1. Introduction

Granulites exposed on the earth's surface and found as xenoliths in basaltic volcanic rocks provide important information on the nature of the lower crust, as well as on the processes associated with crustal growth. Preserved high-grade mineral assemblages and successive lower pressure and/or high temperature overprints in granulites represent clues to the reconstruction of their P-T-t paths.

Bohemian Massif, which belongs to the Hercynian belt of central Europe (Fig. 1.1) is rich in granulite rocks occurrences. In its N part, granulites are present not only in Saxony and Erzgebirge in Germany, but also in the north Bohemian crystalline basement (Fig. 3.1). This work is concerned with the latter ones, encountered in the České středohoří Mts. area, on the E slope of the Erzgebirge (Krušné hory Mts.) and in the Ohře crystalline area. Previous studies in this area consist mainly of mapping (e.g. Hibsch 1920, Sattran & Kopecký 1967), petrography (e.g. Zartner 1929, Sattran 1967) and geochemistry (Fiala 1965, Rost & Grigel 1959). The key geographical position of the high-grade rocks studied in the axial zone of the Variscan orogenic belt accentuates their importance in the construction of geodynamic model of the belt.

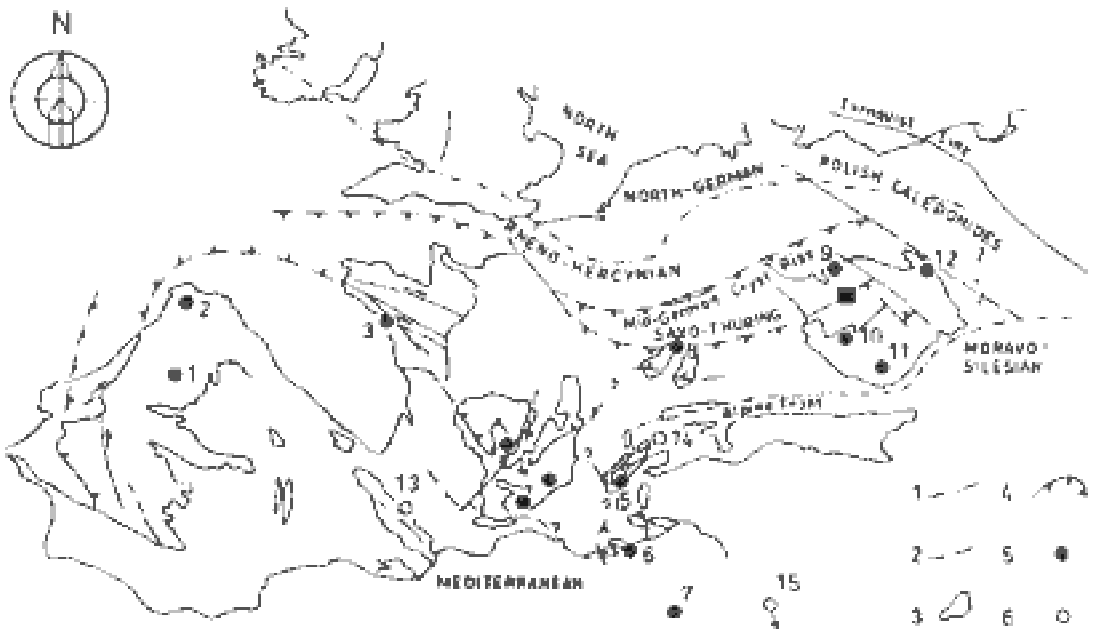

Fig. 1.1 Main structural elements of the Variscan belt of Europe, with indicated outcrops of Variscan basement and granulite occurrences, including the position of the studied area (black square). Compiled according to Franke (1989) and Vielzeuf & Pin (1989). 1+2 - outer limits of Variscan and Alpine deformation, resp.; 3 - contours of Variscan massifs; 4 - major thrusts and suture zones; 5 - type I granulites; 6 - type II granulites; numbers 1 to 15 correspond to: 1 - Braganca-Morais Complex of Northern Portugal, 2 - Western Galicia Complex, 3 - Southern Brittany, 4 - Massif Central, 5 - External Crystalline Massifs of Western Alps, 6 - Maures Massif, 7 - Corsica-Sardinia Block, 8 - Vosges-Schwarzwald Massif, 9 - Saxony, 10 - Bohemia, 11 - Lower Austria, 12 - Polish Sudetes, 13 - North Pyrenean Zone, 14 - Ivrea Zone, 15 - Southern Calabria.

The interpretation of these granulite occurrences is closely related to the problems of granulites in general, such as:

- autochthonous or allochthonous character of units containing granulites (Harley 1989, Vielzeuf & Pin 1989)
- protoliths and the nature of granulites, character of lower crust, proportion of ortho/para-derived and acid/basic rocks in lower crust (Vielzeuf 1984)
- relation between granulites and granites (Clemens 1990, Vielzeuf et al. 1990)
- depleted or undepleted character of granulites (Rudnick & Presper 1990)
- role of dehydration or partial melting (Thompson 1990, Vrána & Jakeš 1982, Vrána 1989) and CO_2-rich fluids infiltration (Newton 1989, Frost et al. 1989) in the formation of granulites
- validity of PT estimates in granulites (Frost & Chacko 1989, Kotková 1991)
- P-T conditions of granulite metamorphism (Bohlen 1987, vs. Harley 1989), evolution of granulites (reaction textures), significance of P-T-t paths in granulites (Harley 1989)
- relation of granulites to the retrograde P-T-t paths of eclogites
- ages of granulite metamorphism (Pin & Pecaut 1986, Vielzeuf & Pin 1989, Mezger 1990)
- relation of granulite formation to tectonic and metamorphic phases of a region, geodynamic interpretation (here constrained to the Variscan belt; Vielzeuf 1984, Carswell 1991, Rötzler J. 1992, Vrána 1992)
- interactions between lower crust (granulites) and upper mantle (peridotites) (Jakeš et al. 1985, Carswell & Cuthbert 1986, Medaris & Carswell 1990, Gardien et al. 1990)

Particular questions concerning the studied area are:

- Do the granulitic occurrences represent a single body or several ones?
- What are their relations to their host rocks and neighbouring units (Krušné hory Mts. crystalline complex)?
- What implies presence of granulite complex rocks at the northern limit of the axial zone of the Variscan belt (Variscan reactivation and/or heritage of Cadomian basement)?
- Is the nature, P-T of metamorphism and evolution compatible with other granulite occurrences in the Bohemian Massif and the Variscan of Europe?

The aim of this work is to bring some answers on above given questions.

2. Geothermobarometry and P-T-t paths in granulites

Granulites represent a good material for geothermobarometry because of the prevalence of unhydrous phases in granulite facies and availibility of thermodynamic data for these phases. Moreover, preservation of reaction textures in these rocks is very useful for the determination of the P-T trajectory. Other important indicators of the P-T path are inclusions of earlier phases in minerals and mineral zonation. The basic principle of the analysis of P-T-t paths is the assumption that the rock records the succession of equilibrium states, which can be analysed using equilibrium thermodynamics (Spear 1989). Reconstruction of the P-T path is conditioned by the definition of pre-, syn- and post-tectonic assemblages (Spry 1969, Vernon 1978), and facilitated by experimentally derived petrogenetic grids (e.g. Thompson 1976b, Vielzeuf & Boivin 1984).

P-T paths followed by metamorphic rocks reflect a complex interplay of tectonics and heat flow (Spear et al. 1984). Metamorphism is constrained to tectonically active belts with increased heat flow, i.e. areas of active plate margins. It is often related to thickening and thinning of the continental crust, and processes such as burial and uplift of the rocks. The shape and sense of the P-T paths are good indicators of processes that contribute to the formation of the rocks.

Recent reviews of P-T metamorphic conditions and P-T-t paths of granulites worldwide show their large variability, reflecting numerous processes leading to their formation (Harley 1989). It is now obvious that P-T conditions of granulite metamorphism are not restricted to the P-T box advocated by Bohlen (1987).

There are basically two types of P-T paths following the peak metamorphism observed in granulites - isobaric cooling (IBC) and isothermal decompression (ITD). These trajectories can be preceded by variable processes, corresponding both to collisional and extensional environment. These processes are indicated by prograde P-T paths, that together with the retrograde one defines a sense of the path. It has been shown that this sense can be 'clockwise' (T_{max} before P_{max}) or 'anticlockwise'. The first type can be generated by many mechanisms (cf. Harley 1989), the second is commonly related to magmatic accretion (cf. Bohlen 1987).

Peak of metamorphism is generally registered by the mineral assemblage in the rocks, as well as their retrograde reequilibration. Prograde portion of the P-T paths in granulites, however, is commonly obliterated due to high temperatures of granulite metamorphism (high diffusion rates). Then, tectonic processes have to be inferred based only on the post-peak segments of the P-T path. For such inferences, knowledge of structural relationships, timing of events, and geochemical data are necessary (see also Harley 1989).

This work makes use of the principles given above to constrain the tectonometamorphic evolution of the north Bohemian granulites.

3. General geology

All the granulite occurrences of the north Bohemia that were studied are situated in the vicinity of the Litoměřice Deep Fault, in the northern part of the Bohemian Massif. This fault represents an eastern part of a NE-SW trending fault zone, and it is considered a boundary between Saxothuringicum (NW) and Bohemicum (SE; Chaloupský 1989) (Fig. 3.1). Its significance as a deep-seated tectonic boundary is also supported by associated ultrabasic volcanic rocks (polzenites), by the presence of an important mylonite zone (Kopecký et al. 1961), and by the different character of the crystalline basement on both sides of the fault. The presence of high-grade rocks (gneisses, granulites) in the crystalline basement of the studied territory (NW block, Saxothuringicum) contrasts with that of the SE block (Bohemicum), with only low- to medium-grade metamorphism (Svoboda et al. 1966).

For the zone mentioned above, Kopecký (1971a in Kopecký 1987, 1988) introduced the term 'Ohře rift' (discussed in Kopecký 1986). The term 'granulite complex' has been used for highly metamorphosed rocks of the north Bohemian crystalline basement (e.g.Zoubek & Škvor 1963).

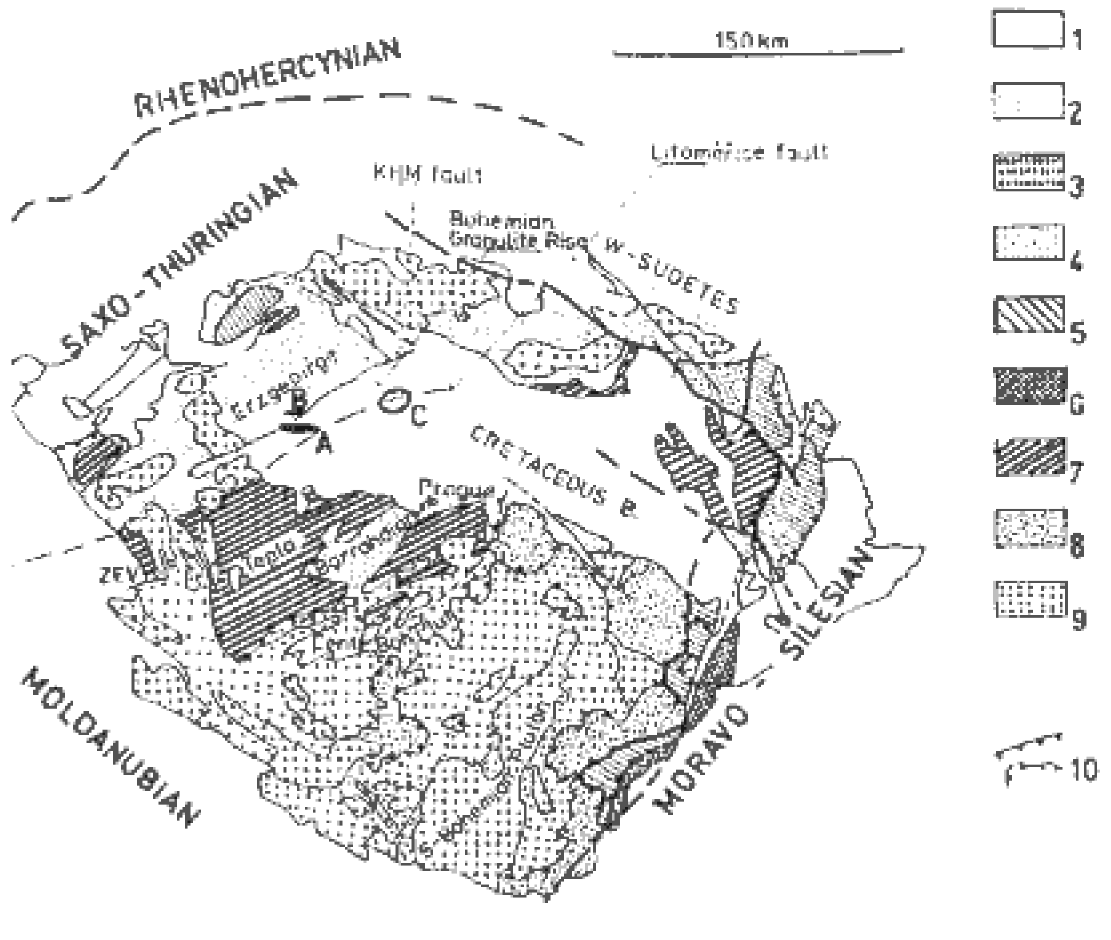

Fig. 3.1 Simplified geological map of the Bohemian Massif (according to Franke 1989), showing the position of studied areas (A - Ohře crystalline area, B - zone Blahuňov - Málkov, C - České středohoří crystalline basement). 1 - Devonian and Carboniferous sedimentary and volcanic rocks, unmetamorphosed, 2 - Pre-Devonian (including Precambrian), partly with Variscan metamorphism, 3 - Paleozoic rocks undifferetiated, partly metamorphosed, 4 - Variscan metamorphic rocks, 5 - Cadomian basement of the Moravo-Silesian, 6 - Cadomian basement (partly with Variscan reactivation) of the Teplá/Barrandian microplate, 7 - Gföhl unit of the Moldanubian region; Sowie Góry block; 8 - Drosendorf unit of the Moldanubian region, 9 - Variscan granites (largely post-tectonic), 10 - main thrusts (partly sutures).

Granulites and granulitic gneisses have been described in three separate areas (Fig. 3.1):

A. The Ohře crystalline area (cf. Zartner 1929; Append. I). Granulites and granulitic gneisses are exposed in the erosive window in young platform sediments and abundant Tertiary volcanic rocks along the Ohře river. They are associated with two-mica orthogneisses, strongly migmatized two-mica gneisses and migmatites. Granulites occur in morphologically distinct, but separate rock outcrops.

B. The zone Blahuňov - Málkov (cf. Holubec 1956; Fig. 3.2). Exposures of granulitic gneisses on the E slope of the Krušné hory Mts. Muscovite - garnet paragneisses and biotite to two-mica paragneisses represent the host rocks of granulitic gneisses. The granulite body is elongated in east-west direction, parallel to the foliation of the surrounding metasediments. Further south, an E-W elongated serpentinite body occurs (Sattran 1966).

C. České středohoří. Granulites are found in boreholes (cf. Kopecký & Sattran 1966) and as xenoliths in Tertiary volcanic rocks (cf. Ebert 1932). They are associated with garnet peridotites, garnet pyroxenites and amphibolite-facies gneisses (Shrbený & Ulrych 1988), and charnockites (Opletal & Vrána 1989). Two of the boreholes - T7 and RPZ31 - and some T38 borehole samples, were studied in detail. All the xenoliths investigated are acid kyanite-bearing granulites (localities Sviňky, Újezd u Trmic, Soběnice - surface exposures; boreholes T21, T32; provided by dr. Opletal and dr. Kopecký).