South Bohemian HP Granulites with Lenses of HP/UHP Mafic and Ultramafic Rocks

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Position and structure of the granulite massifs

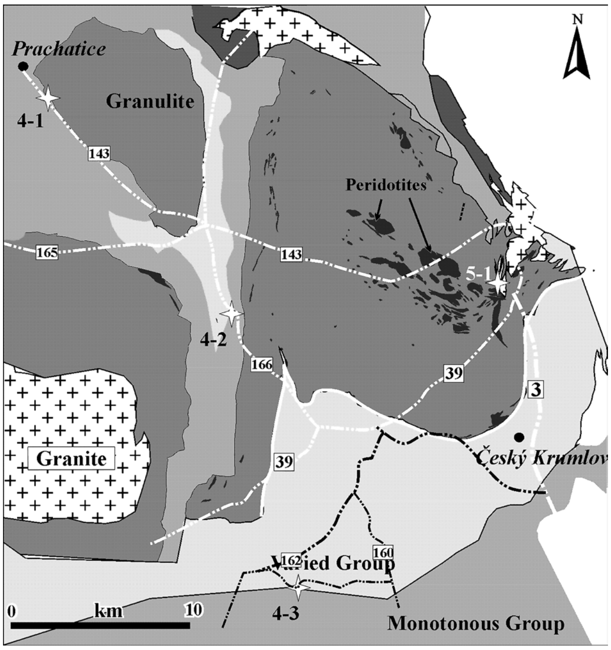
Granulite facies rocks (mostly felsic granulites and granulitic gneisses) with lenses and boudins of serpentinized garnet and spinel peridotite, pyroxenite, retrogressed eclogite comprise- several large, oval-shaped massifs (the Blanský Les, Křišťanov, Prachatice, Lišov, and Krasejovka Granulite Massifs) in the south-western part of the Moldanubian zone (Fig. 1). The granulite massifs also contain lenses of pyroxene-bearing granulite of intermediate composition, whose relation to felsic granulite is unclear (Kodym, 1972; Vrána, 1992). The garnet or spinel peridotites and garnet pyroxenites systematically form discontinuous lenses along the margins of all the granulite massifs. Similar to other granulites in the Moldanubian zone, the southern Bohemian granulites are assigned to the high-grade Gföhl Unit. The granulite massifs are surrounded by amphibolite facies metamorphic rocks of the Monotonous and Varied groups (e.g., Rajlich et al., 1986).

The Blanský Les Granulite Massif preserves the most complete structural record. The oldest fabric is represented by scarce remnants of a compositional banding (Vrána, 1979; Franěk et al., 2006). The subsequent, better-preserved fabric developed under granulite facies conditions. This is a mylonitic foliation, dipping moderately to steeply to the W or E, are defined by elongation of Qtz ribbons and Bt aggregates emphasized by a weak compositional banding. The early fabrics were extensively reworked by steep amphibolite facies mylonitic foliation, which constitutes an ~18-km-wide sigmoidal asymmetric fold parallel to the margins of the massif. Both of the steep fabrics developed during the two-step exhumation of the granulites from lower-crustal conditions to their present tectonic position.

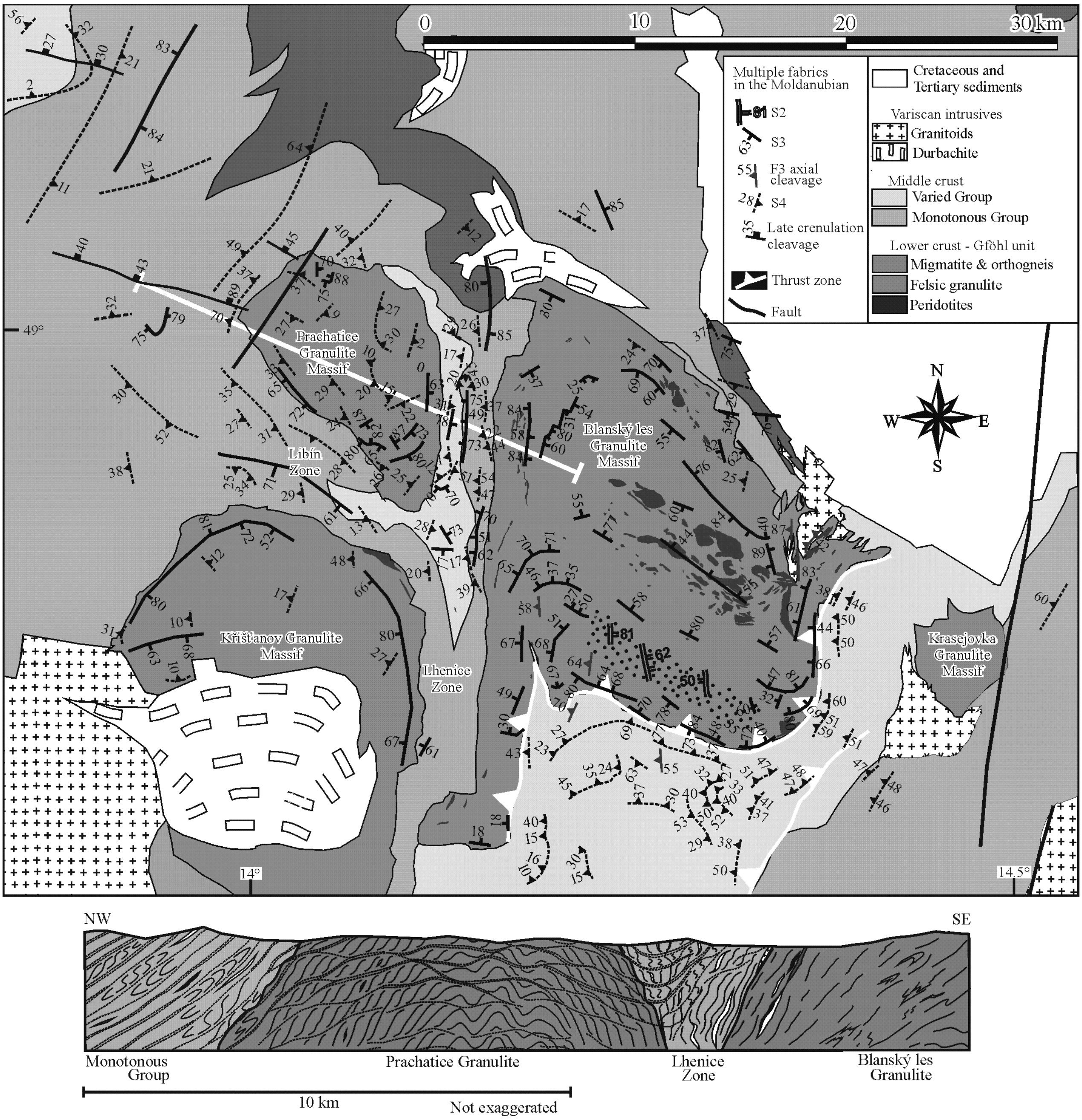
The oldest fabric preserved in the Křišťanov and Prachatice bodies correspond to the steep amphibolite-facies foliation described above. Compared with the Blanský Les, the orientation of these fabrics is less complex. They form between ~15 and ~7 km-wide, large-scale, single folds parallel to the margins of each massif. The folds are characterised by steep axes and roughly N to S-trending, steep axial planes, similar to the Blanský Les Granulite. This arcuate steep fabric was heterogeneously reworked by a younger ductile deformation, which resulted in development of shallowly NW-dipping to flat-lying foliation.

The rocks in the Monotonous and Varied groups are characterised by steep amphibolite facies foliation, generally trending NNE–SSW, which is similar to and concordant with that in granulites (Vrána, 1979). The steep foliation in the Lhenice Zone forms a tight, vertical, N–S elongated, fan-like pattern, while in the Libín Zone it dips steeply to the SW beneath the Křišťanov granulite. Regionally, the most prominent fabric is a flat foliation that generally strikes NE–SW, dipping at gentle angles mainly to the NW. Only in the vicinity of the granulite massifs does it get disturbed and "flow" around the individual bodies. The Lhenice Zone, with a generally higher degree of partial melting, probably represents a remnant of Variscan lower-crustal meta-sediments trapped by felsic granulites during their ascent and exhumation.

Four localities will be visited in the southern part of the Bohemian Massif (Fig. 1), which include two stops (4-1and 5-1) in granulite massifs with HP granulites and lenses of HP/UHP mafic and ultramafic rocks, a stop (4-2) in high-grade gneiss that is structurally beneath the granulite massifs, and a stop (4-3) in eclogites in the Monotonous Unit.



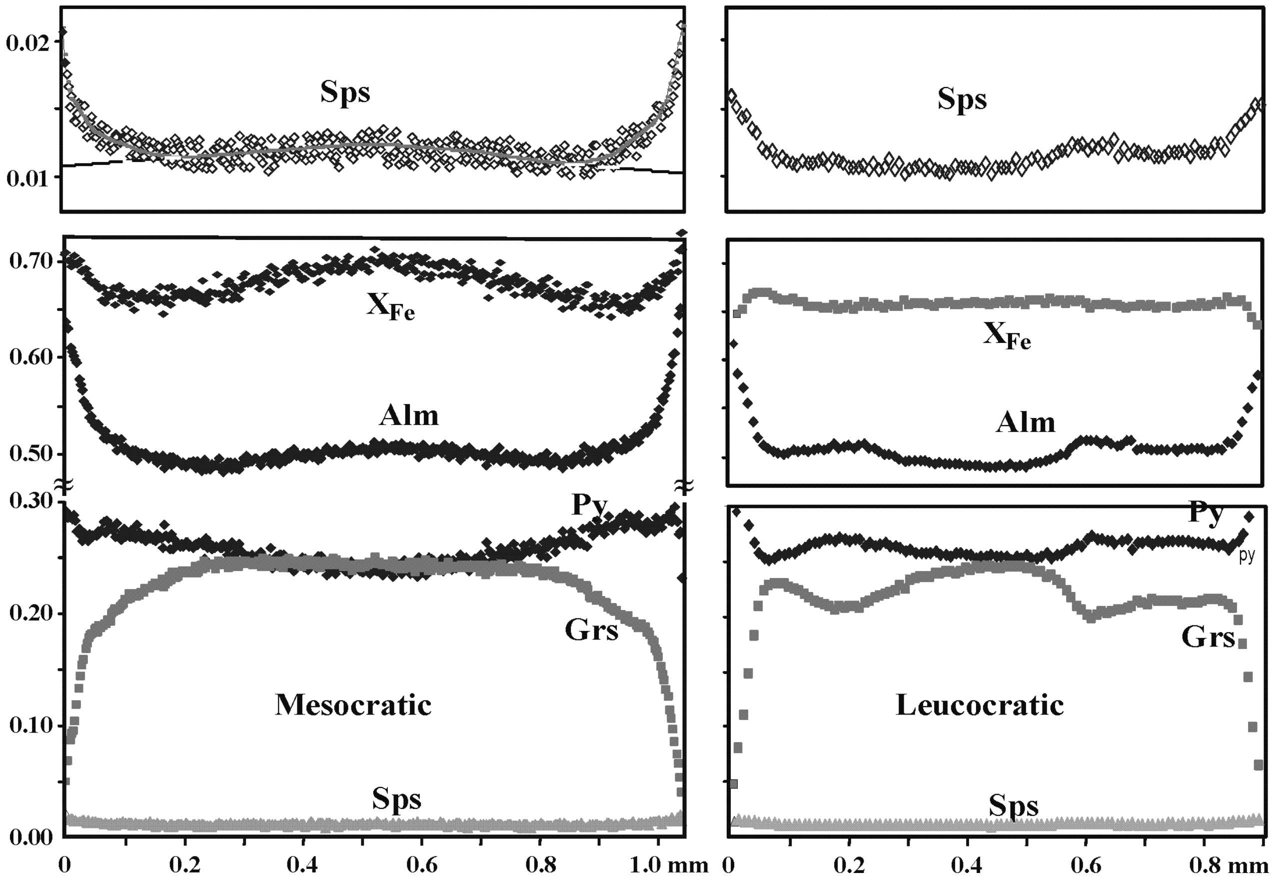
■ **Fig. 2.** Localities of field trip stops in garnet peridotites, garnet pyroxenites and eclogites in the southern Moldanubian granulite massif and adjacent units (area A in Fig. 1 of the Introduction to part III). Stops 4-1 and 5-1: peridotites in granulite massifs; 4-2: garnet-rich gneiss (kinzigite); 4-3: eclogite in the Monotonous group. Dot-dash lines with numbers indicate highways and main roads.



■ **Fig. 2.** Simplified structural map of the South Bohemian Moldanubian region and a NW-SE structural profile, showing the fold-like shape of steep fabrics and their overprint by a flat-lying foliation (Franěk et al., 2006).

Granulite petrology

The origins and protoliths of granulites in the Bohemian Massif have long been a subject of discussion. According to Fiala et al. (1987), the granulites were derived from felsic volcanics or volcanosedimentary rocks. Alternatively, it has been proposed that granulite originated from dry, HP-HT partial melting of sedimentary lithologies (Vrána, 1989; Jakeš, 1997; Kotková and Harley 1999, 2010) or of granitoid/acid volcanic rocks (Vrána, 1989; Janoušek et al., 2004). The granulites have been extensively re-equilibrated under lower-pressure granulite and subsequent amphibolite facies conditions. Relatively well-preserved felsic varieties, which consist of two feldspars, quartz, garnet, kyanite, and rutile, are present in the Blanský Les Massif (Vrána, 1992; Fiala et.al., 1987). The presence and amount of biotite and sillimanite or spinel depend on the degree of re-equilibration. Garnet has a composition in the range, Alm48-62Prp26-.32Grs25-04Sps1-2, and is usually compositionally zoned, with a decrease of Ca and XMg toward the rim. However, some dark, Ca-rich varieties may preserve prograde zoning in the central part, where Mn and XFe decrease outward, but Ca remains constant (Fig. 3). The rims of garnet show a strong



■ **Fig. 3.** Compositional profiles of almandine, pyrope, grossular, and spessartine contents and X_{Fe}=Fe/(Fe+Mg) from prograde-zoned garnets in mesocratic and leucocratic layers of granulitic gneiss. Note that Mn zoning is shown by a vertical scale enlargement in the top figure.

retrograde zoning, with a decrease in Ca and Mg, an increase in Fe, and a slight increase in Mn. In addition to rutile, garnet contains columnar or euhedral inclusions filled mostly by albite, but K-feldspar and plagioclase (An14 and An43) also occur (Figs. 4a, b). These inclusions occur in the Ca-rich internal parts of garnet and usually contain a mixture of Fe oxide + titanite. They are interpreted as pseudomorphs after a Na-rich phase, such as jadeite, paragonite, or glaucophane , or, in the case of plagioclase, after a mixture of paragonite and margarite, which were stable during the prograde PT path to eclogite facies metamorphism (Faryad et al., 2010).

The intermediate compositional variety of granulite consists of quartz, garnet, clinopyroxene, orthopyroxene, mesoperthite, plagioclase, biotite, quartz, rutile, and ilmenite. The garnet shows a flat profile in the core, with a composition of Grs32, Prp25, Alm45, and retrograde zoning near the rim (Grs24, Prp21, Alm51). Omphacite (Jd28) occurs as an inclusion in garnet (Fig. 4c), and symplectite of diopside and plagioclase after omphacite is partly enclosed in the outer part of the garnet. Clinopyroxene in the matrix is diopside, with XMg about 0.78. Orthopyroxene occurs in a corona around quartz in contact with garnet (Fig. 4d), and its XMg value ranges from 0.52 to 0.60.

PT conditions estimated for both felsic and mafic granulites are in the range of 850–1050 °C and 15–20 kbar (Carswell and O'Brien, 1993; Owen. and Dostal, 1996; Kotková and Harley, 1999; Štípská and Powell, 2005). A higher pressure of 2.5 GPa at 700 °C during the prograde stage was proposed by Faryad et al. (2010). The granulites subsequently followed a nearly isothermal decompression path to mid-crustal level pressures with an overprint at 800–900 °C and 8–12 kbar and and a final, near-isobaric cooling.

Most U-Pb ages for metamorphic zircon and monazite from felsic granulites yield ca. 338–340 Ma (van Breemen et al., 1982; Aftalion et al., 1989; Wendt et al., 1994; Kröner et al., 2000; Sláma et al., 2008; Svojtka et al., 2009). However, some older ages of 340–350 Ma by U-Pb zircon and Sm-Nd dating were obtained by Kröner et al., 2000 and Wendt et al., 1994. U-Pb ages for protolith magmatic zircon are ca. 370 Ma (Wendt et al., 1994). Zircons from amphibolite facies Crd patches in granulite yield an age of 338.2 ±3.2 Ma (Kröner et al., 2000). Similar ages of 337 Ma by U-Pb on zircon for felsic granulites were obtained by Sláma et al. (2007).

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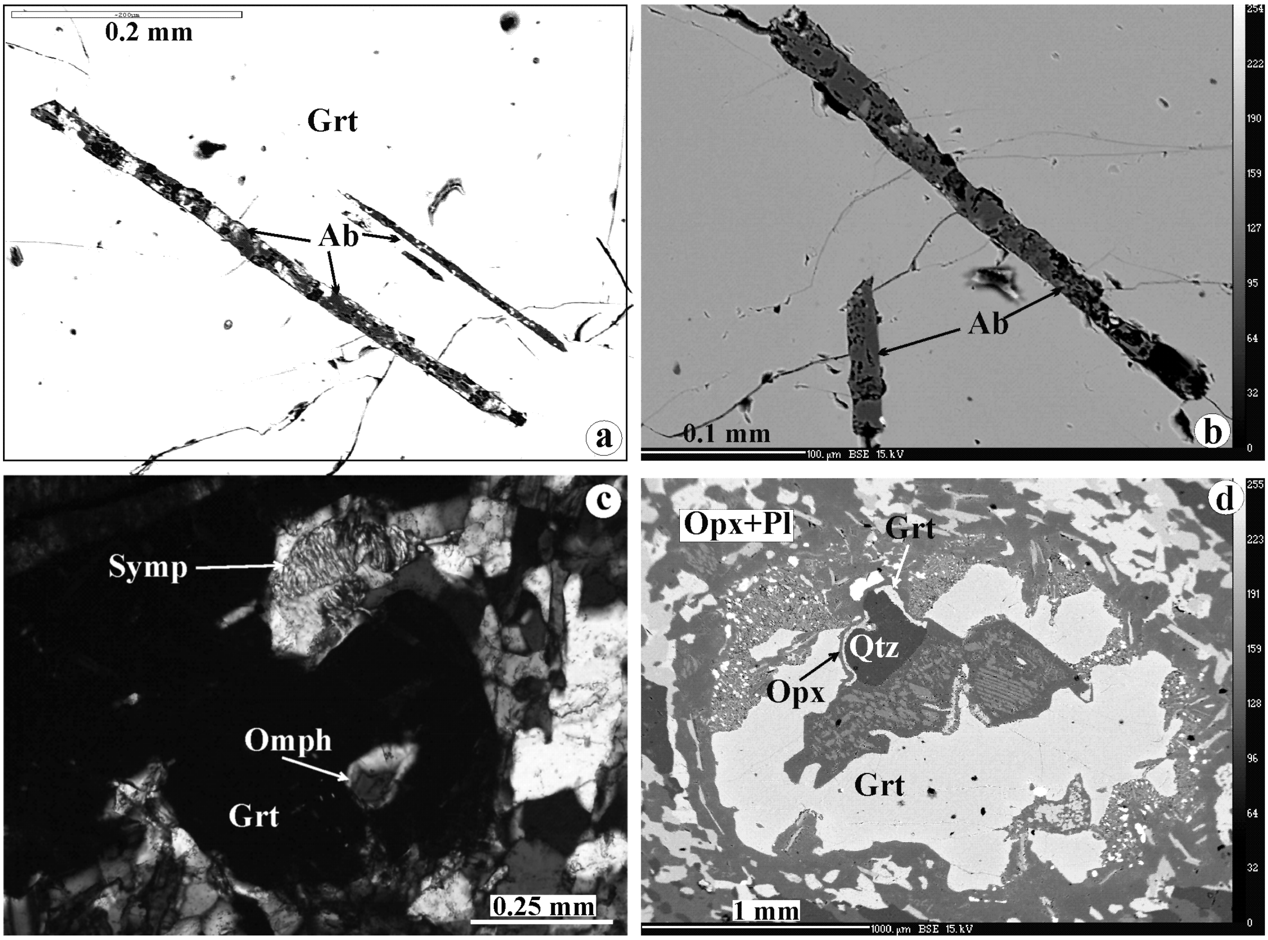

■ **Fig. 4.** Backscattered electron images of garnet crystals with inclusions of albite + Fe-oxides (after clinopyroxene, Na-amphibole, or paragonite?).

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Stop 4-1 (Day 4). Garnet Peridotites and Pyroxenites, Quarry Pod Libínem

Coordinates: N48°59′59.4″ E14°01′21.0″

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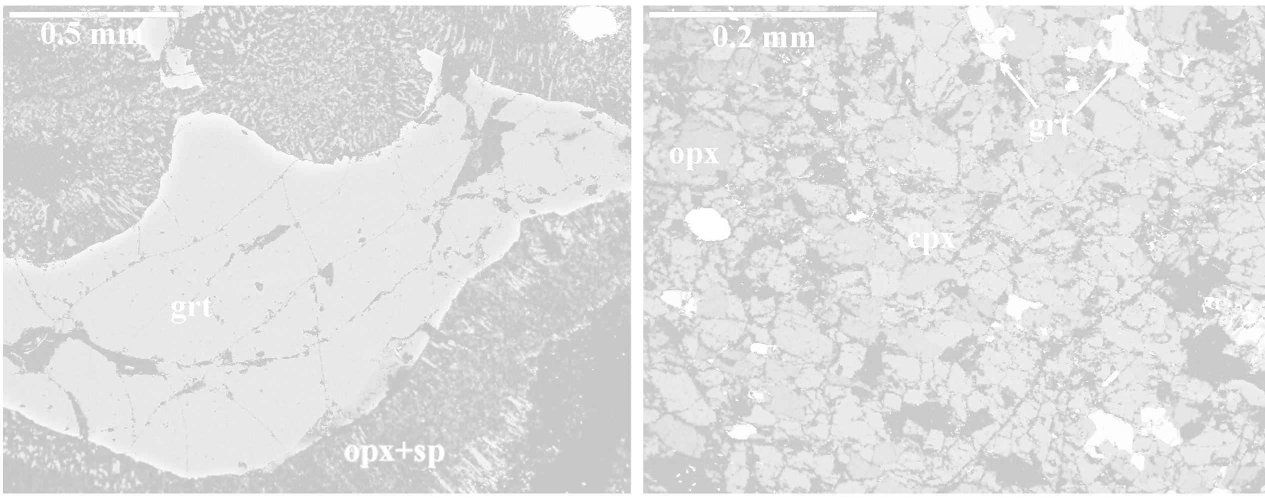
The large active quarry Pod Libínem is located directly at the SW margin of the Prachatice Granulite Massif (Fig. 1). The felsic granulites exhibit penetrative steep fabric and contain bodies of partially serpentinized Grt peridotites and pyroxenites, which form up to 10-m-large boudins. Granulite consists of feldspars, quartz, garnet, biotite, and kyanite (sillimanite), cordierite and accessory, spinel, rutile, zircon, graphite and apatite. Quartz forms mostly platy grains that define foliation of the rocks. Grain boundaries of quartz grains are followed by fine-grained perthitic K-feldspar, plagioclase and locally by biotite and relics of kyanite. Garnet is replaced by biotite or by cordierite, and kyanite is rimmed by spinel or totally replaced by sillimanite. Cordierite occurs along thin veins but mostly forms corona around garnet and finally replaced the whole garnet. Plagioclase forming symplectite with sapphirine is also present. Granulite is locally penetrated by granitic veins.

Garnet peridotites are strongly serpentinized. Pyroxene-rich varieties may contain up to 5- to 7-cm-large garnet porphyroblasts that are mostly replaced by symplectites of pyroxene + amphibole + spinel. They contain inclusions of clinopyroxene. In addition to isolated red-brown spinel, symplectites of spinel + orthopyroxene (former garnet), overgrown by amphibole, are also present. Garnet in peridotite forms relic grains, which have homogeneous composition with Mg and Cr con-



■ **Fig. 1.** BSE images from garnet peridotite and garnet pyroxenite within garnulites (stop 3-1). (a) garnet with corona of opx+sp symplectite from garnet peridotite. (b) microtexture of garnet pyroxenite.