8.2.2 Mantle assemblages

Presence of large Ol and Opx porphyroclasts and the exsolution of spinel from clinopyroxene enclosed in large garnet grain (in dunite) may indicate higher T than calculated, which might correspond to the crystallization from the melt (c.f. Carswell 1991). However, no primary spinel was observed.

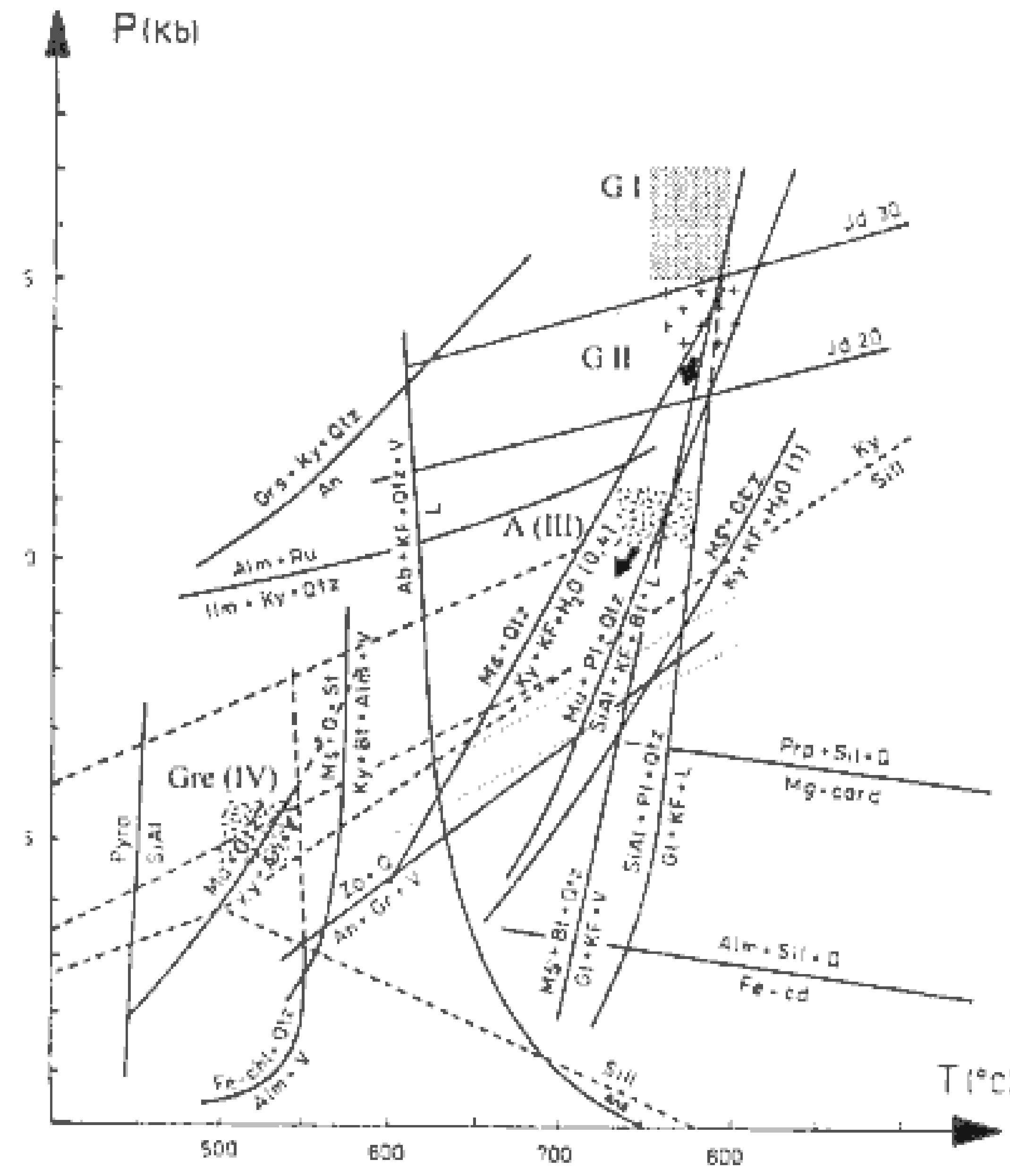

Fig. 8.4 P–T–t path of granulites. Al–silicate triple point according to Holdaway (1971). Reaction boundaries according to Vielzeuf (1984), Newton (1966), Koons & Thompson (1985), Hsu (1968), Chatterjee (1976), Thompson (1982), LeBreton & Thompson (1988), and Holdaway & Lee (1977). Phengite contents from Massone & Schreyer (1987), Jd contents from Gasparik & Lindsley (1980).

Garnet lherzolite stage (stage II; 'eclogite facies' of Carswell 1991) is characterized by temperatures of 859-1022°C and pressures of 28-33 kb (Tab. 8.8). These data represent minimum values, as mineral compositions might have undergone certain reequilibration during later cooling. 'Prograde' Mg zoning in central part of Grt in garnet pyroxenite could indicate prograde metamorphic conditions during the initial garnet formation.

Successive significant decompression is documented by formation of spinel-bearing coronas around garnets. Stage III (Grt+Spl coronas) is characterised by only slight pressure decrease (by 4-5 kb) and probably also some cooling. Presence of Spl-Opx-Cpx coronas (stage IV) places the rocks in the spinel stability field, with upper pressure limit of ca 20kb/1000°C (O'Hara et al. 1971). Additional analyses are needed to define precise pressures, which in case of a high Cr contents can be even higher than 20kb.

Striking is, that Spl coronas are absent in the rocks of lherzolitic composition, in contrast with the dunitic rocks. A viable explanation is that these structures were overprinted by the influence of intensive deformation and recrystallization - replaced by products of Opx, Spl and Ol breakdown reactions. This would be consistent with higher modal amount of Opx in lherzolites compared to dunites, and presence of chlorite ± amphibole ± talc rims around garnets in lherzolites.

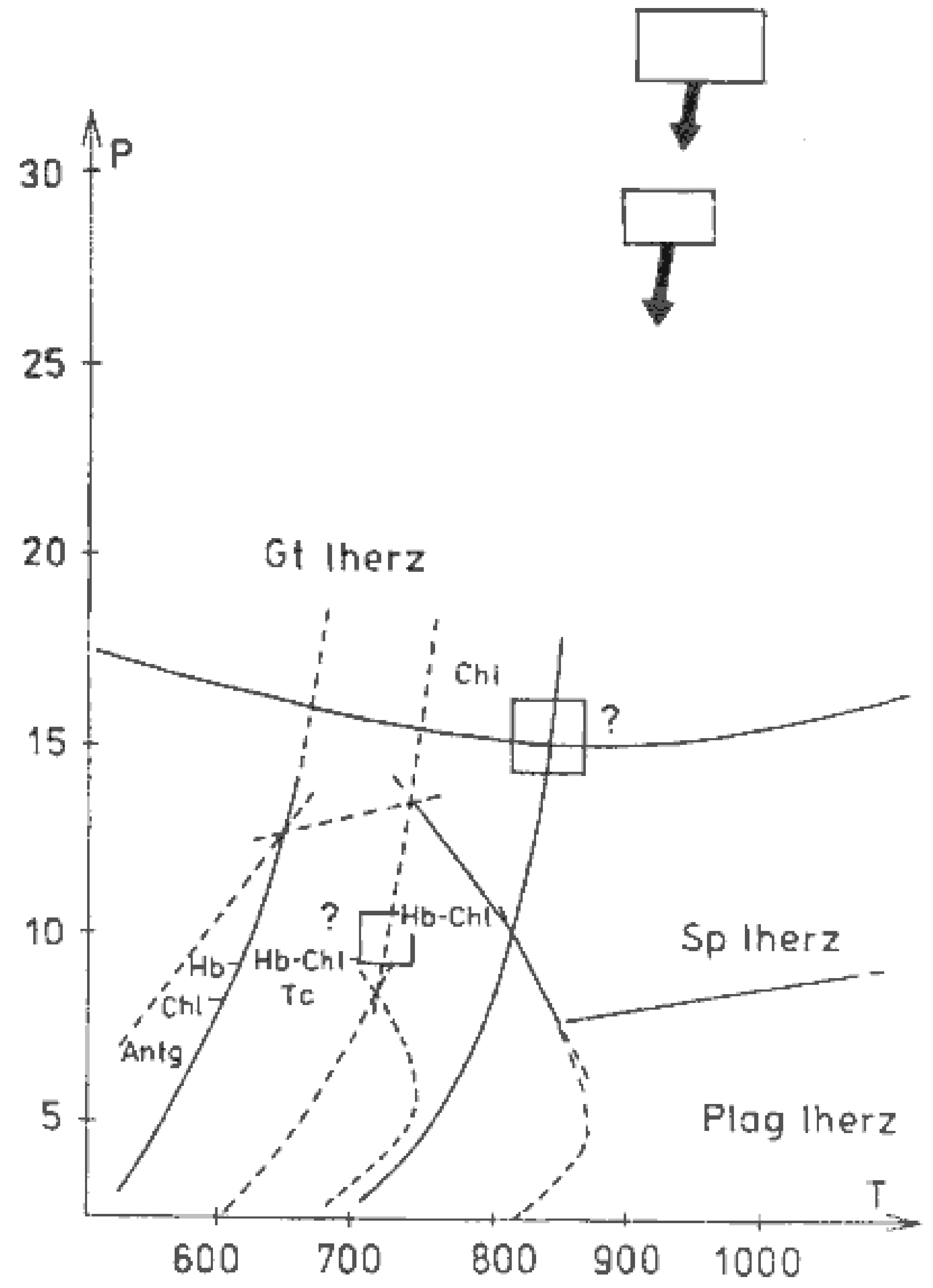

Fig. 8.5 P–T–t path of peridotites. Grid according to Jensen (1981).

P-T-t path of mantle assemblages is comparable to that of the crustal ones. It corresponds to initial near-isothermal decompression, followed by cooling under less significant pressure decrease (near-to-isobaric cooling)(Fig. 8.5).

9. Reconstruction of tectonometamorphic evolution

9.1 Interpretation of the P-T-t paths, tectonic implications

Calculated pressures of 17kb (~ 50km depth) suggest that the granulites studied were formed in the thickened crust. Moreover, isothermal decompression (ITD) paths are conventionally attributed to the later stages of the thermal evolution of overthickened crust. Generally, decompression in the higher pressure domain of the granulite ITD path is consistent with their genesis in settings dominated by tectonic thickening (Harley 1989). Many features such as association with garnet peridotites, high- pressure assemblages and non-depleted LILE and REE character rank the north Bohemian granulites to the geotectonic Group I defined for Variscan granulites by Pin & Vielzeuf (1983) and Vielzeuf & Pin (1989), i.e. granulites formed by continental collision. High pressures and temperatures, and IBC as the last phase of the P-T-t path, are characteristic of the most deeply burried rocks of the doubly-thickened crust (in contrast with rocks in the upper parts of thickened crust, and deep parts of homogeneously or by a thrust sheet thickened crust, England & Thompson 1984, Ellis 1987).

The steep dP/dT slope of the decompressional path of the north Bohemian granulites contrasts with the shallower slope calculated for the erosional (0.29mm/yr) path for relaxation of doubly thickened crust (England & Thompson 1984). As evidenced also by absence of a significant temperature increase during the decompression, the exhumation of the granulites studied must have been more rapid. As the rates as high as 2-5mm/yr might lead to increasing-temperature decompression followed by isobaric cooling (IBC; cf. England 1987, Sonder et al. 1987), and the recorded PT path would then be IBC (Harley 1989), thinning rates of ca 1-2mm/yr (1mm from model of England & Thompson 1986) are assumed to be consistent with the observed ITD geometry. In any case, rates above 1mm/yr imply operation of an active tectonic uplift and exhumation of previously thickened crust (tectonically controlled uplift). According to models of Oxburgh & Turcotte (1974), ITD from the pressure peak, characteristic of the studied granulites, evidences that uplift occurred immediately after the thickening, as the delay would lead to the initial T increase.

Granulite formation and uplift could be related to a single orogenic event. However, many ITD granulites are reported that have not reached the surface during the granulite-forming event. According to Ellis (1987), this is the case of granulites formed in the deeper part of the crust, which require another tectonic event to uplift and expose them on the surface. Such granulites are characterized by cooling at higher pressures, corresponding to their residence at the base of the normal-thickness crust before the final uplift.

For evaluation of the role of rapid tectonic thinning in the formation of granulites showing ITD paths, detailed geochronological studies focused on the timescales of decompression are necessary. In the case of tectonic thinning at 1-2mm/yr, the ITD paths would generally correspond only to 1-12Ma (England & Thompson 1986, Droop & Bucher-Numminen 1984), in contrast with 20-60Ma documented for simple erosional models (England & Thompson 1984).

9.2 Implications for the tectonometamorphic evolution of the larger area

High-pressure granulites interlayered with mantle rocks, tectonically uplifted from the depth, are closely associated with the Litoměřice fault. It is an important tectonic boundary, separating two areas with different character of the crystalline basement (see Chap. 3). According to geophysical data, there is a seismically documented change in the thickness of the crust on the Litoměřice fault (Beránek in Ibrmajer & Suk 1989). Gravimetrically negative KHMts contrast with the positive Teplá-Barrandian zone (Pokorný & Šťovíčková 1980). Based on gravimetrical data and interpretations, the Litoměřice fault is steeply dipping NW in the area studied

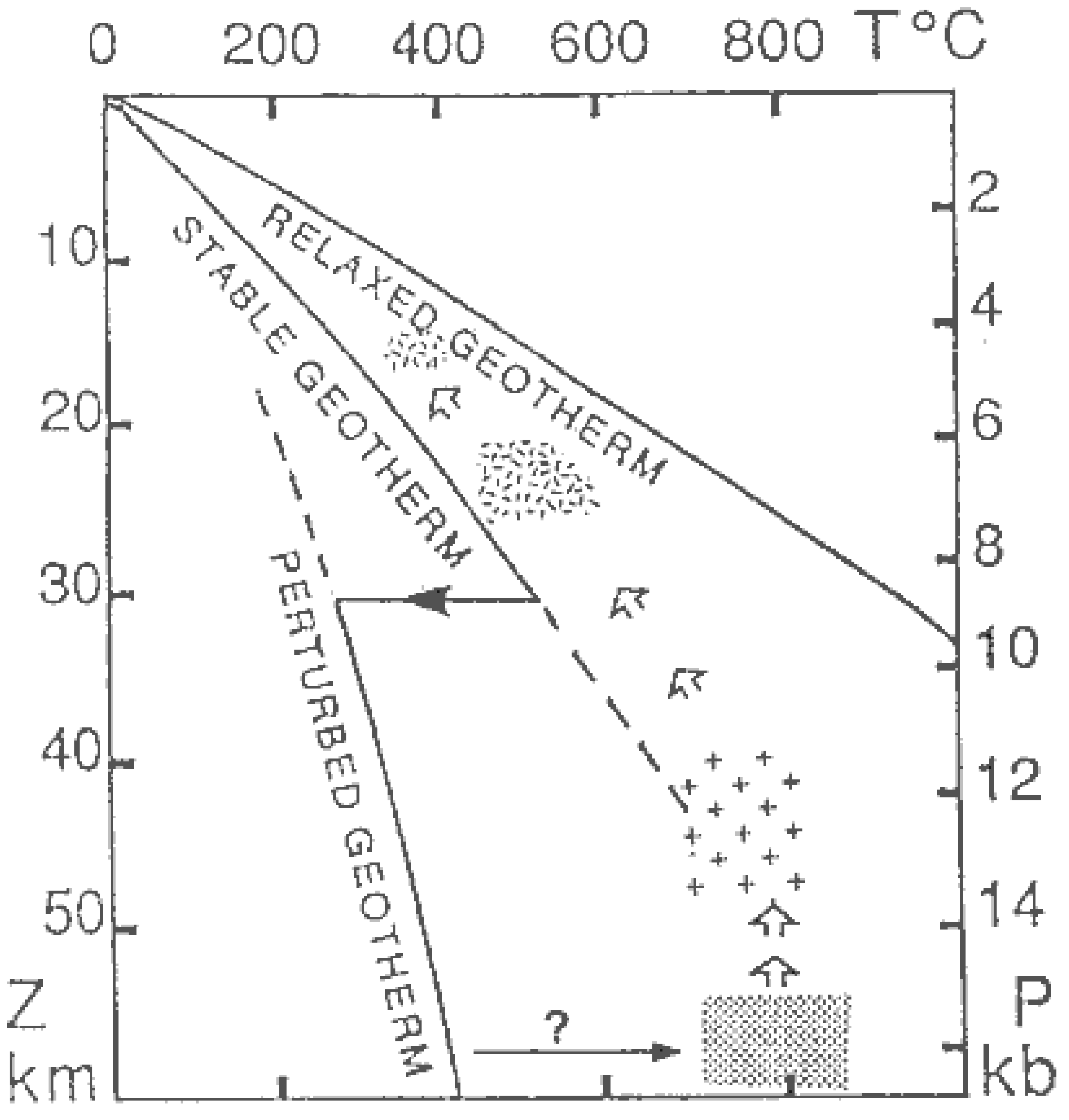

Fig. 9.1 PTt paths of granulites studied in frame of thermal models of England & Thompson (1984).

(Beránek in Kopecký et al. 1970, Pokorný & Šťovíčková 1980).

The importance of the SW continuation of the Litoměřice fault as a suture zone has been recognized in the SW part of the Bohemian Massif (Oberpfalz). Suture is exposed on the surface along the NW margin of the zone Tirschreuth-Mähring (Weber & Vollbrecht 1989). The existence of SE-dipping reflectors at the Saxothuringicum / Moldanubicum boundary has been revealed by deep seismic profiling (Weber & Vollbrecht 1986, Tomek & Vrána 1992), and interpreted as thrust faults implying the NW-directed tectonic transport of the main thrusting (Weber & Vollbrecht 1989). A 'subfluence model' proposed for the evolution of the Münchberg Massif (MM) (Behr 1978, Behr et al. 1982) assumes that the subducted slabs were obducted, and NW-directed emplacement of nappes occurred. The northwards-directed transport for the MM was documented by e.g. Franke 1984, 1984a, Stein 1988).

A complex nature of the north Bohemian crystalline basement is evidenced among others by variability in petrology, metamorphic grade and intensity of deformation of the rocks occurring in erosive windows, xenoliths and boreholes. It has to be expected that direction and sense of the transport of different units of the crystalline basement in time were not constant, corresponding rather to the Alpine than Himalayan collisional model, the same way as suggested for the French Massif Central by Ledru et al. (1989).

Based on the ideas and data given above, it appears that the area studied might represent a suture, and/or a root of nappes.

Some of the main observations and open questions are:

1. Structural and metamorphic style in the zone Blahuňov-Málkov correspond to those of the Central Krušné hory Mts. crystalline area. In this area, regional shear deformations indicate the movement along long-active ductile shear zones in the E-W and SE-NW direction (Klápová 1990). Westward shearing under

the conditions of lower amphibolite facies is documented in Catherine dome in Central Erzgebirge (Mlčoch & Schulmann 1992).

2. Towards the south (Ohře crystalline area), the structural picture gets more complex. Steeply-dipping foliations, generally trending E-W, are re-folded in the SW and central part of the area (see Chap. 4). The E-W system of discontinuities interferes with the paired NW-SE and NE-SW system (Fig. 4.1).

3. The subvertical foliations, both steeply and gently dipping fold axis and stretching lineations, offset of the granulite outcrops (Kotková 1992), and subvertical extensional zones indicate operation of tectonic movements with both vertical and horizontal component, i.e. strike-slip with a dip-slip component.

4. Are there any granulite occurrences linked genetically with the studied areas?

- Granulites of the area B display many similarities to granulite occurrences of the Eastern Erzgebirge (Zöblitz area, to the W). This concerns the rock assemblage (+ eclogites, + peridotites), structural features (Behr et al. 1965), lithology of granulites and their metamorphic evolution (ITD, no HT/LP metamorphism; K.Rötzler 1992).

- Chemical composition of minerals of the T7 borehole garnet pyroxenite ('eclogite') is close to that of Zöblitz and the Krušné hory Mts. eclogites, not Moldanubian ones (Fiala & Paděra 1984).

- The deformation history of granulites is comparable to that of Central Krušné hory Mts. eclogites (Klápová 1990, Klápová et al. 1992). Lower temperatures (max. 730°C corresponding to 15kb for basic rocks, 650°C/22 kb for acid rocks) derived for eclogitic rocks compared to granulites cannot be related to difference in depth, but rather to the timing of burial and uplift, or different position of the rocks in relation to the subduction zone (thermal screen effect; cf. Mercier et al. 1991).

- Granulites of the Saxonian Granulite Massif bear HT/LP overprints, and have a domal structure.

- North Bohemian granulite occurrences bear many similar features with those of the Kutná Hora crystalline complex, situated to the SE from Barrandian; similarity of the two areas was recognized already by older authors (Svoboda et al. 1966). The most important features are: subvertical foliation, absence of HT/LP overprints on HP granulite assemblages, association with orthogneisses, prevalence of garnet peridotite types, occurrence of kyanite-bearing melts, and restricted extent of granulite bodies.

- Moldanubian granulites contrast with the north Bohemian ones by their structural position (shallow dipping foliations), association with paragneisses and migmatites, occurrences of both spinel and garnet peridotites, and common HT/MP-LP overprints on HP granulite assembalges.

5. It remains in question, if the area studied could represent a root zone of nappes. Is the steep NW dip of the Litoměřice fault a syn-collisional or a later feature? Does the steep foliation represent the structure related to the nappe emplacement, or is it a result of later shearing?

6. Relict kyanite found in an orthogneiss-like rock (garnet-kyanite migmatitic gneiss) brings about an idea that maybe large area has experienced granulite-facies metamorphism, the traces of which were to a large extent obliterated by later amphibolite-facies metamorphism. This assumption can be applied to the Krušné hory Mts. area, too. Derivation of metagranitic rocks from the same source as granulites - i.e.by mobilization of granitic liquids and their emplacement in higher levels contemporary with granulite formation (c.f.Clemens 1990) - is incompatible with geochemically undepleted character of granulites studied.

8. Recent geochronological dating yield Palaeozoic ages for garnet peridotites from the T7 borehole. U/Pb data on zircons indicate an age of 424 ± 4Ma for zircon cores and 342 ± 5Ma for their rims (Gebauer 1991). This author interprets these ages as records of a Silurian partial melting event in peridotite at high or ultra-high pressures, and Lower Carboniferous high pressure metamorphism in a solid state, respectively. It is assumed that the first event could lead to differentiation of magma giving rise to garnet pyroxenites, lherzolites and dunites.

High degree of preservation of Grt in peridotites corresponds to garnet peridotites tectonically emplaced into continental crust with their garnet assemblage intact. As such, these peridotites correspond rather to solitary bodies emplaced into their present position along major faults (Medaris & Carswell 1990) than to those associated with granulites, and to Caledonian and Lower Austrian rather than other Moldanubian peridotites (ibid.).

8. Another question is when were the mantle and crustal assemblages brought together. Many authors suggest that peridotites were incorporated into granulites before (Mísař et al. 1984) or during (Medaris & Carswell 1990) the main high-grade deformation of granulites. On the other hand, Carswell (1991, & pers. com.) suggests that the juxtaposition of the two occurred late in the Variscan orogenic evolution, after the HP metamorphic stage of peridotites, maybe as late as the amphibolite-facies metamorphic stage. This concerns Lower Austria, where it is documented by absence of Pl-free, true eclogites in granulites, and intensive amphibolite-facies deformation of the mantle rocks. Such a deformation was not observed in the studied rocks. However, the observations are restricted by absence of outcrops (only borehole section).

10. Conclusions

Granulite occurrences in the erosive window of the Ohře river, on the eastern slope of the Krušné hory Mts., and in the basement of the North Bohemian Cretaceous Basin in the north Bohemia (referred to as areas A, B and C, respectively) were studied.

Polyphase evolution of deformation and metamorphism in the region has been established. All the outcrop area is characterized by steeply south-dipping main foliation S_{1-2}, trending generally E-W. In granulites, it was formed under granulite (D_1) and reactivated under amphibolite facies (D_2) conditions. Folding of the S_{1-2} foliation into open folds (D_3) and development of ductile to brittle subvertical shear zones and intensive fracturation are characteristic of granulites. The deformation was heterogeneous, resulting in formation of low-strain domains with preserved original mineral assemblage, and high-strain domains, where higher strain rates facilitated the retrograde metamorphic reequilibration, conditioned also by fluid influx, as documented by dynamic crystallization of micas. Therefore, lower-grade (amphibolite facies) metamorphic overprinting is confined to the deformed zones, occurring both inside and at the limits of granulite outcrops.