West Bohemian Seismoactive Region between 1993-1996: Crustal Movements, Gravity and Groundwater Level Changes

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Characteristics of the region

Western part of the Bohemian Massif has an extraordinary position in Central Europe from the point of view of recent geodynamic activity. It is characteristic namely in periodical occurrence of intraplate earthquake swarms, juvenile carbon dioxide waters, mineral springs, mofettes, young Quaternary volcanism, steep gravity gradient, and increased heat flow. The 1985/86 strong earthquake swarm initiated a systematic seismological investigation of the region which enabled to define the zones in which the seismic activity concentrates. The Nový Kostel epicentral zone has a dominant position in the seismicity of the whole region (Horálek et al. 1996). In 1993/94, several years after completing local networks of seismograph stations, monitoring of three important quantities gradually started: recent crustal movements, groundwater level, and gravity.

Recent crustal movements

Advanced GPS data processing permits determination of the relative horizontal positions of measured points with a precision 0.5 cm and relative heights with a precision of 2.0 cm. The GPS measurements were accompanied by precise levelling in the most active epicentral zone of the region. The distribution of measuring points respected positions of main geological units, traces of deep tectonic faults, local geomorphology, distribution of earthquake epicentres, and fault plane solutions. At measuring points, special bases were built to enable the compulsory centring of the GPS antennas. The measurements were performed twice a year (spring - autumn) by Trimble receivers with session length of at least 6 hours. Data from all campaigns were processed by the Bernese GPS software. The precise levelling measurements were carried out on a profile across the most active area of Nový Kostel. Horizontal shifts of the measuring points only seldom exceeded 10 mm between subsequent campaigns; such values do not considerably exceed the accuracy of the method. No clear tendency of displacement - either horizontal or vertical - of geological blocks can be derived from the results. Average horizontal displacement of crustal blocks > 5 mm/year would be probably revealed by GPS measurements in the period of 1993-96. It means that only average horizontal displacements less than 5 mm/year could occur in the region in the period 1993-96.

Groundwater level monitoring

These measurements were performed in 2 hydrogeological wells - well H3 (depth 120 m) at Křižovatka, 5 km afar from the epicentral zone of Nový Kostel, and well AD3 (depth 78 m) at Adorf, 7 km afar from the epicentral zone Kopaniny/Bad Elster. Both localities have been equipped with a digital recorder, working with a sampling frequency 1 hour and an accuracy of 1mm. The groundwater level in the well AD3 displayed distinct tidal changes with the amplitude of 2-3 cm. The groundwater level in well H3 in the Cheb Basin shows a remarkable coincidence with the occurrence of December 1994 earthquake swarm, which took place in the Nový Kostel epicentral zone only 5 km apart. To explain the link between water level behaviour in H3 well and earthquake occurrence in the Nový Kostel zone is a subject of our future effort.

Gravity changes

Systematic gravimetric observations has been performed on a profile across the Nový Kostel and Skalná epicentral zones. The profile issues from the area of precise levelling measurements and connects seven GPS points. According to the character of the differences in gravity, which is not random, the measuring points could be divided into 3 groups, each with a distinct position to the Mariánské Lázně fault. There is an apparent difference in gravity variations between the points south-west and north-east of the main fault zone respectively. A correlation between gravity changes and seismic activity shows that the gravity rises to maximum before the peak of the seismic activity. The gravity changes should be connected with inner dynamic processes in the rock massif of the upper crust.

Conclusions

Simultaneous monitoring of groundwater level, gravity changes and recent crustal movements were successfully introduced in the West Bohemia seismoactive region. Several changes of measured quantities apparently reflected tectonic processes in the upper crust. To get more definite results and their unambiguous interpretation, it will be necessary to maintain the measurements in a comparable extent at least until an occurrence of stronger earthquake activity of an order of the 1985/86 earthquake swarm (our current project is ensured by the year 2002).

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References

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Complex Metamorphic Zonation of the Thaya Window: Result of Buckling and Gravitational Collapse of Imbricated Nappe Sequence

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The nappe pile in the southern Thaya window shows an inverted metamorphic zonation ranging from biotite to sillimanite zones. For explanation of the inverted metamorphic zonation in this region a model of imbrication of metamorphic zones associated with their passive deformation was suggested. Whatever the mechanism of inversion, the metamorphic isograds should be subparallel to lithotectonic boundaries in trend and often also in dip. However, the straight NNE trending mineral zones cut the regional structures in the south and in the north. The evolution of inverted metamorphic zonation implies that the oblique angular relationship between metamorphic zones and lithotectonic boundaries appearing in the present erosional section must be produced by a later post-peak effect. We suggest a model involving folding of Moravian nappes that is supported by the following structural and metamorphic evidence:

1) The stretching lineations exhibit a constant SW-NE direction while the foliation planes follow the S shape of the western part of the Thaya window. The synmetamorphic kinematic indicators show top to the NE thrust movements in the southerly dipping dip-slip domain in the south, dextral movements in the western strike slip domain and normal fault movements in the northern termination of the Thaya window. This suggests that the early kinematics are refolded by a large scale antiformal fold with an axis gently dipping to the west.
2) If the nappe sequence with previously developed inverse metamorphic zonation is folded and subsequently cut by a horizontal section the high grade rocks occur in the hinge zone and lower grade rocks in the limb regions. Consequently, the metamorphic zones cut obliquely the individual lithotectonic boundaries so that the metamorphic grade increases towards the hinge zone.

From the observations presented above, we can conclude, that the structure of the Thaya window could be viewed as a large scale antiform with wavelength of 40 - 45 km. Thermal, rheological and fold calculations document and explain mechanism of folding of large scale crystalline nappes. The basic assumption for the model is that the nappes were transported upwards sufficiently rapidly to retain the temperature necessary for their viscous behaviour.

We suggest that in the depth of 15 km of the exhumation path starts the buckling of the Moravian nappe pile and that its wavelength is controlled by the Bíteš orthogneiss because: 1) the Bíteš orthogneiss is the thickest competent layer, 2) the viscosities of the Bíteš and the Weitersfeld orthogneiss became equal and, 3) the viscosity of medium embedding the Bíteš orthogneiss (underlying and overlying metasediments) became homogeneous. Calculated fold wavelength of 38 km is in good agreement with observed wavelength of the Thaya antiform 40 - 45 km.

The depth 15 km of initiation of folding roughly coincides with the depth estimate of 18 km for the burial of the autochthonous Thaya granite. At this depth the autochthonous Thaya granite acted as a buttress which inhibited further nappe thrusting and enhanced buckling of the multilayer system.

The style of folding of the Moravian nappes multilayer sequence is controlled by relatively low ductility contrast ($\mu_{albite}/\mu_{quartz}$) and moderate ratio of incompetent to competent layers. As the competent layers of Bíteš and Weitersfeld orthogneiss lie close to each other, then harmonic fold assemblage is developed.

A relatively low viscosity contrast could be responsible for an important modification of the fold geometry leading to thickening of both competent and incompetent layers in the hinge zone and thinning in the fold limbs. The flattening of megafold limbs is well documented by a similar fold geometry and also by finite strain studies which show oblate strain ellipsoids in limb regions and plane strain fabrics in fold hinge.

The folding of crustal nappes along inclined surface is responsible for a rapid elevation of the fold hinge to supracrustal levels due to horizontal shortening. The overlying thick nappe of Moldanubian migmatites cannot be folded and is therefore affected by extensional faulting along fold limbs. This huge extensional to transtensional faults transport high grade Moldanubian rocks at the direct contact with medium grade Moravian nappes. Extensional faulting also affects the Moravian units and results in reduction of their thickness in the northern and southern parts of the window. The extensional faulting is accompanied by the development of medium-scale gravitational folds in highly anisotropic parts of Moravian nappes and do not affect the whole crustal multilayer.