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Recent vertical movements (map 4)

Neogeodynamica Baltica IGCP-Project 346

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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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