

## Stop 4-3 (Day 4). Eclogite, Světlík-Suš

Coordinates: N48°43'19.5" E14°14'49.2"

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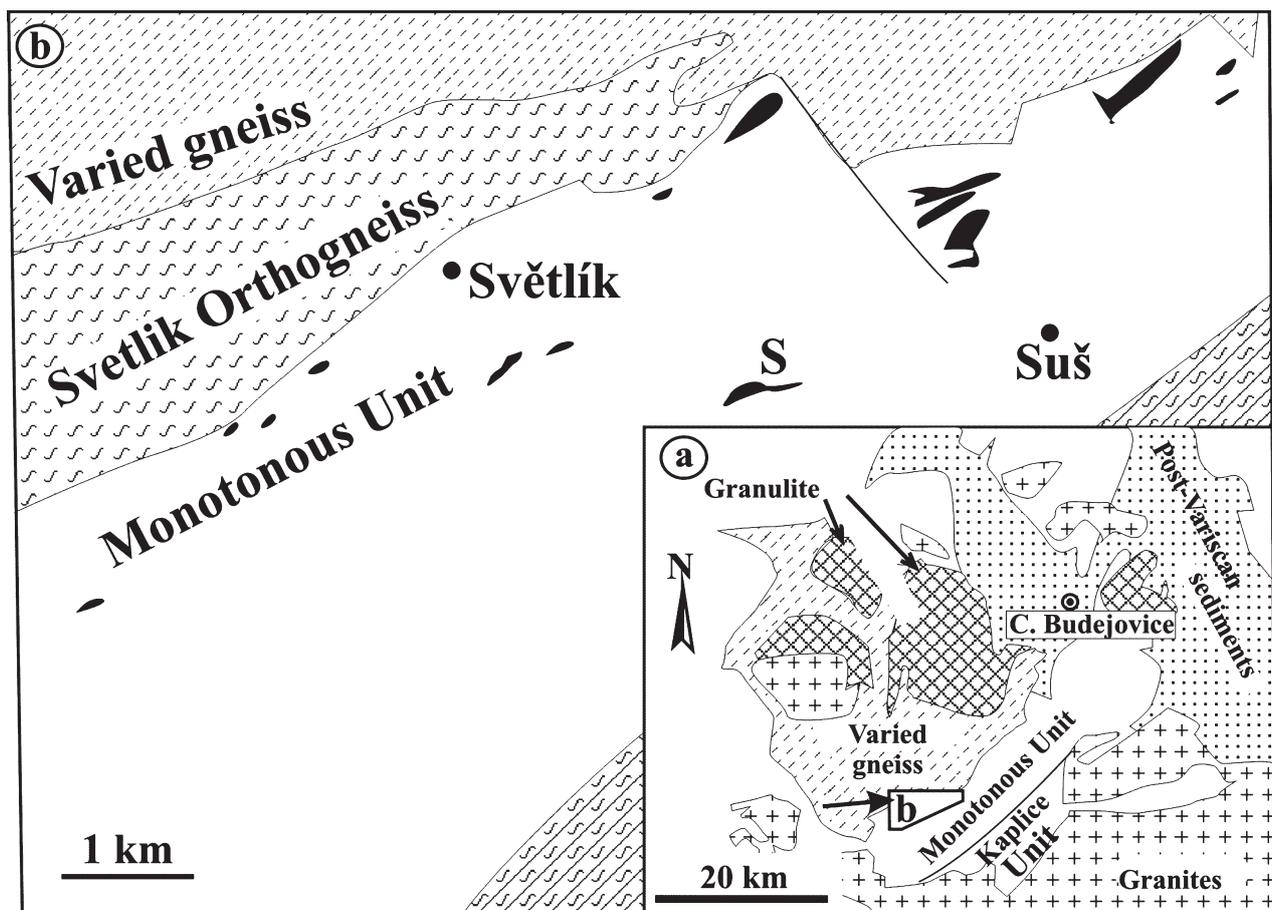
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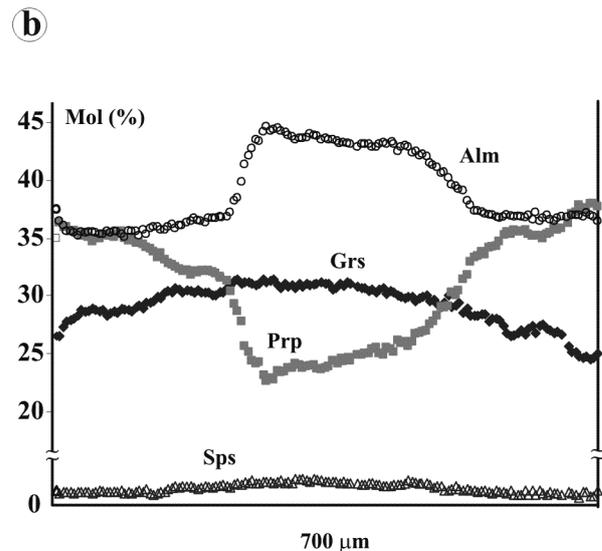
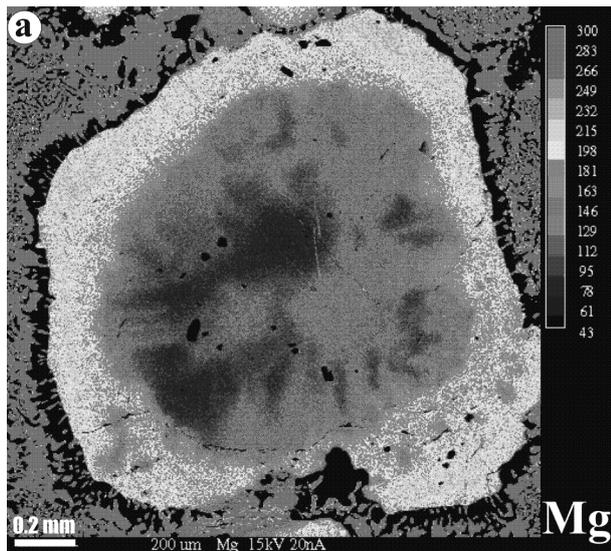
Eclogite near the village of Suš belongs to a group of lens-shaped bodies of mafic and ultramafic rocks (retrogressed eclogites, garnet pyroxenites and partly serpentinized spinel lherzolite) that occur in the Monotonous unit near its northern contacts with the Svetlík orthogneiss and the Varied unit (Fig. 2). Altogether, 11 bodies of eclogite, 6 of garnet pyroxenite, and one of spinel lherzolite are exposed in this area, where the Monotonous unit is structurally overlain by the Světlík orthogneiss and by the Varied unit. The Monotonous unit consists of migmatitic paragneisses containing biotite, K-feldspar, sillimanite and, locally, cordierite and garnet (Vrána, 1979). To the south, the Monotonous unit is gradually retrogressed to biotite + muscovite ± sillimanite gneiss, which is designated as the Kaplice unit. Occasionally, the Monotonous unit contains kyanite, but in contact with the Moldanubian pluton, cordierite

and andalusite are present. Minor pods of calc-silicate rocks are also present in the Monotonous unit. Metamorphic mineral assemblages in the Kaplice unit, the Světlík orthogneiss, and in the Varied unit are representative for amphibolite facies conditions. The northeast-southwest trending units exhibit monoclinical planar fabrics due to regional re-foliation imposed by (syn-metamorphic) shearing. Relics of older structures trending N-S and WNW-ESE are locally preserved (Vrána, 1979).

The eclogite near Světlík-Suš is exposed along a forest road about 2 km west of the village of Suš, where it forms a low, 2 × 4 m outcrop surrounded by fresh eclogite boulders. About 50 m from the outcrop into the forest, boulders of partly retrogressed eclogite and garnet clinopyroxenite (with abundant retrograde magnesihornblende) can be also found.



■ Fig. 2. a—Geological map of the southern part of the Bohemian Massif (after Vrána, 1991, simplified). b—The studied area of the Monotonous unit with eclogite bodies (black). S, Světlík-Suš (stop 3-5).



■ Fig. 3. a. Mg K $\alpha$  X-ray map of strongly zoned garnet in Suš eclogite. b. Rim to rim compositional profiles for garnet in Světlík-Suš eclogite.

## Petrography

### Eclogite

Besides common bi-mineralic garnet-omphacite eclogite, quartz-(clino)zoisite-bearing eclogite is also present. Fresh eclogites are coarse-grained with garnet and omphacite up to 4 mm in size. Accessory minerals include rutile and, rarely, kyanite and titanite, both as eclogite facies phases. Some eclogites show a weak metamorphic foliation. All eclogite varieties experienced a significant degree of partial recrystallization under granulite and amphibolite facies conditions (O'Brien and Vrána, 1995; Faryad et al., 2006). Minerals formed during decompression are orthopyroxene, in reaction domains between garnet and omphacite, and anorthite + spinel  $\pm$  corundum  $\pm$  peraluminous sapphirine, replacing kyanite.

Garnet (Alm<sub>47-60</sub>, Grs<sub>20-36</sub>, Prp<sub>22-41</sub>) is zoned with an increase in Mg and a decrease in Fe from the central part of the garnet (1/3 of the whole garnet) to the rim (Fig. 3). A slight decrease in grossular towards the rim, combined with an increase of  $X_{Mg}$ , may reflect decompression and heating after peak-pressure conditions. The Jadeite content in omphacite from different samples ranges between 22 and 32 mol. %. Titanite coexisting with omphacite and Ca-rich garnet is compositionally homogeneous in individual grains, but varies slightly in Al<sub>2</sub>O<sub>3</sub> (1.42–2.35 wt. %) and F (0.2–0.36 wt. %) in different grains.

The eclogites are interesting for their replacement textures that were formed during high-temperature decompression and cooling. Omphacite is replaced by a symplectite of diopsidic clinopyroxene, plagioclase, and amphibole. Garnet may have thick, kelyphitic rims consisting of fine-grained clinopyroxene, amphibole, and plagioclase, or orthopyroxene + plagioclase rims along garnet and quartz boundaries. Ilmenite represents the main retrograde Ti-phase in most samples, which may rim or contain inclusions of rutile. Titanite coexisting with omphacite is rimmed or replaced by symplectites of ilmenite and clinopy-

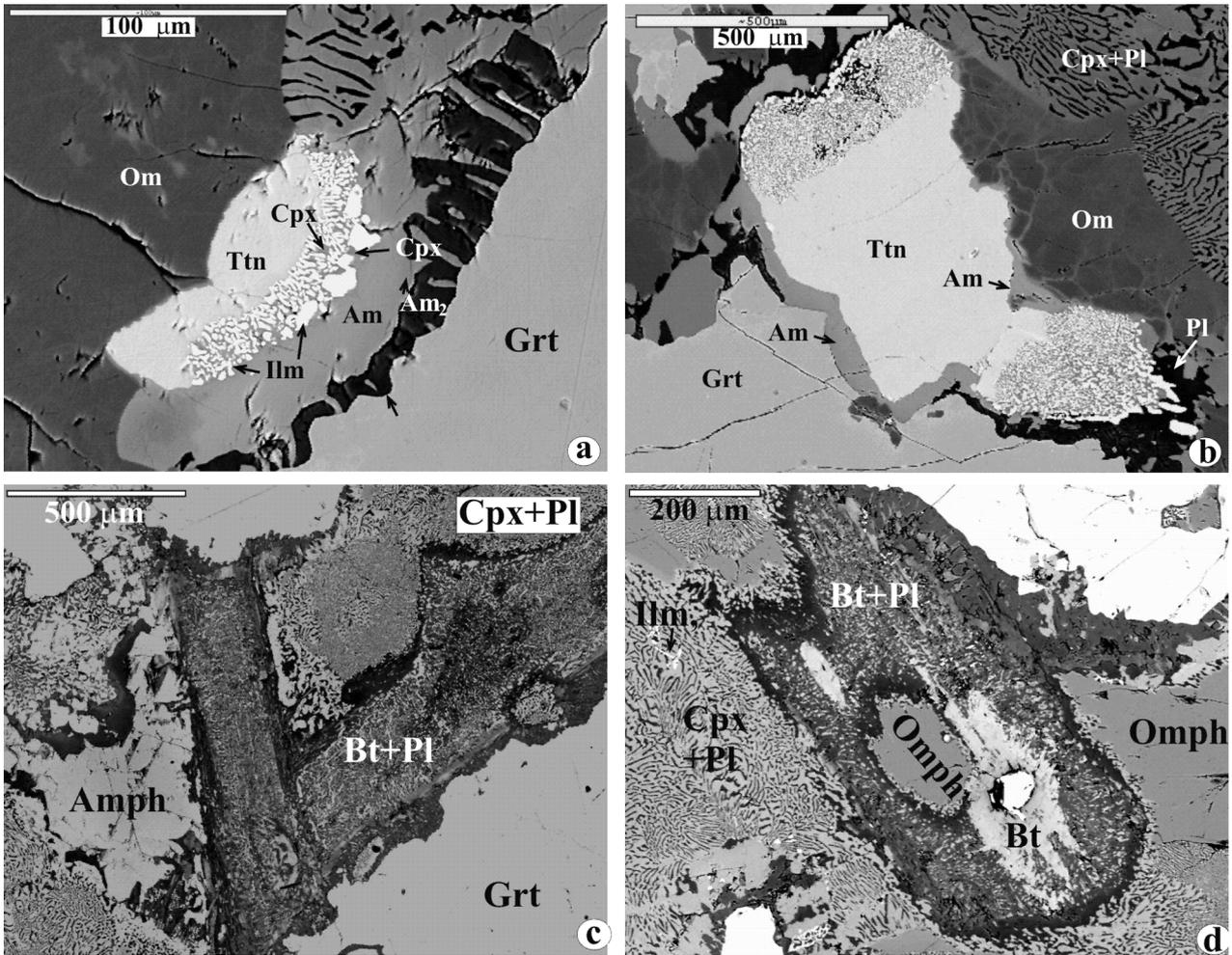
roxene (Fig. 4a). Na-rich pargasite and kaersutite (Ti > 0.5), with Si close to 6.00 a.p.f.u. and  $X_{Mg}$  = 0.47, occur in contact with symplectites of ilmenite + Ti-clinopyroxene. Tabular-shaped symplectites of plagioclase, biotite, and accessory spinel probably represent pseudomorphs after phengite (Figs. 4c and d). Kyanite is preserved in inclusions in garnet, but in the matrix it is replaced by symplectites of sapphirine + plagioclase or spinel + plagioclase (O'Brien and Vrána, 1995).

### Garnet clinopyroxenites

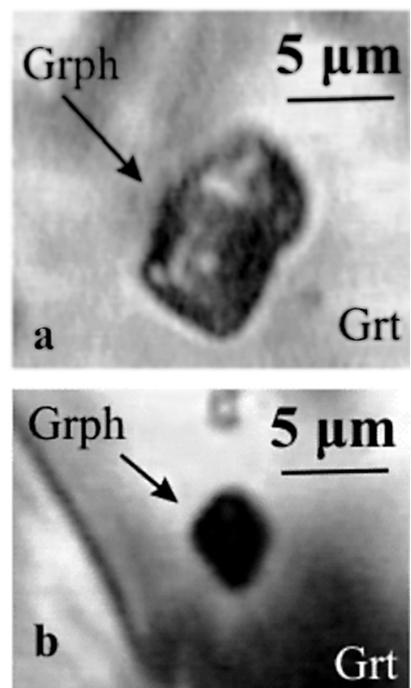
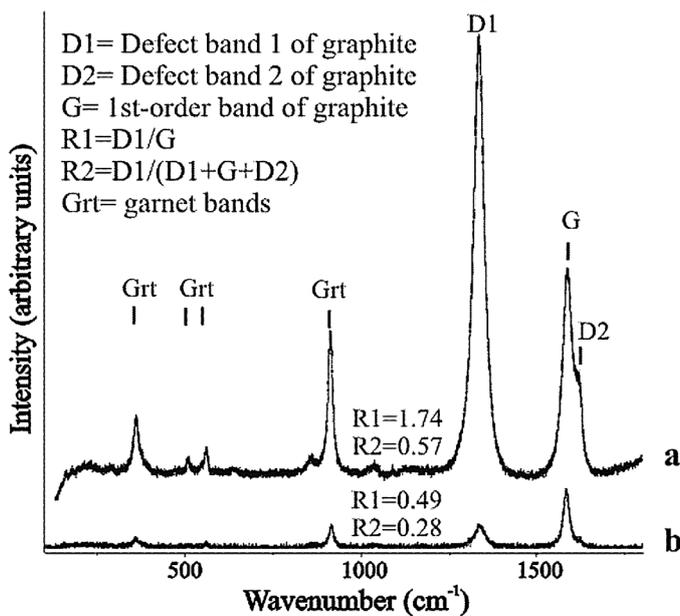
In contrast to eclogites, which have composition of oceanic basalts/gabbros, garnet clinopyroxenites in the Světlík belt correspond to picritic rocks with a high MgO/FeO ratio = 1.55–2.38 (wt. %) (O'Brien and Vrána, 1995). The whole-rock compositions of the garnet pyroxenites are similar to those described by Carswell and Scharbert (1983) from the Gföhl unit in Lower Austria. Clinopyroxene contains only 7.6 mol. % Ca-tschermakite and 6.3 mol. % jadeite, the latter reflecting the relatively low whole-rock Na content with 1.2–1.8 wt. % Na<sub>2</sub>O (O'Brien and Vrána, 1995). Inconspicuous light-coloured garnet (c. 15–20 vol. %) has 53–58 mol. % pyrope, 21–23 % almandine, 16–20 % grossular, and 1–3 % andradite. Accessory phases are rutile, ilmenite and sulphides. Garnet clinopyroxenite samples from the Světlík belt are strongly retrogressed, containing up to 60 vol. % magnesiohornblende. Garnet is rimmed by very fine-grained spinel + orthopyroxene  $\pm$  amphibole + plagioclase symplectite, which is locally replaced by magnesiohornblende.

### Inclusions of disordered graphite in garnet

Disordered graphite has been identified in isolated, cuboidal micro-inclusions in garnet. Most of them are opaque, although trans-



■ Fig. 4. (a) Titanite associated with omphacite and garnet. Note that titanite is in direct contact with omphacite. (b) Amphibole occurs between garnet and titanite. (c, d) Tabular grains of former phengite (?) replaced by symplectite of plagioclase + biotite.

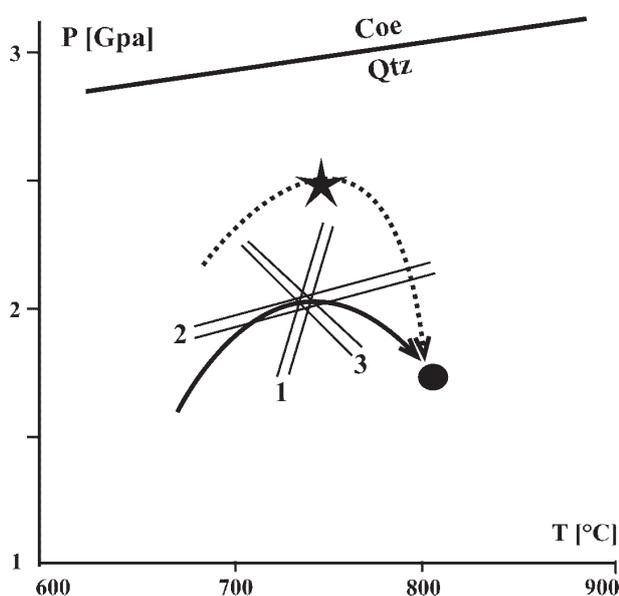


■ Fig. 5. Representative Raman spectra of disordered graphite inclusions in garnet and photomicrographs of the respective analysed inclusions.

parent to semi-transparent grains are also present (Fig. 5). First-order Raman spectra were analysed from 100 to 1800  $\text{cm}^{-1}$ ; in some cases the entire range from 100 to 3350  $\text{cm}^{-1}$  was analysed in order to check the second-order Raman peaks. The analysed disordered graphites show two peaks in the first-order region, at  $\sim 1330 \text{ cm}^{-1}$  and  $\sim 1580 \text{ cm}^{-1}$ , with a shoulder at  $\sim 1618 \text{ cm}^{-1}$  and a broad, second-order peak at  $\sim 2666 \text{ cm}^{-1}$ . It is of interest that not all of the graphites show the same degree of disordering. The R1 (D1/G) and R2 [D1/(D1 + G + D2)] parameters (Beysac et al., 2002) vary from 0.33 to 1.95 and 0.23 to 0.59, respectively. The two most likely mechanisms of formation of disordered graphite in eclogites are (1) fluid-precipitated graphite (Wopenka and Pasteris, 1993; Pasteris and Chou, 1998; Satish-Kumar, 2005) and (2) diamond-graphite phase transition (El Goresy et al., 2001; Willems et al., 2004). The distinction between these two mechanisms, i.e., whether graphite formed from transformation of previous diamond or disordered graphite grew within former fluid inclusions by precipitation, is difficult to ascertain, and crystallinity itself is insufficient to distinguish the origin of the graphite.

## Geothermobarometry and interpretation

Temperatures of 700–800 °C, with a mean value of  $746 \pm 27 \text{ °C}$ , and pressures of 2.0–2.4 GPa (Fig. 6) were obtained for kyanite-bearing eclogite using garnet-clinopyroxene-kyanite thermobarometry (Ganguly, 1996; Ellis and Green, 1979; Powell, 1985;



■ **Fig. 6.** Pressure and temperature conditions calculated using the PTGIBS program (Brandelik and Massonne, 2004) for kyanite-bearing eclogite with Jd-rich clinopyroxene. The star marks the intersection of reactions 1–3, obtained from the method of Ravná and Terry (2004). Arrows indicate PT paths from eclogite to HP granulite facies conditions (filled circle estimated by O'Brien and Vrána, 1995). Reactions 1–3 are:

Alm + Di = Hd + Prp	1
Grs + Alm + Qtz = Ky + Hd	2
Grs + Prp + Qtz = Ky + Di	3

Ai, 1994; Brandelik and Massonne, 2004; Ravná and Terry, 2004). Preservation of prograde zoning in garnet and formation of orthopyroxene, spinel and sapphirine suggest that the eclogites during decompression remained only briefly under granulite facies conditions (O'Brien and Vrána, 1995; Faryad et al., 2006).

PT conditions of the garnet pyroxenites have not been investigated yet. However, the presence of high-pressure metamorphic rocks in the Monotonous unit suggests that tectonic emplacement of eclogites and garnet pyroxenites into lower-grade metamorphic rocks may not be unique to the Gföhl unit. The Monotonous and Gföhl units may have been close to each other during Variscan convergence and may represent different levels in the accretionary wedge or the subduction channel.

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