Brandenburgische Geowiss. Beitr.	Kleinmachnow	8 (2001), 1	S. 43-47	13 Lit.

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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