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Lithospheric Structure of the Carpathian Mountains, Pannonian basin and Eastern Alps Based on Seismic Data

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The network of seismic refraction profiles in the Central Europe covered now the area from the East European craton (EEC), along and across the Trans-European suture zone (TESZ) region in Poland to the Bohemian massif, and through the Carpathians and Eastern Alps to the Pannonian basin. The resulting seismic velocity models show strong variations in crustal and lower lithospheric structure (*Brueckl et al.,* submitted; *Grad et al.* 2006; *Środa et al.* 2006). In the Pannonian basin crustal structure is relatively simple. Beneath the sedimentary layer, two almost homogeneous crustal layers are observed with velocities 6.1–6.2 km/s in the depth interval 5–18 km, and 6.3–6.6 km/s in the lower crust. In this area, the Moho lies at depths of only 24–25 km.

In the Eastern Alps crustal thickness varies between 40 and 50 km. The most complicated structure is observed in the transition from the Pannonian basin to the EEC, which includes the Carpathians and the TESZ. In this area, the sedimentary cover with low velocities (Vp<5.5 km/s) reaches a depth of ~20 km, and the Moho deepens to ~50 km. Further to the northeast, the crustal structure of the EEC is typical for cratonic areas, with a thin sedimentary cover and a three-layer crystalline crust with velocities of 6.0–6.4 km/s, 6.5–6.7 km/s and 6.7–7.0 km/s, respectively. The depth of the Moho for the EEC varies between 42 and 48 km. Beneath the Moho lower lithospheric reflectors were found at depths of ~15 km beneath the Moho and at several deeper intervals.

The longest profile CEL05 (1420 km) shows clear crustal thickening from the Pannonian basin to the TESZ region, together with the configuration of the lower lithospheric reflectors. This result suggests northward subduction of mantle underlying Carpathian-Pannonian plate toward the north under the European plate. *Książkiewicz* (1977) postulated that subduction of the Pannonian lithosphere under the East European craton occurred during the Jurassic–Early (Lower) Cretaceous. In their paleogeographic reconstruction of the circum-Carpathian area *Golonka et al.* (2003) also proposed that north-northwestward subduction of the Meliata-Halstatt Ocean crust was completed by the end of the Jurassic, ~140 Ma ago and that the location of this closure corresponds to the Mid-Hungarian line. The northward subduction however conflicts with strong geological evidence for southward subduction, and we present three tectonic models for the CEL05 area, that are to not totaly mutually exclusive, to explain the lithospheric structure of the area: (1) northward "old" subduction of the Pannonian lithosphere under the East European craton in the Jurassic-Lower Cretaceous, (2) a collisional zone containing a "crocodile" structure where Carpatho-Pannonian upper crust is obducting over the crystalline crust of the EEC and the Carpathian-Pannonian mantle lithosphere is underthrusting cratonic lower crust, and (3) lithosphere thinning due to the effects of Neogene extension and heating with the slab associated with "young" subduction southward in the Miocene having been either detached and/or rolled-back to the east. In the last case, the northwestward dipping in the lithosphere can be interpreted as being due to isotherms that could represent the lithosphere/asthenosphere boundary in the Pannonian region.

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Tectonic Setting of Sokolov Basin in Relation to Prediction of Thermal Water Discharge Zones

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The study area – the western part of the Eger Rift (the Sokolov basin) – belongs to the European Cainozoic Rift System (Kopecký 1978, Sengör 1995, Prodehl et al. 1995, Adamovič and Coubal 1999, Dèzes et al. 2004). This system of graben structures and intraplate volcanic fields spreads over a distance of some 1000 km, including the French Massif Central, the Upper Rhine Graben, the Eifel, the North Hessian Depression, the Vogelsberg, the Eger Rift and the Elbe Zone. Graben structures evolved on top of uplifted basement blocks (Variscan massifs); Tertiary and Quaternary volcanism is mainly concentrated on the flanks of these graben structures along boundary faults or on the adjacent uplifted blocks. Dominantly (ultra-) alkaline, but also more evolved, magmas were erupted. The main rifting phase with incipient graben formation and voluminous intraplate alkaline volcanism lasted from about 42 Ma to 9 Ma. A detailed overview of the Cainozoic volcanic activity in the western part of the Bohemian Massif is given by Ulrych et al. (2003). The most recent expressions of magmatic activities within the European Cainozoic Rift System are the CO_2 degassing fields. The isotope (He, C, and N) composition of CO_2-rich gas emanations of mineral springs and mofettes from the western Eger Rift (Weinlich et al. 1999, 2003) gives evidence for the ascent of gases from fluid reservoirs in the European subcontinental mantle.

The Sokolov Basin is also a place of collision between long-term coal mining and spa Karlovy Vary protection. Both the technology and the method of coal mining in Sokolov Basin are strongly limited due to the existence of Karlovy Vary thermal springs resources that have priority importance. Considering that from the structural and geological point of view, the geohydrodynamic systems of these resources form one single structure, extending as far as the Sokolov basin brown coal deposits, the possibility of natural barrier layers being negatively impacted by human activity (i.e. mining technology in existing protection zones – especially in areas of hydrogeologically active faults and joint systems) is extremely strong (Trčková et al. 2000). This has also become evident recently in the case of uncontrolled opening of some old exit paths (old drills, old mining works, etc.) that had to be solved as emergency or warning states in relation to Karlovy Vary thermal springs. This problem may only be solved by conducting complex structural-tectonic analysis, based on parallel interpretation of geophysical methods followed by regional hydrogeological prospecting.

The Sokolov Basin proper is a bilaterally tectonically limited, transversally asymmetric depression, extending in WSW-ENE direction. In NW it is limited by the Krušné Hory Fault and also characterised by a system of minor parallel faults (especially the Lipnice, Grasset, Sokolov and Nové Sedlo Faults), forming a significant tectonic zone of lithospheric range (Ziegler 1990). According to Adamovič and Coubal (1999), most of this system's accompanying faults are younger than the main stage of the Ohře Rift volcanic and sedimentary development.

Another significant fault system of the Ohře Rift are the faults running in NNW-SSE to NW-SE direction (in the Sokolov Basin these are faults following the Svatava, Chodov and Karlovy Vary faults). This system is especially intensively developed in the neighbouring Cheb Basin, forming part of Mariánské Lázně tectonic zone (e.g. Špičáková et al. 2000). The analysis of the Oharecký Rift filling has shown that some of these faults had already been active synsedimentary. In the area of Sokolov basin the Chodov fault zone striking NW-SE belong to this tectonic system. It interfered with SW limit (contact zone) of Variscan Karlovy Vary granite pluton and was reactivated later in post-rift stage.

Emphasised in the most recent studies of the Ohře Rift tectono-sedimentary development has been the significance of W-E faults that had already been active in the course of sedimentation as extension faults (Rajchl and Uličný 2000, Špičáková et al. 2000).

From the above it follows that the structural development and the current tectonic architecture of the Sokolov Basin, similarly as to the entire Oharecký Rift, have been affected by several basic systems of normal faults, some of which show a less significant strike-slip component. Typical is above all the en-echelon arrangement of faults, horsetail-like virgation of faults, curvature in directional course, but also their normal fault listric geometry (se Fig. 1). Specific deformation conditions occur above