cannot simply be explained by missing recordings due to sparse instrumention or lacking macroseismic observations (WAHLSTRÖM & GRÜNTHAL 1994).
The origin of Fennoscandian earthquakes is obviously due to both, plate tectonic ridge push and isostatic postglacial rebound. According to MUIR WOOD (1993) the isostasy due to the latest era of glaciation-deglaciation should practically be the only contribution to the seismicity. But his conclusions are controversial and were the matter of several criticism (e.g. WAHLSTRÖM 1993). EKMAN (1985) as well as SKORDAS & KULHANEK (1992) conclude, by using different arguments, that the seismicity in northern Fennoscandia is predominantly the result of the uplift while the plate tectonic ridge push, mainly generated from the North Atlantic, generates the seismicity of southern Fennoscandia. ANDERSON (1980) explained the increased seismic activity along the Swedish coastline of the Gulf of Bothnia as a result of differential strain built up along the coastline due to long-term isostasy.
The origin of the seismicity of Estonia and Latvia can probably be compared with that of Finland. Lithuania, Belorussia, Russia and the parts of Poland and of the Ukraine east of the TTZ, are, at least according to the available data sources, almost free of any seismicity. Another point which has to taken into account for such a conclusion is the fact that the data-file for this region has a rather limited extent into history only.
One fact has clearly to be stressed that one of the most prominent tectonic feature in the centre of the study area, the Tornquist-Teisseyre Zone, is not manifested by seismic activity. If the NW prolongation of the TTZ, the Tornquist-Sorgenfrei Zone, is correlated with the seismic activity in Skåne, northern Sjaelland and nearby Kattegat, is not obvious.
According to A. A. NIKONOV (pers. communication 1995) the aseismic nature of some of the events in Belorussia cannot be excluded. Some of the events could in reality be non-tectonic earthquake-like phenomena associated with exhaustion processes of salt-dome tops.

Summary

An up to date compilation and interpretation of the maximal horizontal compressive crustal stress (map no. 5) and the epicentres of earthquakes (map no 6) are given for the study area of the IGCP-project "Neogeodynamica Baltica". At first time new stress data of the East European Platform are presented in comparision with the stress field of western Europe and Fennoscandia. The epicentre map shows the actual data set collected and made homogeneous in the frame of the Global Seismic Hazard Assessment Program (GSHAP).

Zusammenfassung

Für das Untersuchungsgebiet des IGCP-Projekts „Neogeodynamica Baltica“ wurden die aktuellen Daten der maximalen horizontalen krustalen Kompressionsspannung (Karte Nr. 5) und die Epizentren von Erdbeben (Karte Nr. 6) zusammengestellt und diskutiert. Erstmals werden neue Spannungsdaten für die Osteuropäische Plattform im Vergleich mit dem Spannungsfeld Westeuropas und Fennoskandiens präsentiert. Die Karte der Epizentren zeigt den derzeitig katalogisierten Datenbestand, welcher im Rahmen des Globalen Programms zur Einschätzung der Erdbebengefährdung (GSHAP) erfaßt und homogenisiert wurde.

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Depth of Mohorovičić discontinuity (map 7)

Neogeodynamica Baltica IGCP-Project 346

R.Y. Aizberg & R. Garetsky

The Mohorovičić (M) discontinuity structure reflects special features of the Earth's crust thickness variation over the territory, its vertical subdivision and specific association with recent geodynamics. The map of the M-discontinuity includes the information presented on several other previously published maps (their authors are listed in the map's legend). It is based on results of deep seismic and magnetotelluric sounding, study of exchange waves from earthquakes, and correlation calculations of geophysical potential fields.

The M-discontinuity separates the high-gradient crust with prevailing wave velocities less than 6,5-7,5 km/s from the low-gradient upper mantle with velocities mainly exceeding 8 km/s. According to the data available today, the M-discontinuity is a transition zone of variable thickness including interstratified thin layers with high and low velocities of compressional waves. Therefore, the correlation of the different-age M-boundary (or boundaries) in various parts of the young West European and the old East European Platform presents a difficult problem.

These both platforms essentially differ from each other in the character of the M-discontinuity structure. The southwestern boundary of the East European Platform running along the Teisseyre-Tornquist Zone (TTZ) is shown by a vertical displacement of the M-discontinuity of some 10 km, the zone itself being distinguished as a belt where the M-discontinuity occurs at a depth of 50-65 km. This zone separates Europe into territories showing different crust thicknesses: 20-35 km within the West European Platform and 40-65 km in the old platform.

Deep Seismic Sounding (DSS) has not been evenly performed throughout the territory of the western part of the East European Platform including the Belarus-Baltic region, northern Ukraine and eastern Poland. A high density of these data is related to the Ukrainian Anteclise and the TTZ, where the DSS materials available permit the compilation of a quite substantiated map of the M-discontinuity. For the Belarus-Baltic region there are only few DSS profiles and, therefore, the map is compiled using a complex interpretation of the geologic-geophysical data as follows: deep seismic and magnetotelluric sounding, local and regional gravity and magnetic fields and their various transformations, heat flow and data describing the temperature variations in various horizons, M-discontinuity included, the crystalline basement relief and material composition, and density distribution of the sedimentary rocks.

To give a quantitative estimate of the mutual integral correlation of this complex of geological and geophysical data available for the western part of the East European Platform, it should be noted that the confidence of physical and geologic data is about 60 % for the territory as a whole, but ranges from 80- to 85 % for the Ukrainian Anteclise, and is 70 % for the Belarus-Baltic region.

The correlation of neotectonic and deep platform structures with the M-surface in the East European Platform shows a number of peculiarities. Within the recent Ukrainian Anteclise the depth of M-discontinuity varies generally between 38 and 60 km, and from 50 to 60 km over the most part of territory. The Central-Ukrainian Uplift, a part of the anteclise, is confined to the meridional zone of uplifts in the M-discontinuity. The Kirovograd neotectonic unit is located in a zone of jointing meridional and sublatitudinal structures of the M-discontinuity occurring at a depth of some 50 km. The Volyn-Podolian Uplift, like the Central-Ukrainian Uplift, is confined to a meridionally raised structure in the M-surface, and the Rovno Saddle separating the above uplifts is found in an area with deeper Moho occurrence.

It should be noted that the axial part of the recent Dnieper Syneclise - the Krementschug Depression is not represented in the crustal bottom as an independent structure, but occupies the slope of a well-defined large linear elevation of northwestern strike. It is confined to the northern part of the Syneclise, and in the basement surface to the Dnieper-Donets Palaeorift Graben.

The recent Baltic-Belarus Syneclise is bounded to the south and southwest by active faults that roughly coincide with the translithospheric faults, that are defined in the Moho relief and run along the northern boundary of the Ukrainian Anteclise, Volyn-Podolian Uplift and the TTZ.

The Moho discontinuity displays some zonality features within the Baltic-Belarus Syneclise and the adjacent Voronezh-Tver Anteclise. In the first of them there are a western and a central system of big linearly elongated uplifts in the M-discontinuity, that strike northeastward and occur at depths of 45 to 47 km. Both structures are separated by a deep trough (55 km and deeper). In the transition zone between the northern part of the Baltic-Belarus Syneclise and the Voronezh-Tver Anteclise, the M-discontinuity relief shows some anomalies. For example, in the region of the Latgale High there is a big elevation of northwestern strike in the M-relief. A similar situation is observed in the transition zone between the Baltic-Belarus Syneclise and Ukrainian Anteclise. So, the recent Pripyat Step overlying the central and southern zones of the Pripyat palaeorift corresponds to an uplift in the M-discontinuity relief, which is replaced by a large latitudinal negative structure close to the northern boundary of the anteclise.

The analysis of the above anomalies in the M-relief together with the other data available suggests that the activity of these latitudinal zones became evident in the Late Devonian and later as volcanism and some transformations at the crust-mantle interface. This resulted in the development of the crust-mantle mixed layer in the young M-discontinuity, which formed a positive structure against the background of an old trough.

The East-Baltic System of Grabens is not generally reflected in the strike and composition of the main M-relief features. However, some local areas with low crust thickness are found in the region of the West- and East-Gotland Grabens and southern parts of the Grabens of Bothnia and Finland, where the depths of the M-discontinuity vary by 10-15 km. This may be due to the beginning of transformation at the crust-mantle interface, which was caused by the pre-rift endogenic regime. Attention should be drawn to the fact that maximum sea depths and amplitudes of neotectonic subsidences are confined to just these anomalous areas.

In the zone of transition from the East-Baltic System of Grabens and Baltic-Belarus Syneclise as a whole to neotectonic structures of the West-European Platform there is a rotation of the M-relief features into the northwestern direction parallel to the TTZ strike.

The analysis of correlation the recent structures of the East European Platform with the main M-discontinuity features shows that both are in general fairly corresponding.

The other features of neotectonic structures are evident within the West European Platform. Even in the area where it joins the East European Platform, the West-Baltic Step is distinguished from its southeastern part being coincident with a sharp bench in the M-relief in the TTZ. The Silesian Zone and the Poland Uplift are found within just this area. The depth of M-occurrence within the above structures changes from 40 to 60 km, according to data of Polish geophysicists there is a high-amplitude trough with border steps. A monoclinal structure of the same northwestern strike in the M-relief corresponds with the northwestern part of the recent West-Baltic Step. Within the recent Jütland-Rügen Swell, the monocline is replaced by a small depression, and in transition to the recent Skagerak depression by an elevation in the M-relief.

The Central European Subsidence Zone paralleling the TTZ coincides in area with a linear low in the M-discontinuity. Generally latitudinal trend of the M-discontinuity structures has been revealed within the area occupied by the Central European Zone of Uplifts running latitudinally. It should be noted that the recently active grabens to the southwest, Lower Rhine Graben, Upper Rhine Graben, are characterized by inverse correlation with the corresponding elevations in the M-relief.

In conclusion it should be mentioned once again that recent structures of the West European Platform are typically conformable or inverse to major elements of the M-discontinuity. Neotectonic structures of the East European Platform correspond to only individual elements in the M-discontinuity.

Summary

The information containing the presented map of the Mohorovičić discontinuity (Moho) as well as the compiled data are explained. The studied area comprises the young West European and the old East European Platform. Owing to the geological reasons both platforms essentially differ from each other in the structure of the Moho. The different platform reaches defined by their tectonical and geological features are described in relation to the position of the Moho.

The fairly correlation between the recent structure of the East European Platform and the features of the Moho is generally shown. Within the West European Platform the correlation of neotectonic structures with the Moho is more evident, either in a direct conformable manner (e.g. Central European Subsidence Zone) or in a inverse one (e.g. Upper Rhine Graben) to major elements of the Moho.

Zusammenfassung

In der Kurzerläuterung zur Karte „Depth of Mohorovičić discontinuity“ werden die Ausgangsdaten und darauf aufbauend die Unterschiede in der Tiefenlage der Moho-Diskontinuität im Untersuchungsgebiet dargestellt. Die Tiefenlage der Moho unterscheidet sich wesentlich zwischen der alten Osteuropäischen und der jungen Westeuropäischen Tafel. Sie resultiert aus dem unterschiedlichen geologischen und tektonischen Werdegang beider Großstrukturen. Die Beziehungen zu den neotektonischen Strukturen werden diskutiert, wobei es im Bereich der Westeuropäischen Tafel engere Bezüge zwischen der Ausbildung der Moho-Tiefenlage und den neogeodynamischen bzw. neotektonischen Strukturen gibt als auf der alten Osteuropäischen Tafel. Einige Beispiele für konforme und inverse Beziehungen zwischen der Moho-Tiefenlage und den neotektonischen Strukturen werden aufgeführt.

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The neogeodynamic state of the Baltic Sea depression and adjacent areas – some conclusions from the IGCP-Project 346: "Neogeodynamica Baltica"[1]

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General remarks

The work on the IGCP project No 346 "Neogeodynamica Baltica" has provided new data which reveal the main peculiarities of the neogeodynamic evolution of the East European Platform (EEP) west and the adjacent part of the young West European Platform (WEP).

Compromises had to be made on a somewhat diachronous reference level: the base of Rupelian beds (Lower Oligocene) in the west to the base of Miocene beds in the east, because of the lack of Rupelian beds over large areas in the estern parts of the studied area. The latter fact and the much more thickness of the cover on the WEP compared with that on the EEP called, in parts, for applying different research methods to both geotectonic units. From that resulted a higher degree of interpretation concerning the data of the EEP part of the map.

Neotectonic movements and structures

Values of total amplitude of neotectonic vertical movements (map area) are nearly one power more in the WEP than in the EEP. They amount to 2500 m in the WEP (1500 m subsidence in the Roer-Lower Rhine graben and in the North Sea region and to about 1000 m uplift in the Erzgebirge Mts.) in contrast to only 630 m total amplitude in the EEP (250 m subsidence in the Central Baltic Sea and 380 m uplift in the Podolsk block) (Ludwig & Schwab 1995, Palijenko & Matoshko 1995). But several km subsidence (Carpathian foredeep) are faced with >2000 m uplift (post-Oligocene) in the Carpathian orogen (Ostaficzuk 1995). That makes a total amplitude of >7 km in that region. The Norwegian mountain's neotectonic uplift reached also >2000 m against 2500 m subsidence in central part of the North Sea basin (up to 1 500 m in the map area).

The study of the Holsteinian Interglacial marine deposits (Likhvin, Mazovian, Alexandrian) showed that the amplitudes of vertical movements during Holsteinian to Holocene times reached their maximum values (150-200 m) in the western part of the East European Craton namely in the eastern Baltic Sea basin (the Gotland depression, Gulf of Bothnia, Šliaupa et al. 1995). In the area where Holsteinian marine respectively lacustrine deposits exist, especially southeast of the North Sea basin, the amplitudes of post-Holsteinian vertical movements in North Germany amount only up to a few metres, seldom to some few tens of metres. NW-SE- and NNE-SSW-oriented tectonic features were established to be dominant, in particular, the Roer-Lower Rhine Graben and the area of lower Elbe river that were most distinctly pronounced.

Hence, a major tectonic subsidence after the Holsteinian took place east of the Tornquist-Sorgenfrei-Teisseyre zone, i.e. just within the East European Craton, and exerted a considerable influence upon the formation of the central and eastern parts of the Baltic Sea depression. In contrast to, a number of the West Baltic regions (e. g. Rügen Island) experienced slight uplifting perhaps during and after the Holsteinian Interglacial.

Generally, the average rates of subsidence outside the Carpathian orogen vary between 0,03 and 0,6 mm/y and there seems to be an obvious tendency to increasing vertical movements in the Pleistocene compared to the earlier neotectonic stage of the region's evolution. That is most peculiar for the Central Baltic Sea area.

A south to north section in the west shows a widely spaced undulation of the Earth´s crust. The main structures in the WEP are the Central European Uplift zone and the Central European Subsidence zone, followed in the north by the Fennoscandian Uplift with the Tornquist-Sorgenfrei-Teisseyre zone and the region south of it.

The Central European Uplift zone which strike is nearly parallel to the front of the Alpine-Carpathian orogen, continued pre-neotectonic uplift tendencies and is charaterized by much stronger uplifts of individual blocks and massifs above the

[1] This manuscript summarises the short explanations regarding the maps one to seven of the IGCP-project 346: *Neogeodynamica Baltica* presented before and draws some conclusions to the neotectonic state and subdivision (see map eight) of the investigated area.

average level of the region, accompanied by significant strengthening the relief.

The ruptural and non-ruptural vertical movements had mainly posthumous character as they continued the development of pre-neotectonic structures. This is also valid with regard to the inversion structures originated in the Late Mesozoic (e. g. the Tornquist-Sorgenfrei-Teisseyre zone). In the order of a few hundred metres but without stronger rise of small blocks occurred uplift and subsidence in the EEP.

Within the largest part of the region outside the Alpine-Carpathian orogen a system of neotectonicly active faults shows a rather regular pattern. Its most important elements are faults of mainly diagonal and orthogonal orientation.

Faults of all the directions of the orthogonal and the diagonal net, mostly the meridional directed, have been active, more or less temporally alternating. That points to a meridional arranged stress regime. The vertical displacements along a single fault as a rule do not exceed several tens of metres, but the most considerable amplitude, 400 m, was observed in the Roer-Lower Rhine graben. Along a single fault the vertical shift ranges from 0 m to its maximum amount, therefore, only sections of it have been activated with more or less intensity.

Tensional rupturing in the Central European Uplift zone has supported the development of the graben structures and the neovolcanic activities. Therefore neovolcanism remained restricted to faults in the area from the Ardennes to the Rhenish massif as far as to the Sventoksh Mts. in the East. The volcanic eruptions were of alkalibasaltic type. In consequence of the meridional arranged stress regime eruptions mainly occurred at submeridional running fault structures, and therefore neovolcanism extended far to the north following the Hesse graben, Elbe zone, and the fault zone along the river Lusatian Neisse. Climaxes of the volcanic activities were combined with that of fault tectonics at the beginning and during the Neogene (Miocene). Neotectonically active faults control also the distribution of earthquake foci.

North of the Central European Uplift zone is developed the neotectonic Central European Subsidence zone with an extension of about 1000 km. The axial part of the latter (the Hamburg - Cottbus depression) coincides with the late Palaeozoic North German-Polish basin and the Elbe fault system (STACKEBRANDT et al. 2001). This zone shows a steady tendency to downwarping during the whole Cenozoic. In the northwest it merges with the even deeper North Sea basin which is in conformity with the Meso-Cenozoic syneclise located over the North Sea palaeorift system. The North Sea basin's downwarping was inherited from its development from the late Cretaceous to early Tertiary. In its central part outside the map 1 the base of Rupelian layers occur as low as - 2,5 km at maximum.

Downwarping of the Central European Subsidence zone was to about 350 m and in the same order like the regional updoming of the Central European Uplift zone. Until now the subsidence zone has controll over the main features of the hydrographic system in North Germany. The extreme subsidences of the two submeridional troughs in the Lower Elbe region, as high as 1 km, point to locally strong vertical block movements rsp. to fault activities in the basement during neotectonic times because salt tectonics had been there only of subordinate significance. The adjacent southwestern portion of the Baltic Sea area had been partly involved into a moderate uplift since Neogene times (Rügen island, parts of Ringkøbing-Fyn High, and the region of the Danish islands north of it, LYKKE-ANDERSEN (1999)).

In the EEP part the neotectonic structures of larger dimensions (Ukrainian anteclise, Baltic-Belarussian and Dniepr syneclises, see structures on map 8), but with smaller amplitudes of vertical movements, could be separated from each other compared to the significantly smaller blocks and massifs in the more differentiated WEP part. Uplifts within in the Ukrainian and the Voronesh-Tver anteclises and with minor amounts in the linear Dnieper syneclise, are in contrast to subsidences in the northern parts of Belarus and especially in the Central Baltic Sea region with its significant meridional East Baltic systems of grabens (Baltic-Belarus Syneclise).

Minor horizontal displacements (strike-slip movements e.g. along the Tornquist-Sorgenfrei-Teisseyre zone and in the EEP also occurred all over the map area, above all at faults of the diagonal net (dextral at NW-SE and sinistral at NE-SW faults).

A system of neotectonically active faults is more clearly defined within the East European Craton, than that within the West European Plate. In the young platform these faults are distinctly pronounced only within the Central European Zone of uplift and within some young grabens. The basement composed of crystalline rocks is evidently more consolidated within the territory of the East European Craton and is, therefore, more brittle. In addition the platform cover is rather thin there and more readily replies to rupture dislocation. Within the West European Plate the basement was less consolidated and subsided to great depths and rupture dislocations attenuate in thick platform cover.

Correlation of neotectonic elements with structures of the lithosphere

The correlation of the neotectonic structures with the structures in the pre-neotectonic platform cover, with relief of basement surface, and with Mohorovicic discontinuity was found more regular within the West European Platform than in the East European platform. There are also strong differences in crustal thickness, 25 to 35 km are true for the WEP and 40 to 60 km for EEP. A regular increase of the crustal thickness is observed in both platforms within the positive tectonic features, and a decrease within the negative ones. The same is true for the lithospheric thickness (GARETSKY et al. 1996, 1997).

However, in the East Baltic systems of grabens there are areas of anomalously thin Earth's crust, since in the Central Baltic Sea and the Finnish Gulf regions the depth of the Moho discontinuity ranges between 10 and 15 km. Maximum amplitudes of the neotectonic downwarping coincide with positiv anomalies of heat flow there.

Controlling Processes

Major factors that had an impact on the course of neogeodynamic processes during the last 37 million years were the evolution of the Alpine-Carpathian Orogen that once appeared and continues its evolution to the present day in the collision zone between the Eurasian and African lithospheric plates as well as inherited downwarping of the North Sea basin and associated structures within the continent. Since the Middle Pleistocene (0,4 ma) the beginning of the young Baltic Belarussian syneclise and the East Baltic system of grabens occured. Dynamic effects of the Alps and Carpathians are responsible for the main crustal stress features (south to north compression) and favoured the origin of the Central European Uplift zone with its superimposed block uplifts and grabens (Sim et al. 1999). In addition the evolution of the North Sea basin and East Baltic system of grabens in the western margin of the Eurasian lithospheric plate was associated with submeridional tension belts that occur subparallel to the Middle Atlantic speading zone.

The formation of the system of grabens in the East Baltic area started in the Middle Pleistocene or somewhat earlier. It seems to represent an embryonic three-armed rift structure indicated by several geological and geophysical features and anomalies in the Earth´s crust there.

Genesis of the Baltic Sea basin

Data obtained evidently suggest a tectonic nature of the most part of the Baltic Sea depression (firstly, its central and eastern parts). The analysis of distribution of the Quaternary strata thickness and composition and the calculation of proportions of materials removed from the central and eastern parts of the basin and redeposited rocks show that only about 40-50% of the total basin volume can be attributed to exaration (Levkov & Karabanov 1994, Karabanov et al. 1994). The tectonic genesis of the most parts of the Baltic Sea depression is confirmed by some unconformities revealed in the pattern of the glacial series, by the gradual subsiding below the sea level of the Estonian glint (lower Palaeozoic rocks), as well as by a lowered block of Early-Palaeozoic deposits in the Gulf of Bothnia, preserved there from erosion.

In Miocene to the early Quaternary times the surface drainage developed across the Baltic area from the north to south towards large fresh-water bodies (at the beginning intermittent sea water and fresh-water) in Central Europe. It changed into an south to north drainage from eastern part of Central Europe into the southern Baltic Sea depression (rivers Odra, Vistula) at least since the Holsteinian Interglacial. Therefore, the Baltic Sea depression had been mainly formed during the last 0,4 ma.

The transgression of the Holsteinian Interglacial sea started from the North Sea in the eastward direction, crossed northern Germany and possibly reached as far as to Lithuania and Latvia on this way, but one more way, across central Sweden, cannot be excluded. (Ludwig 1999). The Bothnian and Finnish graben systems (Gulf of Bothnia and Gulf of Finland) mainly were also formed since the beginning of the Holsteinian time.

All the above findings suggest a young age of the depressions within the East Baltic Sea (and gulfs) east of the Tornquist-Sorgenfrei-Teisseyre zone that possibly form parts of an embryonic riftogenous triple-arm system. The last conclusion is supported by a variety of evidence. Firstly, there are deep depressions in the sea bottom relief, which maximum amplitudes of neotectonic downwarping are associated with it. The depressions are shaped as graben-type structures. The only downwarping one of Likhvin-Holsteinian times shows there maximum values (150-200 m). The most recent fault system bounds and clearly delineates the graben-type structures. A number of horst- and graben-type structures are outlined by faults within the bottom of the Gulfs and the East Baltic area. High seismic values are confined to the bounding zones of grabens. Local positive heat flow anomalies were determined in the off shore parts (regions of the Gotland Island, Gulfs of Kursh and Finland, etc.).

The evolution of the East-Baltic graben system and the deep North Sea depression in the western margin of the Eurasian lithospheric plate was probably due to submeridional tension belts that occurred subparallel to the Mid-Atlantic spreading zone (Garetsky et al. 1999). In contrast to the flat depressions in the modern Baltic Sea the area west of the Tornquist-Sorgenfrei-Teisseyre zone are to assign more to glacial exaration than to neotectonic subsidence.

Applied aspects of research

The results of research for the project "Neogeodynamica Baltica" are right for better understanding the neotectonic processes and their effects on surface relief, evolution of the hydrographic net work, geological structure during the last 37 ma. The recent state of tectonic mobility in its relation to the earlier tectonic development is also presented. Areas of high tectonic activities could be separated from those of less vertical movements.

All that is of great importance applied to problems of ecology, water supply, search for building materials and other raw materials, siting for large engineering constructions, of high tide and flood protection, and last but not least assessment and forecast of seismic hazards.

Special attention is payed to the study of active fault zones regarding the impact of geochemical and geophysical anomalies on the life of people, selection of safe places for industrial waste disposal, groundwater contamination.
Peculiarities of radionuclide migration in the Chernobyl radioactive contamination zone could be used to develop recommendations on decontamination works during the cleaning of the Chernobyl zone. Beyond it new scientific data are suitable for education and culture of people of European countries and are used for that already.

Abstract

Investigations performed for the IGCP project No 346 „Neogeodynamics of the Baltic Sea Depression and adjacent areas" resulted in a serie of eight maps compiled for the territory of Northern-Central Europe. The studies of the nature of neotectonic movements revealed the most important neotectonic features: Baltic-Belarussian syneclise involving the East Baltic and Finnish graben zones, Fennoscandian shield, Voronezh-Tver and Ukrainian anteclises, Dnieper syneclise, etc. (within the East European Platform), North Sea depression, Central European subsidence zone, Central European uplift zone etc. (within the young West European Platform). The features of the first group demonstrate a superimposed structural pattern more or less against the older platform tectonic units, those of the second group are of posthumous character. In general, positive structures show the thicker crust and the negative ones the thinner crust. Neotectonically active faults are of orthogonal or diagonal trend. The latter dominates and is most clearly pronounced within the East European Craton. Active faults are responsible for the distribution of earthquakes and in the West European Platform of neovolcanism.

The most important factors controlling neogeodynamic processes occurred in Central Europe are the uplift of the Alpine-Carpathian Orogen, the downwarping of the North Sea depression and the Central European subsidence zone, as well as the development of the young East Baltic rift system. The origination of the Baltic Sea depression which dates back at least to the Holsteinian time is associated with it.

Zusammenfassung

Im Ergebnis von Untersuchungen zum IGCP-Projekt 346 „Neogeodynamics of the Baltic Sea Depression and adjacent areas" entstanden 8 Karten zur Charakterisierung der Neogeodynamik des nördlichen Mitteleuropas. Wichtige neotektonische Strukturen sind: die Baltisch-Belorussische Syneklise mit den Ostbaltischen und Finnischen Grabenzonen, der Fennoskandische Schild, die Voronesh-Tver und Ukrainische Anteklise, die Dnjepr-Syneklise etc. (alle im Bereich der Osteuropäischen Platform) sowie die Nordsee-Senke, die Mitteleuropäische Senkungszone, die Mitteleuropäische Hebungszone etc. innerhalb der Westeuropäischen Tafel.
Während die Strukturen der ersten Gruppe das tektonische Inventar der alten Tafel überprägen, sind die der zweiten Gruppe von postumem Charakter. Generell gilt, dass positive Strukturen eine dickere Kruste aufweisen und negative eine dünnere. Neotektonisch aktive Störungen weisen sowohl orthogonalen als auch diagonalen Trend auf. Letzterer dominiert im Bereich der Osteuropäischen Plattform. Die aktiven Störungszonen nehmen Einfluß auf die regionale Verbreitung der Erdbeben und im Bereich der Westeuropäischen Tafel auch auf den Neovulkanismus.
Die neogeodynamischen Prozesse Mitteleuropas werden durch folgende wichtige Faktoren kontrolliert: Hebung des Alpen-Karpaten-Orogens, Eintiefung der Nordsee-Senke und der Mitteleuropäischen Senkungszone sowie der Entwicklung des jungen Ostbaltischen Riftsystems. Die Anlage der Ostseesenke, die mindestens bis in die Holstein-Zeit zurückdatiert, ist damit verbunden.

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1997, Heft 1,	**96 S.,**	**57 Abb.,**	**2 Tab.**	**Ehrenkolloquium für Dr. G. Schwab**
1997, Heft 2,	**96 S.,**	**61 Abb.,**	**14 Tab.**	
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1999, Heft 2,	**80 S.,**	**34 Abb.,**	**5 Tab.**	**Lithofazieskartenwerk Quartär (DDR)**
2000, Heft 1/2,	**196 S.,**	**121 Abb.,**	**23 Tab.**	**Quartär, Inlandeistheorie**

Geologische Karten zum Land Brandenburg (Auswahl)

Geologische Übersichtskarte des Landes Brandenburg 1 : 300 000
- Geologische Grundkarte (GÜK 300); 15,34 €
- Tiefenlinienkarte der Zechsteinoberfläche (GK 300 Z-OK); 10,17 €

Satellitenbildkarte des Landes Brandenburg 1 : 300 000, 7,00 €

Bodenübersichtskarte des Landes Brandenburg 1 : 300 000
- Bodengeologische Grundkarte (BÜK 300); ca. 13,00 €

Karte der oberflächennahen Rohstoffe Steine und Erden des Landes Brandenburg 1 : 300 000 (KOR 300), 2. überarb. Aufl.; 20,00 €

Geologische Karte von Berlin und Umgebung 1 : 100 000
- Geologische Grundkarte (GÜK 100); 7,00 €
- Karte ohne Quartär mit Darstellung der Tiefenlage der Quartärbasis (GKoQ); 12,73 €

Bodengeologische Karte 1 : 50 000 (BK 50),
Blatt L 3744 Potsdam; 10,17 €

Hydrogeologische Karte 1 : 50 000 (HYK 50)
Blatt L 3744 Potsdam, bestehend aus:
· Hydrogeologischer Schnitttafel (HYK 50-S); 15,00 €,
· Karte der oberflächennahen Hydrogeologie (HYK 50-1); 15,00 €,
· Karte des weitgehend bedeckten Grundwasserleiterkomplexes GWLK 2 (HYK 50-2); 15,00 €,
Alle weiteren Blatt-Nr. werden als Plots zu einer Gebühr von 10,00 € pro Einzelkarte herausgegeben.

Rohstoffgeologische Karte 1 : 50 000, Karte der oberflächennahen Rohstoffe (KOR 50),
flächendeckend für das Land Brandenburg, 88 Karten, je Plott 14,00 €

Atlas zur Geologie von Brandenburg 1 : 1 000 000, 2. erw. Aufl.; 25,00 €

Weitere thematische Karten sowie ältere Unterlagen sind im Archiv des LGRB auf Anfrage verfügbar.
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