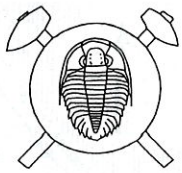
# Retrograded eclogite from the Staré Město Belt, NE margin of the Bohemian Massif

## Retrográdní eklogit ze staroměstského pásma, sv. okraj Českého masivu (Czech Summary)



*(5 text-figs., 1 plate)*

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Strongly retrograded eclogite was found at the NE edge of the Staré Město Belt most probably representing a suture zone, in the eastern rim the Orlice-Klodsko Unit. While primary garnet is preserved, (Alm 51-59, Grs 17-31, Pyr 13-17, Sps 1.3-2.1), clinopyroxene I is completely replaced by clinopyroxene II (Jd 18) - plagioclase I (An 10-14) symplectite. Continuing retrogression led to growth of hornblende + plagioclase II (An 17-42) at the expense of symplectite. Amphibolite sampled nearby displays a prograde zoning of garnet in the range of amphibolite facies, (Alm 56-62, Grs 24-30, Pyr 5-10 Sps 0.4-10); the assemblage includes hornblende, plagioclase (An 12-31), quartz and biotite.
Thermobarometry indicates that local equilibrium of rocks of different previous P-T histories has been attained at conditions of high amphibolite facies at 650-725 °C and 8-11 Kb. The highest pressure record of 11.5-12.5 Kb at 600-680 °C, indicating conditions transitional between eclogite and amphibolite facies, yielded the sample of retrograded eclogite with preserved symplectite. The partial P-T path of retrograded eclogite shows a moderate uplift between 40-30 km and a re-equilibration at depth of about 30 km.

*Key words:* eclogite, mineral chemistry, P-T conditions, retrogression, Staré Město Belt, West Sudetes, Variscides

## Introduction

Staré Město Belt (SMB), composed of the structurally lower Velké Vrbno Unit and upper Staré Město Unit (Květoň 1951, Skácel 1981) is situated at the eastern edge of western Sudetes, between the western Orlice-Sněžník Dome (Don et al. 1990) and the eastern Silesicum (Suess 1912). The structure of the SMB is in reality more complex than the above mentioned division shows (Kölbl 1927, Skácel - Vosyka 1959, Mísař in Svoboda ed. 1964). The presence of numerous small bodies of serpentinized peridotite and several occurrences of retrograded eclogite (Němec - Němcová 1977, Kopa 1989a,b) indicate that SMB is a suture melange (comp. Cháb 1987).

The purpose of this article is to present and compare compositional data and petrological evolution of eclogitic amphibolite and adjacent non-eclogitic garnetiferous amphibolite from northern part of the SMB.

## Samples and methods

A boudine of retrograded eclogite was recently discovered near the NE margin of the SMB during geological mapping of the sheet 14-223 Lipová Lázně (Fig. 1). The locality studied represents a small exposure situated between large body of amphibolite and mylonitized two-mica schist accompanying the Ramzová dislocation (identified with the Moldanubian overthrust by Suess 1912), located about 120 m westwards. In a wider vicinity, amphibolites, amphibolite-quartzofeldspathic stromatites (so called leptyno-amphibolite complex) and various more of less mylonitized schists with minor calc-silicates occur. Locally small bodies of biotite metagranite and/or biotite metapegmatite have been recorded. Numerous small bodies (dm up to about 20 m size) of garnetiferous amphibolite most probably representing retrograded eclogites occur as boudins in amphibolites and amphibolite - quartzofeldspathic stromatites (Fig. 1).

Sample 42a was collected from centre of the small exposure (approximately 2 x 1.5 m), it represents massive unfoliated rock rich in 1-2 mm sized grains of garnet, with green fine-grained matrix. Towards margin of the exposure, the matrix becomes black-green to black (sample 42b). About 15 m to the west, the sample of foliated garnetiferous amphibolite with up to 5 mm sized garnet porphyroblasts was collected for comparison from a rock debris (sample 42c).

Estimated modal (vol. %) composition and texture:

1. Sample 42a: garnet (30 %), hornblende (20 %), symplectite (40 %), quartz (3 %), plagioclase (2 %), rutile (3 %), ilmenite (1 %). Symplectite consists of clinopyroxene and plagioclase. Titanite, clinozoisite, epidote and Fe-sulphide are accessories, epidote occurs as inclusions in garnet only. The minerals are randomly oriented, the rock is not foliated.
2. Sample 42b: garnet (30 %), hornblende (50 %), symplectite (10 %), plagioclase (5 %), quartz (5 %), rutile (1 %), and ilmenite (1 %). The matrix amphibole and the symplectite are coarser-grained compared to sample 42a.
3. Sample 42c: hornblende (55 %), plagioclase (17 %), garnet (15 %), titanite (8 %), chloritized biotite (3 %), ilmenite (2 %). Quartz, apatite, rutile, zircon, potassium feldspar and calcite occur as

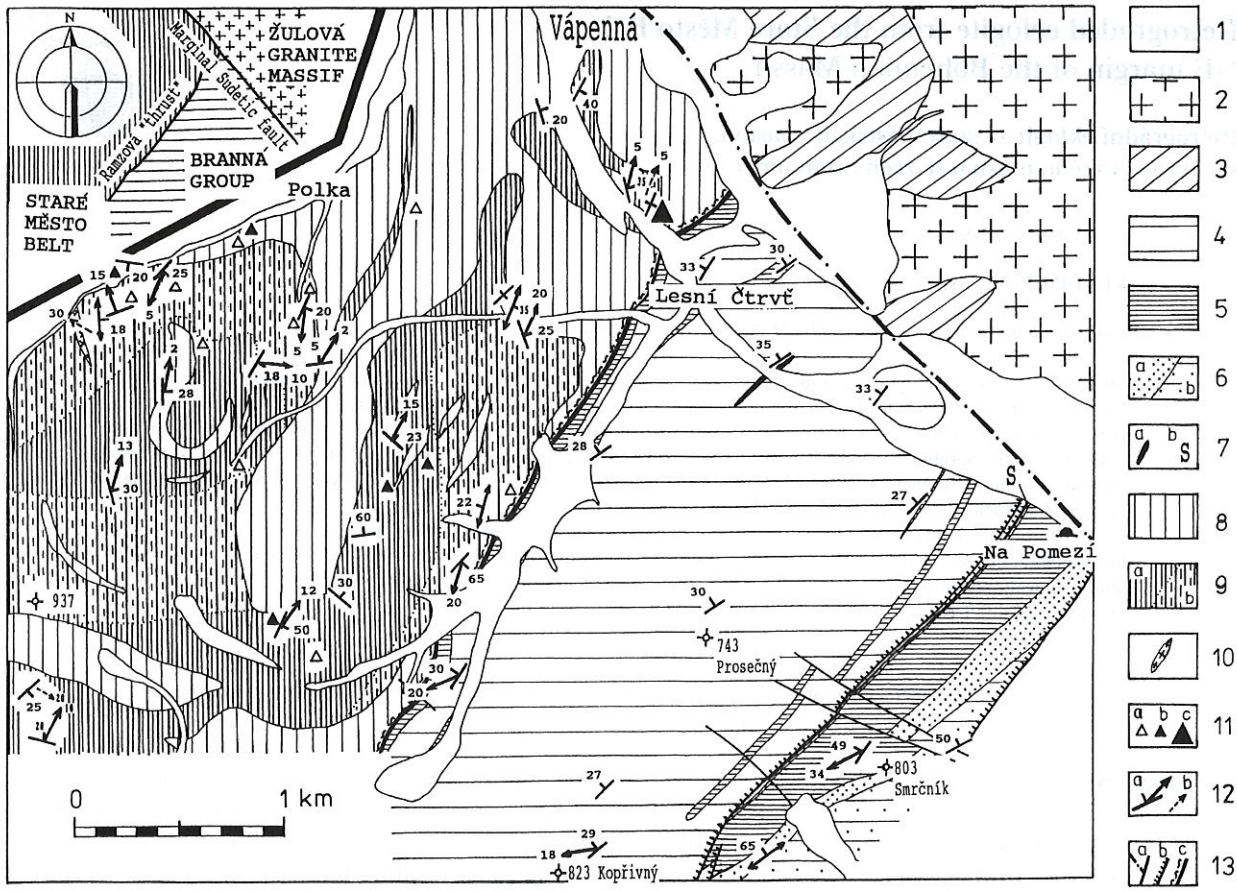


Fig. 1. Simplified geological map of the area studied
*1* - Quaternary; *2-3* - Žulová Granite Massif (late Variscan): *2* - Granite, *3* - Roof pendants (migmatite and calc-silicate rocks); *4-7* - Branná Group, Devonian: *4* - Phyllite, *5* - Marble, 6a - Quartzite, Quartz metaconglomerate, 6b - Quartz-rich schist, *7a* - Metabasites, *7b* - Staurolite schist (tectonic slice); *8-11* - Staré Město Belt: *8* - Complex with the prevalence of mylonitized gneisses and mica-schists, *9a* - Amphibolite (generally garnet-free), *9b* - Amphibolite-quartzofeldspathic stromatite, *10* - Metagranite, *11* - Occurrences of retrograded eclogites: *a* - free blocks, *b* - exposures, *c* - the locality studied; *12a* - Dip of foliation, *12b* - Stretching lineation; *13a* - Normal fault, *13b* - Low-angle fault, *13c* - Mylonitized zone (Ramzová "thrust")

accessories. The rock is foliated, amphibole and biotite display parallel arrangement.

The samples were analysed with energy-dispersive electron microprobe Camscan-Link eXL, operating conditions 20 kV, 3 nA, counting time 80s, and Co as calibration element. Synthetic oxides, plagioclase and potassium feldspar were used as standards. The analyses were made in the Laboratories of the Czech Geological Survey in Prague, J. Frýda, analyst.

## Mineral chemistry

### *Garnet*

Garnet forms subhedral to anhedral porphyroblasts in samples 42a and 42b (Plate I a-b), the size of which varies usually between 0.2-1 mm, the groups of porphyroblasts can reach the size of about 2 mm. The porphyroblasts include frequently rutile, quartz, in marginal portions also hornblende, in the sample 42a also Fe-poor epidote.

Garnet compositions of samples 42a and 42b range from Alm 51-59, Grs 17-31, Pyr 13-17, (Tab. 1). Spessartite concentration is low (1.3-2.7 mol. %). The concentration of andradite calculated on the basis of garnet stoichiometry varies between 1.5-5 mol. %. Garnets are Cr-low (<0.1 wt. % $Cr_2O_3$), $TiO_2$ concentrations vary in the range 0.0X-0.27 wt. %. Garnets are zoned (Tab. 1, Fig.2) with the maximum chemical gradient (inrease in Grs and decrease in Alm, Pyr and Mg/(Mg+Fe) ratio) located at the transition from the central, inclusion-rich zone, to the marginal, inclusion-poor zone.

Garnet from the sample 42c exhibits Mn-rich core with a low number of inclusions and a wide marginal zone enriched in Alm and Pyr with numerous inclusions of quartz, plagioclase, chloritized biotite, amphibole, ilmenite and titanite. Character of the zoning indicates generally prograde evolution under amphibolite facies conditions (e.g. Tracy 1982). As shown from Fig. 2, Pyr, Alm and XMg increase rimwards not continuously, but in two steps, coinciding with a decrease of Grs concentration. These variations can represent an alternation of periods of loading followed by slight temperature increase and moderate decompression in closing stages of garnet growth. Note, that here is not

Table 1. Chemical analyses, numbers of ions based on 12 atoms of oxygen and molar per cent of garnet-end-members from samples 42a (1414-1420), 42b (1368-1370) and 42c (2263-47)

| | 1414c | — 1415 | — 1416 | — 1419 | → 1420r | 1368c | — 1369 | → 1370r | 2263c | — 2254 | → 2247r |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 37.50 | 37.97 | 37.55 | 37.95 | 37.99 | 38.13 | 36.75 | 37.02 | 38.00 | 37.97 | 37.65 |
| $TiO_2$ | 0.09 | 0.17 | 0.13 | 0.24 | 0.0 | 0.27 | 0.15 | 0.08 | 0.26 | 0.06 | 0.24 |
| $Al_2O_3$ | 20.77 | 21.15 | 20.85 | 21.17 | 21.13 | 21.10 | 20.57 | 20.65 | 21.03 | 21.18 | 20.95 |
| FeO* | 27.88 | 24.42 | 25.89 | 5.56 | 25.15 | 27.31 | 27.28 | 27.71 | 25.76 | 26.89 | 27.83 |
| MgO | 4.31 | 4.25 | 3.62 | 4.29 | 4.35 | 4.23 | 4.18 | 4.29 | 1.38 | 1.98 | 2.41 |
| MnO | 0.94 | 0.58 | 0.66 | 0.84 | 0.74 | 0.81 | 1.18 | 1.14 | 4.53 | 1.87 | 0.62 |
| CaO | 7.63 | 10.47 | 9.91 | 10.03 | 9.62 | 8.90 | 8.13 | 7.85 | 9.81 | 10.32 | 9.51 |
| Total | 99.02 | 99.01 | 98.61 | 100.08 | 99.00 | 100.75 | 98.24 | 98.74 | 100.77 | 100.27 | 99.21 |
| Si | 2.990 | 2.997 | 3.000 | 2.978 | 3.003 | 2.984 | 2.963 | 2.969 | 3.010 | 3.003 | 3.005 |
| Ti | 0.005 | 0.010 | 0.008 | 0.014 | - | 0.016 | 0.009 | 0.005 | 0.015 | 0.004 | 3.014 |
| Al | 1.954 | 1.967 | 1.964 | 1.958 | 1.969 | 1.946 | 1.954 | 1.952 | 1.963 | 1.974 | 1.971 |
| Fe | 1.861 | 1.612 | 1.730 | 1.677 | 1.663 | 1.787 | 1.839 | 1.859 | 1.706 | 1.779 | 1.858 |
| Mg | 0.513 | 0.500 | 0.431 | 0.502 | 0.513 | 0.494 | 0.502 | 0.513 | 0.163 | 0.233 | 0.287 |
| Mn | 0.064 | 0.039 | 0.045 | 0.056 | 0.050 | 0.054 | 0.081 | 0.077 | 0.304 | 0.233 | 0.042 |
| Ca | 0.653 | 0.885 | 0.849 | 0.843 | 0.815 | 0.746 | 0.702 | 0.675 | 0.832 | 0.125 | 0.813 |
| TOTAL | 8.070 | 8.010 | 8.027 | 8.029 | 8.013 | 8.027 | 8.051 | 8.050 | 7.993 | 8.019 | 8.000 |
| %Alm | 59.2 | 52.5 | 56.0 | 53.3 | 54.2 | 56.9 | 57.4 | 58.1 | 56.2 | 58.7 | 61.5 |
| %Prp | 17.0 | 16.7 | 14.3 | 16.6 | 17.1 | 16.4 | 16.6 | 17.0 | 5.5 | 7.8 | 9.6 |
| %Sps | 2.1 | 1.3 | 1.5 | 1.9 | 1.7 | 1.8 | 2.7 | 2.6 | 10.2 | 4.2 | 1.4 |
| %Grs | 17.8 | 27.7 | 25.8 | 24.8 | 25.3 | 21.5 | 17.9 | 17.0 | 26.7 | 28.1 | 26.5 |
| %Adr | 3.9 | 1.8 | 2.4 | 3.4 | 1.8 | 2.4 | 5.4 | 5.3 | 1.4 | 1.2 | 0.9 |
| Mg/(Mg+Fe) | 0.216 | 0.237 | 0.199 | 0.230 | 0.236 | 0.225 | 0.214 | 0.216 | 0.087 | 0.116 | 0.134 |

* all iron as FeO, c - centre, r - rim

an increase of Sps concentration near the rim, indicating retrogressive re-equilibration at lower temperatures. The compositions (Tab. 1) vary in the range: Alm 56-62, Grs 24-30, Pyr 5-10, Sps 0.4-10, Adr 1-3; $TiO_2$ concentrations vary in the range 0.06-0.26 wt. %.

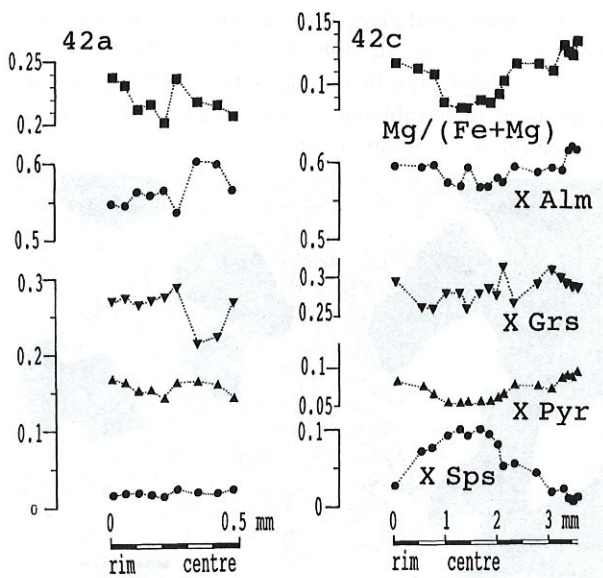


Fig. 2. Garnet zoning profiles. Sample 42a - retrograded eclogite, sample 42c - garnetiferous amphibolite

## *Amphibole*

Subhedral to euhedral porphyroblasts having the size 0.X-2 mm exhibit intense grass-green (Z) to yellow green (X) pleochroism. All amphiboles studied are calcic, being relatively compositionaly homogeneous in the respective sample (Fig. 3, Tab. 2).

Amphibole from sample 42a is ferroan pargasitic-edenitic hornblende according to Leake (1978), with Si = 6.41-6.56, Ti = 0.08-0.13, K = 0.15-0.18, $(Na+K)_A$ = 0.67-0.71 and Mg/(Mg+Fe) = 0.56-0.58. (24 O+OH p.F.U.)

Amphibole from sample 42b (edenitic-ferroedenitic hornblende) shows small but significant differences of all these parameters in comparison with the sample 42a; Si = 6.62-6.71, Ti = 0.06, K = 0.10, $(Na+K)_A$ = 0.41-0.47, Mg/(Mg+Fe) = 0.48-0.51, indicating a decrease in P-T conditions.

Amphibole from sample 42c (ferroan pargasitic hornblende) displays the Ti, K and $(Na+K)_A$ values between those of the samples 42a and 42b, but it is significantly much ferroan (Mg/(Mg+Fe) = 0.41-0.44), see Fig.3, Tab. 2.

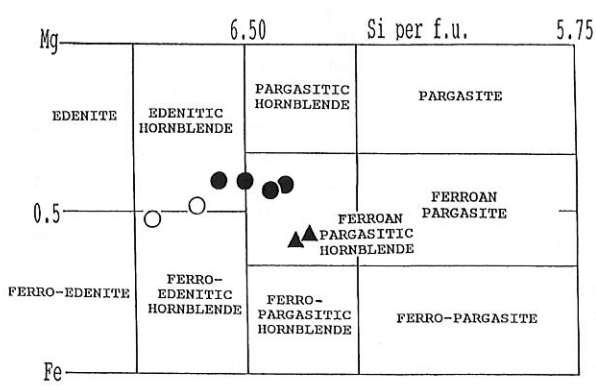


Fig. 3. Hornblende compositions in the plot after Leake (1978) *Full circles* - retrograded eclogite (sample 42a), *open circles* - garnetiferous amphibolite of eclogite origin (sample 42b), *triangles* - garnetiferous amphibolite (sample 42c)

Table 2. Amphibole analyses from samples 42a (1340-51), 42b (1367-72) and 42c (2265-69). Numbers of ions based on 22 oxygen atoms and 2 (OH)

| | 1340 | 1341 | 1347 | 1351 | 1367 | 1372 | 2265 | 2269 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 42.85 | 43.43 | 43.03 | 44.02 | 44.14 | 44.15 | 41.97 | 42.10 |
| $TiO_2$ | 1.05 | 1.10 | 0.76 | 0.75 | 0.55 | 0.50 | 1.00 | 0.85 |
| $Al_2O_3$ | 13.09 | 11.52 | 14.62 | 14.11 | 11.61 | 11.18 | 13.72 | 14.14 |
| FeO* | 14.51 | 14.53 | 14.09 | 13.95 | 17.79 | 17.43 | 19.39 | 18.50 |
| MgO | 10.72 | 11.14 | 10.24 | 10.94 | 10.53 | 9.02 | 7.52 | 8.10 |
| MnO | 0.22 | 0.0 | 0.0 | 0.0 | 0.24 | 0.37 | 0.21 | 0.26 |
| CaO | 11.20 | 11.12 | 9.63 | 9.92 | 11.10 | 11.71 | 11.08 | 11.05 |
| $Na_2O$ | 2.28 | 2.29 | 2.81 | 2.55 | 1.04 | 1.28 | 1.47 | 1.43 |
| $K_2O$ | 0.91 | 0.78 | 0.95 | 0.88 | 0.54 | 0.52 | 0.78 | 0.80 |
| $H_2O$** | 2.00 | 1.99 | 2.00 | 2.03 | 2.00 | 1.97 | 1.97 | 1.98 |
| Total | 98.83 | 97.90 | 98.13 | 99.15 | 99.54 | 98.13 | 99.11 | 99.21 |
| Si | 6.420 | 6.560 | 6.437 | 6.501 | 6.607 | 6.713 | 6.389 | 6.362 |
| Ti | 0.118 | 0.125 | 0.085 | 0.083 | 0.062 | 0.057 | 0.114 | 0.097 |
| $Al^{IV}$ | 1.580 | 1.440 | 1.563 | 1.499 | 1.393 | 1.287 | 1.611 | 1.638 |
| $Al^{VI}$ | 0.731 | 0.611 | 1.015 | 0.956 | 0.655 | 0.716 | 0.850 | 0.881 |
| Fe | 1.818 | 1.836 | 1.763 | 1.723 | 2.227 | 2.216 | 2.468 | 2.338 |
| Mg | 2.394 | 2.508 | 2.284 | 2.408 | 2.350 | 2.044 | 1.706 | 1.825 |
| Mn | 0.028 | - | - | - | 0.030 | 0.048 | 0.027 | 0.033 |
| Ca | 1.798 | 1.800 | 1.544 | 1.570 | 1.780 | 1.908 | 1.807 | 1.789 |
| Na | 0.662 | 0.671 | 0.815 | 0.730 | 0.302 | 0.378 | 0.434 | 0.419 |
| K | 0.174 | 0.150 | 0.181 | 0.166 | 0.103 | 0.101 | 0.151 | 0.154 |
| OH | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| TOTAL | 17.721 | 17.701 | 17.687 | 17.636 | 17.509 | 17.468 | 17.557 | 17.556 |
| Mg/(Mg+Fe) | 0.568 | 0.577 | 0.564 | 0.583 | 0.513 | 0.480 | 0.409 | 0.438 |

* all iron as FeO, ** $H_2O$ calculated

Symplectite from sample 42a consists of fine clinopyroxene and plagioclase. Minor fine hornblende associated closely with the symplectites is probably younger (Fig. 4). The width of plagioclase lamellae is 5 to 10 microns (Plate I c-d, Fig. 4). Clinopyroxene is sodic diopside (about 2.5 wt. % $Na_2O$ and 5 wt. % $Al_2O_3$), with the Mg/(Mg+Fe) ratio 0.74-0.76 and the jadeite concentration 17-17.5 mol. %; the content of acmite component is negligible (Tab. 3, analyses 1342, 1344). Associated plagioclase is albite-sodic oligoclase, 10-14 mol. % An (Tab. 4, analyses 1343, 1349).

Table 3. Chemical analyses of clinozoisite-epidote and clinopyroxene. Numbers of ions based on 12 oxygen and 1 (OH) (clinozoisite-epidote) and 6 oxygen atoms (clinopyroxene), respectively

| | czo 1330 | ep 2274 | ep 2275 | cpx 1342 | cpx 1344 |
|---|---|---|---|---|---|
| $SiO_2$ | 38.77 | 39.22 | 38.75 | 52.77 | 53.06 |
| $TiO_2$ | 0.0 | 0.14 | 0.19 | 0.14 | 0.11 |
| $Al_2O_3$ | 30.22 | 27.04 | 28.62 | 4.95 | 4.94 |
| $Fe_2O_3$** | 3.15 | 7.09 | 6.14 | | |
| FeO* | | | | 7.20 | 6.77 |
| MgO | 0.30 | 0.0 | 0.0 | 11.72 | 11.70 |
| MnO | 0.0 | 0.11 | 0.0 | 0.0 | 0.0 |
| CaO | 23.42 | 23.18 | 23.52 | 20.57 | 20.70 |
| $Na_2O$ | 0.0 | 0.0 | 0.0 | 2.47 | 2.51 |
| $H_2O^c$ | 1.91 | 1.91 | 1.93 | | |
| Total | 97.47 | 98.69 | 99.15 | 99.82 | 99.79 |
| Si | 3.036 | 3.076 | 3.018 | 1.952 | 1.958 |
| Ti | - | 0.008 | 0.011 | 0.004 | 0.003 |
| Al | 2.789 | 2.499 | 2.627 | 0.216 | 0.216 |
| $Fe^{3+}$ | 0.185 | 0.418 | 0.360 | | |
| $Fe^{2+}$ | | | | 0.223 | 0.209 |
| Mg | 0.035 | - | - | 0.646 | 0.644 |
| Mn | - | 0.007 | - | - | - |
| Ca | 1.965 | 1.948 | 1.963 | 0.815 | 0.818 |
| Na | - | - | - | 0.177 | 0.180 |
| OH | 1.000 | 1.000 | 1.000 | | |
| TOTAL | 9.010 | 8.956 | 8.979 | 4.033 | 4.033 |

* all iron as FeO, ** all iron as $Fe_2O_3$, $H_2O^c$ calculated

The symplectite in sample 42b is coarser-grained, composed of hornblende + plagioclase with possible scarce relics of clinopyroxene.

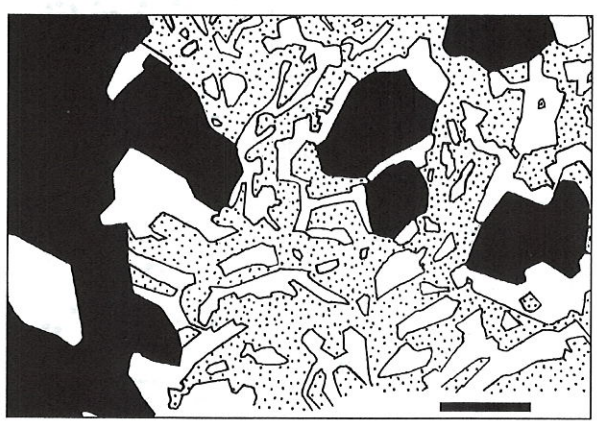

Fig. 4. Line-drawing based on back-scattered electron image of symplectite from sample 42a. *White* - plagioclase, *dotted* - clinopyroxene, *black* - hornblende. The black bar represents 30 microns

## *Plagioclase*

Matrix plagioclase of the sample 42a is more calcic, in comparison with the symplectite plagioclase and exhibits a slight zoning in the range 17-21 mol. % An with a decrease of XAn towards rim (Tab. 4, analyses 1345-46).

Table 4. Chemical compositions of plagioclase from samples 42a (1343-1349), 42b (1371-1373) and 42c (2251-2270). Numbers of ions calculated on the basis of 8 oxygen atoms

| | 1343 | 1345 | 1346 | 1349 | 1371 | 1373 | 2251 | 2259 | 2270 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 64.52 | 63.50 | 62.68 | 65.76 | 57.35 | 61.77 | 64.70 | 66.89 | 65.46 |
| $Al_2O_3$ | 21.46 | 22.06 | 23.00 | 21.13 | 26.00 | 22.05 | 22.07 | 21.00 | 22.87 |
| FeO | 0.38 | 0.41 | 0.37 | 0.22 | 0.35 | 0.39 | 0.18 | 0.19 | 0.09 |
| CaO | 2.86 | 3.57 | 4.35 | 2.09 | 8.44 | 4.63 | 3.15 | 2.55 | 3.28 |
| $Na_2O$ | 9.91 | 9.56 | 8.74 | 10.01 | 6.39 | 8.52 | 9.60 | 10.25 | 9.97 |
| $K_2O$ | 0.18 | 0.12 | 0.17 | 0.19 | 0.08 | 0.18 | 0.13 | 0.19 | 0.14 |
| Total | 99.31 | 99.22 | 99.31 | 99.40 | 98.70 | 98.44 | 99.83 | 101.95 | 101.72 |
| Si | 2.866 | 2.830 | 2.792 | 2.907 | 2.602 | 2.780 | 2.852 | 2.883 | 2.838 |
| Al | 1.124 | 1.159 | 1.208 | 1.101 | 1.395 | 1.217 | 1.147 | 1.117 | 1.164 |
| Fe | 0.014 | 0.015 | 0.014 | 0.008 | 0.013 | 0.015 | 0.007 | 0.007 | 0.003 |
| Ca | 0.136 | 0.170 | 0.208 | 0.099 | 0.410 | 0.223 | 0.149 | 0.113 | 0.152 |
| Na | 0.854 | 0.826 | 0.755 | 0.858 | 0.562 | 0.743 | 0.820 | 0.857 | 0.838 |
| K | 0.010 | 0.007 | 0.010 | 0.011 | 0.005 | 0.010 | 0.007 | 0.010 | 0.008 |
| TOTAL | 5.004 | 5.007 | 4.986 | 4.984 | 4.987 | 4.989 | 4.892 | 4.987 | 5.003 |
| % An | 13.61 | 17.00 | 21.36 | 10.23 | 42.20 | 22.85 | 15.27 | 11.50 | 15.26 |

In the sample 42b, the composition varies in a wide range of An 23-42.

In the sample 42c, plagioclase occurs both as inclusions in garnet porphyroblasts and as matrix mineral. Matrix plagioclase contains about An 15 (Tab. 4, analyse 2270). Plagioclase, forming inclusions in garnet is zoned, with an increase of An (11.5-17.6) towards rim. Furthermore, the XAn of plagioclase inclusions increases towards rim of garnet porphyroblast.

### *Clinozoisite - epidote*

In the sample 42a, Fe-rich clinozoisite - Fe-poor epidote forms small, 5-10 microns sized rounded inclusions, concentrated together with quartz, mainly in the cores of garnet porphyroblasts. The concentration of $Fe_2O_3$ is 6-7 wt. % (Tab. 3, analyses 2274, 2275). Clinozoisite with 3.15 wt. % $Fe_2O_3$ was recorded as a single grain rimming garnet porphyroblast in the same sample (Tab. 3, analysis 1330).

### *Rutile, ilmenite and titanite*

Rutile occurs frequently as a matrix mineral and as inclusions in garnet porphyroblasts in samples 42a and 42b. Rutile aggregates are rounded to quite irregular, up to first tenths of mm. Rutile associates with less abundant ilmenite, both minerals are frequently replaced by titanite. In the sample 42c, titanite strongly prevails over other Ti-minerals, it forms abundant lenticular to equant porphyroblasts sized 0.1-0.3 mm, arranged in the more or less continuous belts parallel with the foliation plane. Rutile occurs as small inclusions in titanite in the sample 42c. Analyses of titanite and ilmenite are given in Tab. 5.

### *Biotite and products of its decomposition*

Biotite in the sample 42c is strongly chloritized or rarely decomposed to the assemblage: chlorite + titanite + plagioclase (An 31) + potassium feldspar (Ab 1.2). Although biotite displays slight brown pleochroism in some places, microanalyses give only traces to 1.1 wt. % $K_2O$. Mg/(Mg+Fe) ratio, equal to 0.41 to 0.43, seems to be independent of $K_2O$ concentration. The aggregates replacing biotite exhibit a character of symplectite with lenticular (5-30 microns thick) grains of both feldspars (potassium feldspar prevails) arranged parallel with the original biotite cleavage.

Table 5. Chemical analyses of titanite and ilmenite from samples 42a (1332-37) and 42c (1257-64). Numbers of ions based on N oxygen atoms

| | tit 1337 | ilm 1332 | ilm 1335 | ilm 2258 | tit 2257 | tit 2264 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 30.15 | 0.24 | 0.25 | 0.26 | 30.29 | 30.23 |
| $TiO_2$ | 38.78 | 50.43 | 52.43 | 51.48 | 27.15 | 38.86 |
| $Al_2O_3$ | 0.80 | 0.0 | 0.0 | 0.0 | 1.69 | 0.75 |
| $Cr_2O_3$ | 0.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.15 |
| FeO* | 0.39 | 4.65 | 45.22 | 44.74 | 0.50 | 0.28 |
| MgO | 0.10 | 0.0 | 0.82 | 0.0 | 0.0 | 0.0 |
| MnO | 0.0 | 1.55 | 0.89 | 1.80 | 0.0 | 0.0 |
| CaO | 27.85 | 0.0 | 0.0 | 0.08 | 28.13 | 28.19 |
| Total | 98.07 | 96.87 | 99.61 | 98.36 | 97.76 | 98.47 |
| N | 10 | 6 | 6 | 6 | 10 | 10 |
| Si | 2.007 | 0.012 | 0.013 | 0.013 | 2.019 | 2.004 |
| Ti | 1.941 | 1.975 | 1.984 | 1.982 | 1.862 | 1.937 |
| Al | 0.063 | - | - | - | 0.133 | 0.059 |
| $Cr^{3+}$ | 0.005 | - | - | - | - | 0.008 |
| Fe | 0.021 | 1.945 | 1.904 | 1.916 | 0.028 | 0.016 |
| Mg | 0.010 | - | 0.061 | - | - | - |
| Mn | - | 0.068 | 0.038 | 0.078 | - | - |
| Ca | 1.987 | - | - | 0.004 | 2.009 | 2.002 |
| TOTAL | 6.034 | 4.000 | 4.000 | 3.993 | 6.051 | 6.026 |

* all iron as FeO

## Thermobarometry

Thermometers based on cation exchange among garnet - hornblende (Graham - Powell 1984), hornblende - plagioclase (Blundy - Holland 1990) and garnet - clinopyroxene (Powell 1985) were applied; furthermore a garnet - hornblende - plagioclase barometer (Kohn - Spear 1990) and a barometer based on molar fraction of jadeite in clinopyroxene (Holland 1980) were used. All iron analysed was assumed as divalent for thermo-

Table 6. Thermobarometric data of the samples studied

| Thermobarometer | Reference | 42a | 42b | 42c | |
|---|---|---|---|---|---|
| Grt-Cpx | Powell (1985) | 590-680 | | | (°C) |
| Grt-Hb | Graham - Powell (1984) | 680-710 | 680-725 | 600-680 | (°C) |
| Hb-Plg | Blundy - Holland (1990) | 600-670 | 630-690 | 680-725 | (°C) |
| Grt-Hb-Plg | Kohn - Spear (1990) | 11-13 | 8-11 | 9.3-11 | (Kb) |
| Cpx-Plg-Qtz | Holland (1980) | 11.5-12.5 | | | (Kb) |

barometric calculations because garnet-bearing amphibolites display generally low $Fe^{3+}$ concentrations in contrast to garnet-free amphibolites and the recalculations schemes may significantly overestimate $Fe^{3+}$ content in hornblende (Graham 1974, Graham - Powell 1984). Mineral compositions are within the limits of thermometers and barometers used. P-T conditions calculated for samples studied are consistent for all geothermobarometers applied, although here is the textural evidence (samples 42a and 42b), that garnet, clinopyroxene and hornblende originated in different stages of petrological evolution. However, only slight discrepancy between garnet - amphibole and garnet clinopyroxene thermometry shows, that partial re-equilibration was attained between coexisting minerals. The problem of stability of "eclogitic" amphibolites and application of thermobarometers is widely discussed e.g. by Ghent - Stout (1986) and Graham - Powell (1984). Marginal garnet compositions and matrix hornblende compositions were taken for thermobarometric calculations.

Sample 42a yielded temperatures ranging from 590 to 680 °C for clinopyroxene - plagioclase (symplectitic) pairs and 600-670 °C for hornblende - plagioclase pairs. The temperatures derived from garnet - hornblende pairs are slightly higher - 680-710 °C. The minimum pressures calculated using garnet-hornblende - plagioclase barometer (for temperature range 600-680 °C) are 11-13 Kb. Based on molar fraction of jadeite in clinopyroxene (Holland 1980), the minimum pressures, 11.5-12.5 Kb were inferred for the same temperature range, displaying good agreement with pressures calculated using garnet hornblende-plagioclase barometer.

Sample 42b yielded slightly lower pressures (8-11 kb), and the same or slightly higher temperatures (630-690 °C for hornblende-plagioclase pairs and 680-725 °C for garnet-hornblende pairs).

Although of different texture, mineral assemblage and garnet zoning pattern, P-T conditions calculated for sample 42c are similar to those of 42b. However, in contrast to samples 42a and 42b, the P-T conditions calculated represent most probably a metamorphic peak. The increase of the XAn in plagioclase inclusions towards rim of garnet porphyroblast (in sample 42c) associated in marginal portion with the decrease of XGrs, versus increase of XPyr and Mg/(Mg+Fe) towards rim and low XSps concentrations in the outermost rim, provide evidence for decompression and contemporaneous temperature increase in closing stages of garnet crystallization. The garnet-hornblende-plagioclase barometer gives the pressures of 9.3-11 Kb, the temperatures were constrained at 680-725 °C at 10 kb (hornblende-plagioclase pairs) and at 650-680 °C (garnet-hornblende pairs).

## Conclusions

Strongly retrograded eclogite boudins occur in the amphibolite and amphibolite-quartzofeldspathic complex of the Staré Město Belt. During an uplift and decompression, eclogitic rocks were hydrated and transformed to garnet amphibolites, relics of eclogitic assemblages are scarce. Consistent P-T values and textural criteria indicate, that samples attained local equilibrium during decompression under conditions on the transition from eclogite to amphibolite facies. Application of a variety of thermometers and barometers yielded a temperature range 600-725 °C and a pressure 8-12.5 kb for samples studied (Fig. 5). The assemblages reflecting pre-eclogite stage and the peak of eclogite metamorphism are not preserved. The highest pressure recorded - 11.5-12.5 Kb at 600-680 °C, yielded the sample 42a; in the more retrograded sample 42b the values of 630-725 °C, 8-11 Kb were obtained. Comparing P-T record of samples 42a and 42b (Fig. 5), a retrograde, decompressional P-T path, indicating moderate uplift can be constructed (see e.g. England - Thompson 1984). A prograde zoning of garnet from sample 42c shows, that this rock cannot represent retrograded eclogite. However, the values of P and T calculated (650-725 °C, 9.3-11 Kb), show a convergence of PT-paths and common final equilibration of the samples studied.

Numerous occurrences of granulitic and eclogitic rocks have been reported from Western Sudetes (from the Czech and especially from Polish part of Orlice-Klodsko Unit), e.g., Smulikovski 1967, Bakun-Czubarow 1968, Smulikovski - Bakun-Czubarow 1973, Pouba et al. 1985, Smulikowski - Smulikowski 1985, Bakun-Czubarow - Brueckner 1991. Their protolith age was estimated at 510 MA, the age of the peak of eclogite metamorphism at 329-352 MA (Bakun-Czubarow - Brueckner 1991). The authors cited range these rocks to transitional facies between eclogites and granulites. The temperatures in the range of 620 to 880 °C and pressures at 14-22 Kb were recorded for eclogitic and granulitic rocks from various tectonic partial units of the Orlice-Klodsko Unit. Petrological composition and PT-paths of these rocks

give evidence for relatively fast uplift. (e.g. Bakun-Czubarow 1986, Bakun-Czubarow - Brueckner 1991, see Fig. 5).

The SMB eclogites studied are much more retrogressed in comparison with granulite and eclogite rocks of the inner part of the Orlice-Klodsko Unit. Their P-T path indicates moderate uplift.

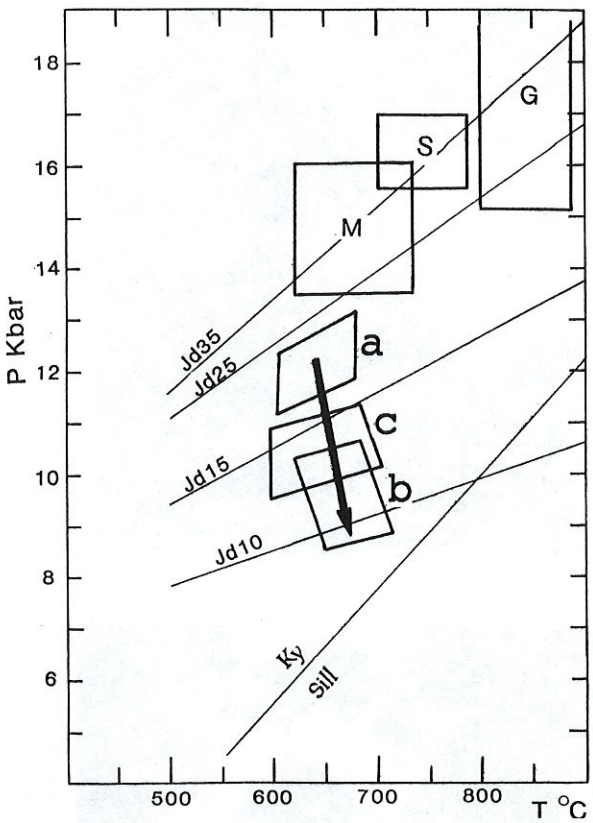


Fig. 5. P-T diagram and partial P-T-t path for the retrograded eclogite (a and b) and garnetiferous amphibolite (c) from the Staré Město belt compared with P-T boxes for eclogites and granulites from the centre of Orlice-Klodsko Unit (after Bakun-Czubarow - Brueckner 1991): M - eclogites of the Miedzygorze tectonic unit, S - eclogites of the Snieznik tectonic unit, G - granulites of the Gieraltów tectonic unit. The jadeite isopleths are after Holland (1980), the kyanite-sillimanite univariant curve from Salje (1986)

*Appendix*: During the advance of geological mapping of the Staré Město Belt in 1995 (1:25 000 sheet map Lipová Lázně), a unique sample of retrograded eclogite with preserved relics of primary omphacite was found 2.5 km south of Nýznerov (sampling point No 280/2). The sample displays a similar assemblage and mineral compositions as sample 42a. In addition, it contains scarce relics (sized 0.X-2 mm) of primary omphacite (Jd = 28-31.5 mol.%, Mg/(Mg+Fe) = 0.73-0.76, $Cr_2O_3$ = 0.7 wt.%) in the matrix, with small inclusions of quartz, Cr-rutile and chlorapatite. Omphacite relics are rimmed by complicated corona of clinopyroxene-plagioclase symplectite, with the jadeite content varying in a wide range of 3-19.5 mol.% (prevailing compositions correspond to 17-19 mol.%). P-T conditions (T = 710-745 °C, $P_{min}$ = 14.5-15.5 Kb) calculated using garnet and omphaceite compositions, represent most probably a peak of eclogite metamorphism.

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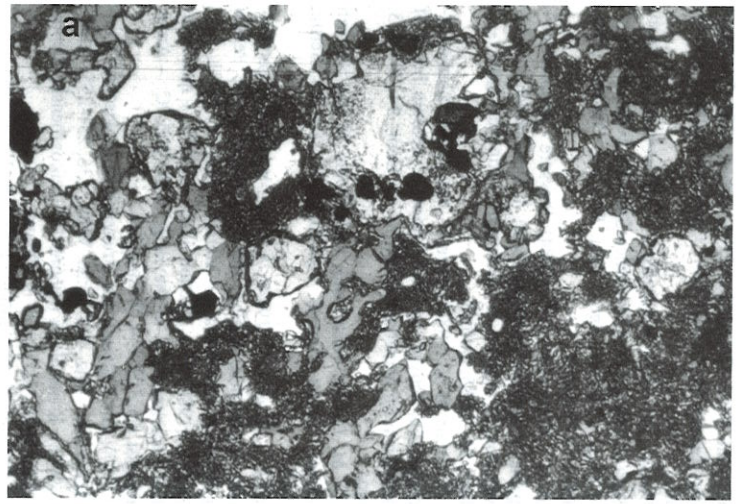
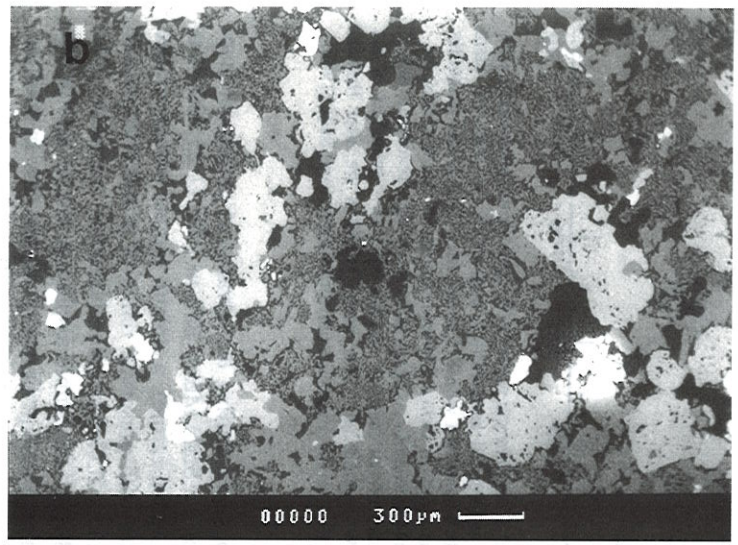
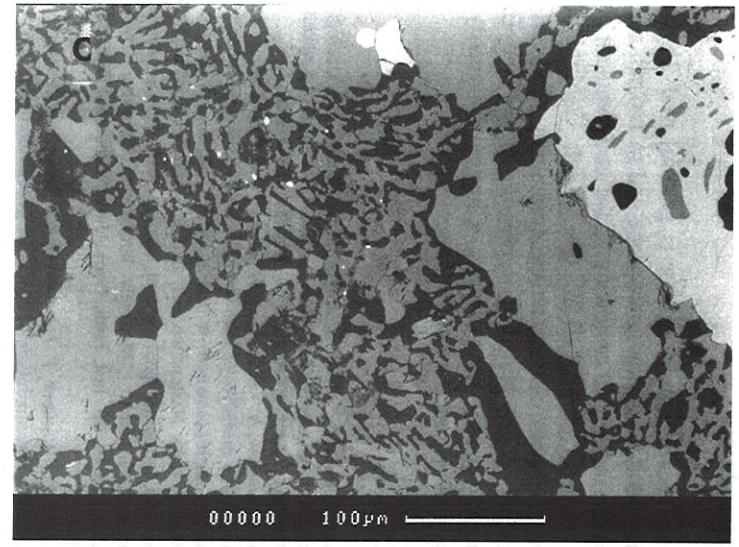



a - Photomicrograph of sample 42a with fine symplectite aggregates, white plagioclase and quartz, gray hornblende and lighter garnet porphyroblasts, rutile is nearly black. Note the absence of kelyphytic rims and irregullar shape of symplectite aggregates. The photo width represents 1.8 mm




b - backscattered electron image of sample 42. Light-coloured garnet porphyroblasts associate both with symplectite and with coarser - grained gray hornblende. Quartz and plagioclase are black




c - Detail from 1b. Fine symplectite associates with gray, coarse hornblende and with light-gray garnet. The inclusions in garnet are quartz (black) and Fe-poor epidote (gray)


d - Detail from 1a. Width of the area shown is 0.75 mm

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## Retrográdní eklogit ze staroměstského pásma, sv. okraj Českého masivu

Při sv. okraji staroměstského pásma (v. okraj orlicko-kladské klenby) byl nalezen silně amfibolizovaný eklogit. Zatímco primární eklogitový granát je zachován (Alm 51-59, Grs 17-31, Pyr 13-17, Sps 1.3-2.1), původní omfacit (Cpx I) je kompletně nahrazen symplektitem klinopyroxenu II (Jd 18) a plagioklasu I (An 10-14). Retrogrese postupně vedla k zatlačování symplektitu amfibolem a novotvořeným plagioklasem II (An 17-42). Vzorek neeklogitového granátického amfibolitu z těsného sousedství vykazuje prográdní zonálnost granátu v rozmezí Alm 56-62, Grs 24-30, Pyr 5-10, Sps 0.4-10, charakteristickou pro metamorfózu v amfibolitové facii. Vypočtené teploty a tlaky ukázaly, že obě tyto horniny s původně rozdílnou PT-historií byly společně reekvilibrovány v podmínkách amfibolitové facie při 650-725 °C a 8-11 kb. Reliktní eklogitová asociace vznikala při teplotách 600-680 °C a tlacích 11.5-12.5 Kb, v podmínkách na rozhraní eklogitové a amfibolitové facie. Částečná PT-trajektorie ukazuje na středně rychlý uplift mezi 40-30 km.