Chapter 1

Geological and tectonic setting

1.1 Regional overview

The Bohemian Massif is the largest coherent surface exposure of basement rocks in central Europe. It shows records of at least two orogenic phases: The Cadomian cycle spanned the period from Neoproterozoic to Cambrian. The Variscan collage and orogeny was active from Silurian to Permian times. It shaped a belt which extended from the Appalachian Mountains and Morocco/Northern Algeria via Western-, Central-, Southern Europe and Asia Minor to the Ural before the opening of the Atlantic ocean. It is now established that the Variscan belt resulted from the collision of two main continents – Gondwana to the south and Laurentia-Baltica to the north (*Matte,* 1986). Between these two continents, small microplates, separated by oceanic basins, drifted during the early Palaeozoic. Two main microplates have been defined as Avalonia and Armorica. Geological studies allow smaller microplates to be defined within Armorica (*Matte*, 1991; *Franke*, 2000). Between Avalonia and the Armorica microplate, the Rheic ocean was situated (*Matte*, 2001). Its closure led to the Variscan orogeny by collision of Avalonia plus Armorica with Gondwana.

During the period of plate convergence, each of the active margins developed into a separate band of the orogenic belt. Most of these separate bands can be traced across Europe. In central Europe, this led to a regional tectonic subdivision into the following zones from north to south (Figure 1.1): the Rhenohercynian, the Saxothuringian (subdivided into the Mid-German Crystalline High in the north and the Saxothuringian basin in the south), the Moldanubian including the unmetamorphosed sequences of the Teplá-Barrandian unit and the Moravo-Silesian. The main phase of folding, combined with metamorphosis, granite intrusions and uplift took place in the Carboniferous. While the outer parts of the Variscan orogen are mostly not or only weakly metamorphic, the central parts were stronger or highly metamorphosed.

Later phases of the collisional history were characterized by extensive intrusions of granites, followed by Late Carboniferous to Permian volcanism and renewed extension. The Variscan orogens had been leveled down by erosion already in Late Carboniferous/Permian times, and were subsequently covered by Permo-Mesozoic sediments.

In Mesozoic and Cenozoic times, the Bohemian Massif formed the northern foreland of the Alpine orogen. Alpine compression led to inversion tectonics and thrusting of basement blocks on top of Mesozoic strata (e.g. along the Frankonian lineament, Figure 1.2). Thus, large parts of the Bohemian Massif were uplifted during late Cretaceous reverse faulting (*Dallmeyer et al.*, 1995; *Zulauf*, 2005).

In Cenozoic times the European Cenozoic Rift System pervaded the lithosphere of western and central Europe over large distances (*Ziegler*, 1992; *Prodehl et al.*, 1995; *Dèzes et al.*, 2004). The widespread rifting and alkaline volcanism is often explained by effects of the Atlantic opening and Alpine orogeny. In the Bohemian Massif, the Variscan shear zones were reactivated during Cenozoic extension. This holds particularly for the Lower Carboniferous North Bohemian shear zone. Reactivative extensional slip along this shear zone led to the evolution of the Eger Rift (Figure 1.2), which is characterized by elevated heat flow, alkaline volcanism, active tectonics and recent escape of mantle-derived gas.

To the west, the Bohemian Massif is bounded by the Frankonian lineament (Figure 1.2), a NW trending, deep reaching system of reverse faults of late- to post-Variscan origin which was repeatedly reactivated until recently by Alpine Foreland deformation (*Wagner et al.*, 1997). Its continuation in the Moldanubian is a more extended fault system comprising mainly the Bavarian Pfahl and Donaurandbruch faults. Southwest of the Frankonian lineament, Permo-Mesozoic sediments cover the basement. The insufficiently

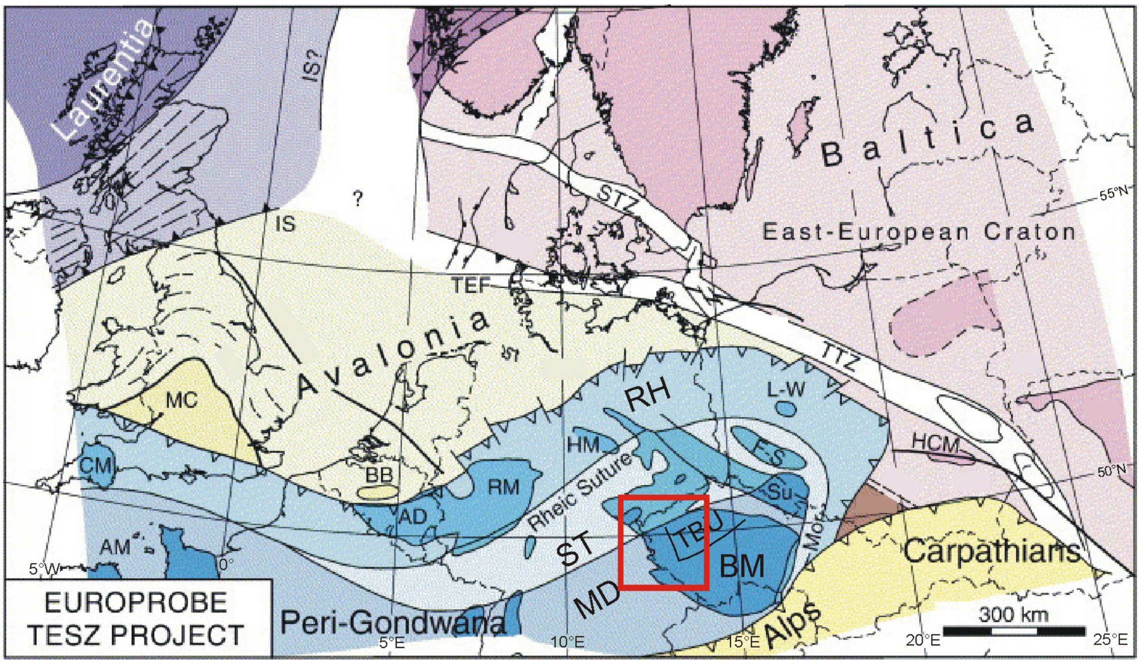

Figure 1.1: Structural sketch map of the northern Variscan Belt in central and eastern Europe and Palaeozoic terranes/continents, slightly modified from *Shomali et al.* (2006). The red rectangle shows the investigation area of this study. Key: AM – Armorican Massif, BB – Brabant Massif, BM – Bohemian Massif, CM – Cornubian Massif, F-S – Fore Sudetic Block, HM – Harz Mountains, HCM – Holy Cross Mountains, IS – Iapetus Suture (Avalonia-Laurentia), IS? – uncertain location of Laurentia-Baltica Suture, L-W – Leszno-Wolsztyn Basement High, MD – Moldanubian Variscan structural unit, MC – Midlands microcraton, Mor – Moravia, RH – Rhenohercynian Variscan structural unit, RM – Rhenish Massif, ST – Saxothuringian Variscan structural unit, STZ – Sorgenfrei-Tornquist Zone, Su – Sudetes Mountains, TBU – Teplá-Barrandian Variscan structural unit, TEF – Trans-European Fault Zone, TTZ – Tornquist-Teisseyre Zone.

constrained fault throw is estimated for different parts of the lineament between several 100 m to a few kilometres (*Franke*, 1989; *Freudenberger*, 1996). To the southeast, the Moldanubian region is bounded by the Moldanubian overthrust.

To explain the present thin overall lithospheric thickness beneath the Bohemian Massif, *Willner et al.* (2002) relate the fast exhumation of large volumes of high-pressure rocks from the crustal root after the closure of oceans to delamination and complete detachment of the lithospheric mantle. According to *Schott and Schmeling* (1998), subduction of the Rheic ocean between Avalonia and Gondwana in pre-Variscan time could have had enriched the subduction zones and the upper mantle involved in the Variscan orogeny with a significant amount of water. This might have led to weakening of parts of the Variscan orogenic root, propelling the delamination and detachment of the lithospheric root. *Zulauf* (1997) also uses the concept of lithospheric thickening and delamination in the Moldanubian area to explain the large amounts of plutons (partly derived from mantle melt) along the shear zones in the Moldanubian region. However, *Babuška and Plomerová* (2001) argue against large-scale detachment of the crust from the mantle lithosphere on the basis of their observations of the different orientations of the fabrics in the subcrustal lithosphere of the Saxothuringian and the Moldanubian, as well as the consistency of the fabric within each unit.

1.2 Geological setting of the western Bohemian Massif

1.2.1 Variscan structural units

The area of this study is situated at the junction of three Variscan structural units: the Saxothuringian in the north, the Teplá-Barrandian and the Moldanubian in the south (Figures 1.1 and 1.2).

The Saxothuringian unit consists of Variscan folded Palaeozoic sediments and a variety of Precambrian rocks that are discordantly overlain by unfolded Permo-Carboniferous sedimentary rocks (*Walter*, 1995). The Münchberg Gneiss massif, traditionally interpreted as part of the Saxothuringian zone, is now considered as Teplá-Barrandian allochthone nappe complex (*Behrmann and Tanner*, 1997). The Eibenstock, Fichtelgebirge and Karlovy Vary plutons are Variscan granitic intrusions into the upper Saxothuringian crust.

The Teplá-Barrandian unit consists of a Cadomic basement overlain by Late Cambrian to Devonian sediments and volcanic rocks (*Franke*, 2000). It forms a largely supracrustal complex which, in contrast to the surrounding Moldanubian and Saxothuringian high-grade units, was not affected by Carboniferous high-temperature/low-pressure metamorphism (*Dörr et al.*, 2002).

The contact between the Teplá-Barrandian upper crustal complex and adjacent lower crustal rocks of Moldanubia and Saxothuringia is formed by the Bohemian Shear Zone, a crustal-scale ductile shear zone that is characterised by sharp (up to 90 degrees) bends at the surface (*Zulauf et al.*, 2002a). These deflections of the Bohemian Shear Zone in map view (see Figure 1.2) are unusual and have led to a subdivision of the zone into the North Bohemian shear zone (the later Eger Graben and Eger Rift) (*Zulauf et al.*, 2002b), West Bohemian shear zone (the later Bohemian quartz lode) (*Zulauf et al.*, 2002a), Hoher-Bogen shear zone (*Bues et al.*, 2002) and the Central Bohemian shear zone (*Scheuvens and*

Zulauf, 2000). All these shear zones are characterised by a mylonite belt, dip-slip or oblique-slip normal movements and retrograde metamorphism during shearing (*Zulauf et al.*, 2002a; *Zulauf*, 1994). In former times, the Teplá-Barrandian unit was considered to be a superposition of the Moldanubian unit. Nowadays, the hypothesis that both units were originally spatially separated and that the Teplá-Barrandian might be closer related to the Saxothuringian unit is preferred. Thus, the contact between both units is considered to be a tectonic contact (*Schönenberg and Neugebauer*, 1997).

The term "Moldanubian" is used with two different meanings: the Moldanubian s.str. (sensu stricto) which is the largest unit within the Bohemian Massif, and the Moldanubian s.l. (sensu lato) as a zone of the regional tectonic subdivision of the Variscan belt of central Europe (see Figure 1.1). In the following, the term is generally used in the meaning "sensu stricto".

The Moldanubian is a complex association of rocks whose protolith ages are mostly unknown. The structure of the Moldanubian is dominated by large scale, thrust-related inversion of metamorphic facies, which has emplaced high pressure rocks (Gföhl Assemblage) over the paraautochthonous Drosendorf Assemblage (*Franke*, 2000; *Tollmann*, 1982). The Gföhl unit consists of various metaigneous and metasedimentary rocks, which include granulites, eclogites, and peridotites. The Drosendorf unit consists essentially of fairly monotonous metasedimentary sequences which include quartzites, graphitic quartzites, and carbonates.

1.2.2 Tectonomagmatic structures

The approximately 300 km long and 50 km wide ENE-WSW striking Eger (Ohře) Rift (Figure 1.2) is a tectonomagmatic active intracontinental rift with predominantly vertical movements (*Kopecký*, 1978). It is part of the European Cenozoic Rift System. The Eger Rift evolved at the Upper Cretaceous/Tertiary and reactivates the Variscan Saxothuringian-Moldanubian suture zone. Its tectonomagmatic evolution comprises several phases (e.g. *Ulrych and Pivec*, 1997; *Kämpf et al.*, 1999; *Špičáková et al.*, 2000; *Bräuer et al.*, 2005). The main rifting phase took place at 42-9 Ma, with beginning graben formation and intraplate alkaline volcanism. The Eger Rift is characterized by Miocene sedimentation and some basaltic flows. It showed volcanic activity mainly in the Tertiary and with low intensity in the Quaternary until about 0.3-0.5 Ma ago (*Wagner et al.*, 2002). During the Tertiary the small Cheb Basin developed at the western end of the Eger Rift (see Figure 1.2). The basin was initiated by reactivation of basement faults. It covers granites and Lower Palaeozoic series. The asymmetric basin is deepening towards east and limited there by the Mariánské Lázně fault, at the other sides Tertiary sediments overlap basement series (*Bankwitz et al.*, 2003).

At present, the rifting process is still active, which results in further formation of the Cheb basin, accompanied by CO_2 emanations at the surface in NW-Bohemia, southern Vogtland and eastern Fichtelgebirge area, neotectonic uplift in some southern parts of the rift flank and earthquake swarm activity in the Vogtland/NW-Bohemia area.

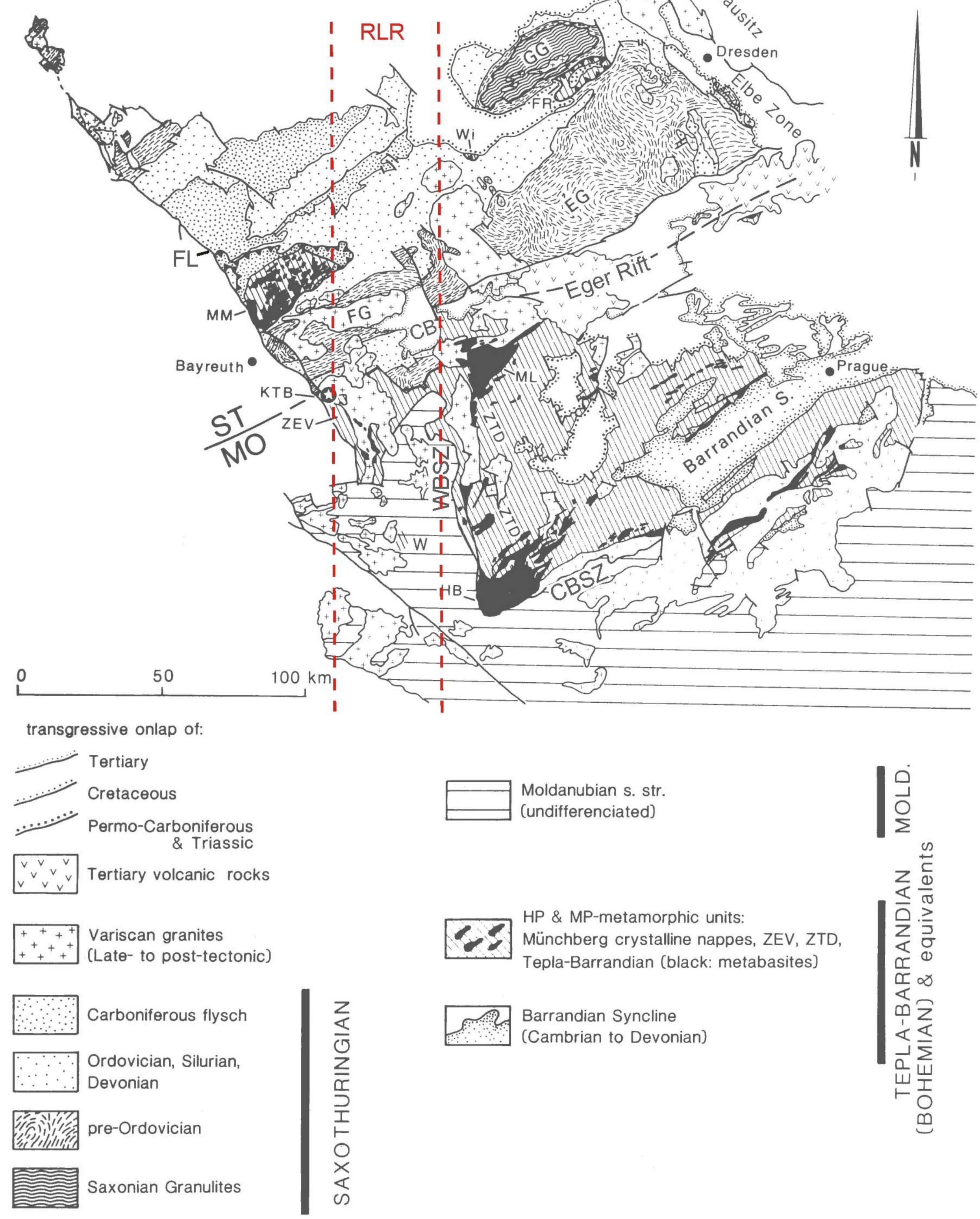

Figure 1.2: Structural map of the northwestern Bohemian Massif (slightly modified from *Franke et al.*, 1995). Abbreviations: ST Saxothuringian; MO Moldanubian region; FL Frankonian Lineament; WBSZ West Bohemian Shear Zone; CBSZ Central Bohemian Shear Zone; GG Saxonian Granulite Complex; MM, Wi, FR metamorphic klippe of Münchberg, Wildenfels, and Frankenberg, and underlying low-grade allochthons; EP, KP Eibenstock and Karlovy Vary plutons, CB Cheb basin, FG, EG antiform of the Fichtelgebirge and Erzgebirge; KTB Continental Deep Drilling Site; ZEV zone of Erbendorf/Vohenstrauß; ZTD zone of Teplá/Domazlice; W high-grade metabasites near Winklarn; ML Mariánské Lázně ophiolite; HB Hoher Bogen (Neukirchen-Kdyně) igneous complex; RLR (red) Regensburg-Leipzig-Rostock zone after *Bankwitz et al*. (2003).

The Regensburg-Leipzig-Rostock zone (Figure 1.2) is described by *Bankwitz et al.* (2003) as one of several prominent sinistral N-S running faulting zones within a belt between the French Massif Central and the northern part of the Bohemian Massif. It was defined on the basis of observations within satellite images (*Bankwitz et al.*, 2003). The Regensburg-Leipzig-Rostock zone is seismically active in its middle part (about 150 km between Cheb and Leipzig), where it consists of a set of subparallel faults. Its intersection area with the Eger Rift is known for geophysical and geological phenomena such as the occurrence of earthquake swarms, mineral springs and mofettes (dry gas outbursts), mantle-derived CO_2 emissions, increased heat flow, a steep gravity gradient, and Tertiary/Quaternary volcanism.

Two Quaternary volcanoes, Komorní Hůrka and Železná Hůrka, are located only 15 and 25 km away from the main epicentral zone at Nový Kostel. A detailed overview about Cenozoic volcanism in western and central Europe is given by *Wilson and Downes* (1991, 1992) and for the western Bohemian Massif by *Ulrych et al.* (2003).