ULTRAHIGH-PRESSURE METAMORPHISM IN THE BOHEMIAN MASSIF

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Summary

The Bohemian Massif represents one of the major exposed portions of the Late Palaeozoic Variscan orogen. It is situated in the northeastern edge of this orogen in eastern Central Europe. Like other Variscan basement areas, the Bohemian Massif is characterized by the duality of anchi- to low-grade metamorphic rocks and those of relatively high-grade. In the high-grade units quartzofeldspathic rocks dominate except for the presence of large Late Variscan S-type granitoid bodies.

Within such metamorphic rocks, felsic granulite and gneiss, several peridotite bodies occur in various parts of the Bohemian Massif. Although the appearance of garnet already points to the origin of these peridotites in the deeper upper mantle, very low Al contents of orthopyroxene prove the ultrahigh pressure (UHP) nature of this rock type. Lenses of medium to high temperature eclogites, although often broadly transformed to amphibolite or basic granulite, are relatively abundant in the high-grade metamorphic units of the Bohemian Massif. Due to numerous geochronological studies high-pressure metabasites formed in Early Devonian and Early Carboniferous times. Both events had led to UHP eclogites exposed in the Bohemian Massif. However, true indicators for UHP metamorphism such as high Si phengite or coesite are very rare. Thus, the peak P conditions for many eclogite lenses are hardly known.

The same is true for the felsic metamorphic rocks. So far, only one UHP occurrence of a metasediment was undoubtedly recognized through the appearance of abundant microdiamonds preserved in garnet, kyanite and zircon. This occurrence in the Saxonian Erzgebirge, situated in the northern Bohemian Massif, is, however, related only to a few lenses some hundred meters in length. Recent geodynamic models are summarized and discussed in regard to their explanatory potential for surficially exposed HP and UHP rocks.

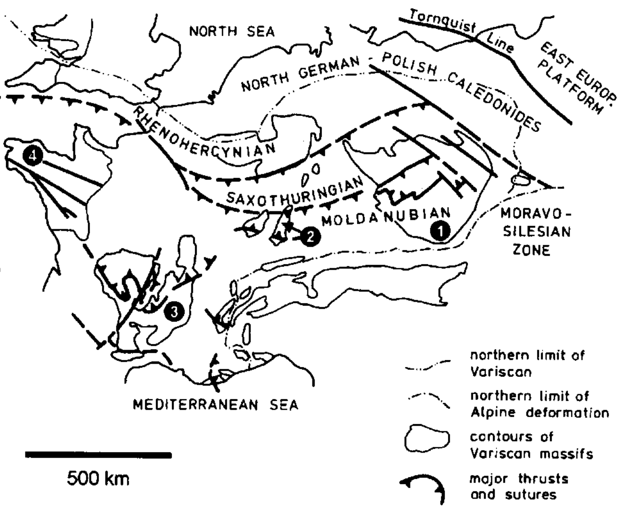

Fig. 1: Zones and areas of the Variscan orogenic belt in Middle and Western Europe simplified after Franke (1989). Among these areas, that are broadly uncovered by Post-Carboniferous rocks, are: 1 = Bohemian Massif, 2 = Schwarzwald, 3 = Montagne Noir, 4 = Armorican Massif.

Introduction

Rocks of the Late Palaeozoic Variscan orogen are exposed in wide areas of Europe except in its northern and northeastern portions where older rocks of the craton Baltica and the Caledonian orogen dominate. However, large parts of the Variscan belt are either covered with rocks of younger strata or were even involved in younger mountain chains such as the Pyrenees, the Alps and the Carphathians. The Bohemian Massif represents one of the major exposed portions of the Variscan orogen (Fig. 1). It is situated in its northeastern edge in eastern Central Europe. Like other Variscan basement areas, the Bohemian Massif is characterized by the duality of anchi- to low-grade metamorphic rocks and those of relatively high grade. In the high-grade units quartzofeldspathic rocks dominate except for the presence of large Late Variscan S-type granitoid bodies. Among these high-grade units there are those showing evidence for high-pressure metamorphism. In addition, we meanwhile know several localities where ultrahigh pressure (UHP) metamorphic rocks occur, for instance, proven by the occurrence of microdiamonds. The aim of this paper is to summarize such occurrences and to present recent geodynamic models possibly explaining their appearance.

Subdivision of the Bohemian Massif

The Bohemian Massif is a collage of numerous units characterized by different age and metamorphic evolution. This even holds true within one of the five major zones in Central Europe (see Fig. 1) called the Saxothuringian, the Moldanubian, the Tepla-Barrandian and the Moravo-Silesian zone and the Lugicum, to which the Western Sudetes belong to (Fig. 2). These zones, that at least partly belong to the Bohemian Massif, are separated by major faults and shear zones. Units of high-grade metamorphic rocks occur in close vicinity to almost non-metamorphic sediments with metamorphic and sedimentary ages being contemporaneous (Franke and Engel 1986). Fault and shear zones are also responsible for this situation (Matte *et al.* 1990) as well as former nappe tectonics probably is (Tollmann 1982). Concerning only the various medium to high-grade metamorphic units, a subdivision into those with low-pressure mineral assemblages and those with high-pressure signature is possible. Among the latter, two types different in age can be distinguished (see Fig. 2). Metamorphic ages related to the high-pressure event are either around 400 or 340 Ma (see Kröner and Willner 1998).

Occurrences of HP and UHP rocks in the Bohemian Massif

Lenses of medium to high temperature eclogites, although often broadly transformed to amphibolite or basic granulite, are relatively abundant in the high-grade metamorphic units of the Bohemian Massif. Numerous eclogite lenses exposed in the Münchberg Gneiss Massif were early studied petrologically (Matthes *et al.* 1975). Several studies followed (e.g. Franz *et al.* 1986; Klemd 1989). In the northwestern edge of the Tepla-Barrandian zone near Mariánské Lázně numerous relics of eclogites occur (O'Brien 1991; Beard *et al.* 1995). Furthermore, O'Brien *et al.* (1992) recognized retrograded eclogites in the Zone of Erbendorf-Vohenstrauß. Due to several geochronological studies the above mentioned high-pressure metabasites formed in Early Devonian times. Eclogites from the Śnieżnik dome (Glatzer Schneegebirge), that were, for instance, reported by Smulikowski and Smulikowski (1985), the Gföhl Unit (Medaris *et al.* 1998), the high-grade metamorphic units (Gföhl Unit *sensu latu*) located about 50 km southeast and 100 km south of Praha (Prague) described by Dudek and Fediuková (1974), and from the Granulitgebirge (Mathé 1969) formed in Early Carboniferous times. Both events had probably led also to UHP eclogites. However, true indicators for UHP metamorphism such as high Si phengite as reported from an eclogite of the Münchberg Gneiss Massif (Massonne 1993) or coesite that was only recognized by pseudomorphs for instance in eclogites from the Śnieżnik dome (Bakun-Czubarow 1992) are very rare. In most cases, the peak P conditions for the eclogite lenses are unknown.

Frequently associated with eclogites are numerous garnet peridotite bodies that occur in various parts of the Bohemian Massif. Bakun-Czubarow (1981) reported such rocks from the Sowie Góry (Eulengebirge). Occurrences in the Granulitgebirge were described by Rost (1961). Dobretsov *et al.* (1984) and Medaris *et al.* (1990) studied garnet peridotites from the Gföhl Unit. Although the appearance of garnet already points to the origin of these peridotites in the deeper upper mantle, very low Al contents of orthopyroxene occasionally prove the UHP nature of this rock type.

Felsic granulites and gneisses in the vicinity of eclogite and garnet peridotite lenses often show HP signature. Examples for such rocks yielding pressures around 20 kbar are granulites from the Sowie Góry and the Śnieżnik dome studied by Kryza *et al.* (1996) and metasediments from the Münchberg Gneiss Massif (Klemd *et al.* 1991). Typically, such rocks formed on a decompression path and did not conserve the mineral assemblage of the peak P conditions (see e.g. Carswell 1991).

UHP rocks of the Erzgebirge and their P-T evolution

The Variscan metamorphic area of the Erzgebirge (Krušné hory) in the eastern edge of the Saxothuringian zone can be subdivided into several major units. One of them is the Gneiss-Eclogite Unit (GEU) that dominates the central portion of the Erzgebirge. Within the GEU abundant eclogite lenses and several garnet peridotite bodies which have been mapped in detail more than hundred years ago (e.g. Hazard 1886) occur in various types of para- and orthogneisses. Maximum P-T conditions for the garnet peridotites were derived to be almost as high as 40 kbar and 1100°C (Massonne and Grosch 1995) or at least 33 kbar (Schmädicke and Evans 1997). Schmädicke *et al.* (1992) estimated maximum metamorphic temperatures of 800 to 900°C for the eclogites of the GEU. Somewhat lower temperatures were determined by Massonne (1994). Coesite pseudomorphs but no coesite relics have been reported by Schmädicke *et al.* (1992) from eclogites of the GEU. These were recently related rather to

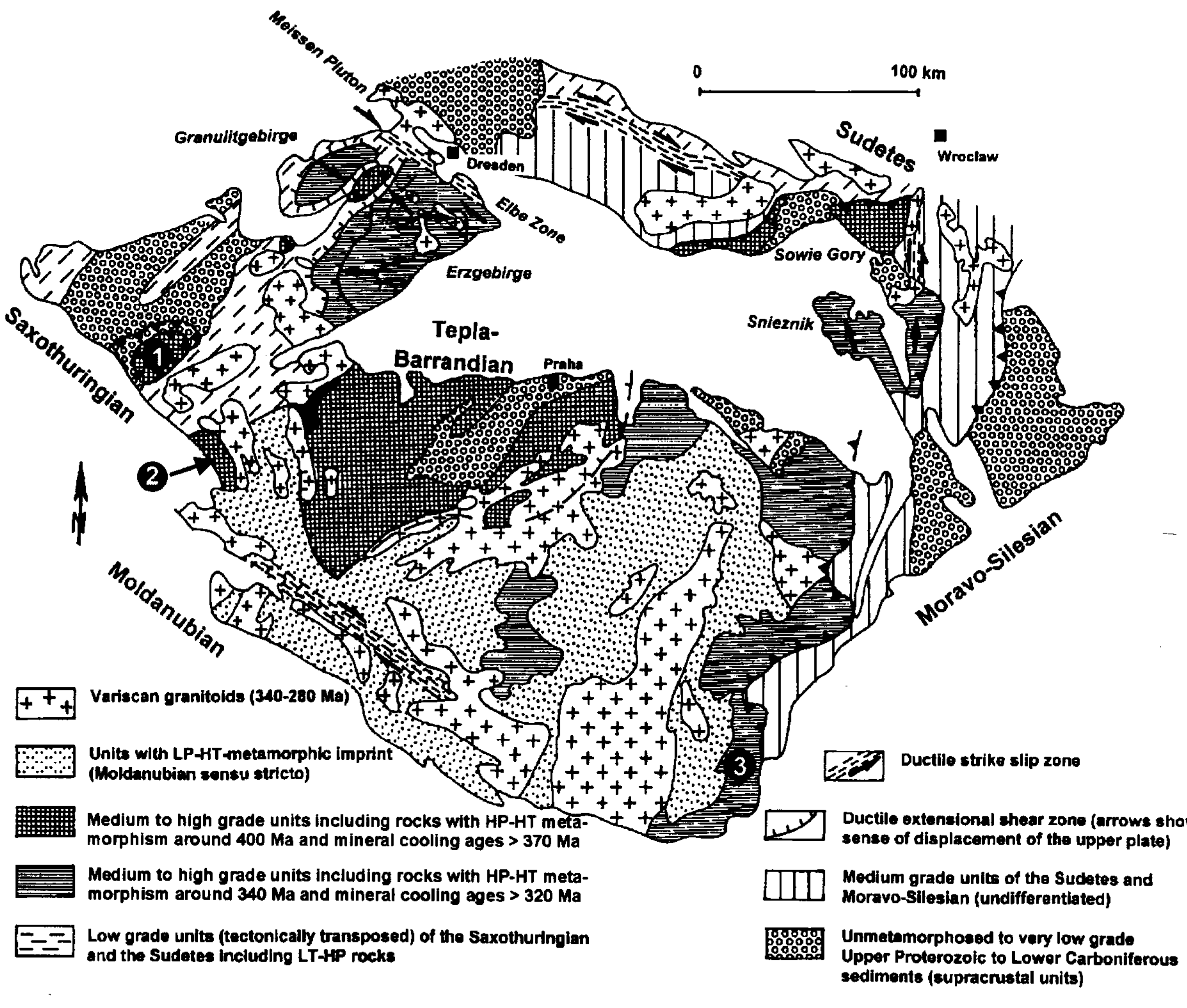

Fig. 2: Simplified geological map of the Bohemian Massif according to Willner *et al.* (2000a). In addition to major zones (bold) and areas, specific regions are marked: 1 = Münchberg Gneiss Massif, 2 = Zone of Erbendorf-Vohenstrauß, 3 = Gföhl Unit.

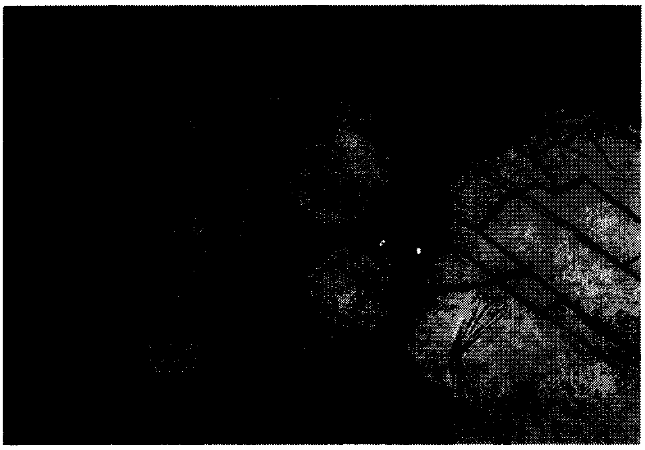

Fig. 3: Microphotographs of garnets (light) in diamondiferous gneisses from the Saidenbach reservoir, Saxonian Erzgebirge, taken under reflected light (Massonne 1999a). Garnet typically shows rounded shapes and enclosed microdiamonds discernible by their high reflectance and a striation pattern around them resulting from the polishing procedure. Image length is a) 3 mm, b) 0.2 mm.

pseudomorphs of K-cymrite (Massonne *et al.* 2000) because inclusions in omphacite, looking like coesite pseudomorphs, are symplectites consisting of quartz and K-feldspar. However, the lower pressure limit of the stability field of K-cymrite is similar to that of coesite (Massonne 1995). Very recently, coesite relics were recognized by Massonne (2000) in a fresh eclogite sample from the Saidenbach reservoir.

Gneisses of the GEU had experienced maximum P-T conditions of about 20 kbar and 800°C (Willner *et al.* 1997) in Early Carboniferous times (Kröner and Willner 1998). In rocks from several lenses of weakly foliated garnet-muscovite gneiss occurring in the easterly portion of the Saidenbach reservoir area about 1.5 km northwest of the village of Forchheim, Massonne (1999a) detected microdiamonds as inclusions in garnet, kyanite and zircon (Figs. 3a and 3b). The true inclusion character of these microdiamonds was proven by micro-Raman spectroscopy (Nasdala and Massonne 2000). The P-T evolution of the corresponding rock (Fig. 4) was derived from compositional zonation of garnet, where the microdiamonds occur in a specific compositional zone, from the composition of phengites that appear as inclusion in garnet and in the matrix and from additional observations.

Geodynamic models involving HP and UHP rocks

The Variscan orogen is the result of a collision between Baltica, Laurentia and Gondwana as well as microplates such as Armorica. HP and UHP metamorphism is, for instance, explained by stacking of large crustal segments during a process related to subduction of plates (Matte 1998). During a late stage between 340 and 320 Ma, the thickened crust of this orogen collapsed leading to a thinner almost equilibrated crust. Due to oblique plate convergence, different crustal blocks also representing various

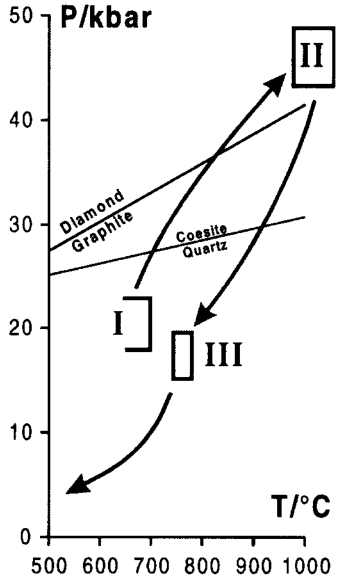

Fig. 4: P-T evolution of the diamondiferous gneisses from the Saxonian Erzgebirge somewhat modified after Massonne (1999a) due to new results of Massonne (1999b).

crustal levels were bound together mainly by strike-slip faults (Krohe 1996; Zulauf 1997). Recently, Willner *et al.* (2000a, 2000b) presented a model that explains the exhumation of crustal segments from the base of a thickened crust within some Ma.

Conclusions

UHP metamorphic rocks are, so far, known from a few localities within the Bohemian Massif only. However, if we would more often succeed to decipher the P-T conditions of early metamorphic stages, it might be that we recognize UHP rocks in wide distribution even in the entire Variscan belt, because in other Variscan massifs HP rocks are also widely distributed. This task which also requires progress in geothermobarometry is necessary to understand the corresponding geodynamic processes. At the moment, it is not clear if there was once a Variscan crust extremely thickened to 140 km and then rapidly exhumed (Willner *et al.* 2000b) or if there was a fluid driven mechanism to exhume small portions of crustal and mantle material from a subduction zone environment to the base of a crust thickened to only 70 km (Massonne 1999a, 1999b).

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