Meta-harzburgites and meta-pyroxenites of the Austroalpine Sieggraben structural complex between Steinbach and Gschorrholz, Austria: An example of subducted mantle

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Abstract: The Sieggraben structural complex occupies a middle position in the Austroalpine basement nappe system in the Eastern Alps. Investigated area is located at the southeastern part of Austria between the Steinbach and Gschorrholz villages (approximately 150 km south of Vienna). The aim of this paper is to characterize petrographic and mineral chemical composition of meta-harzburgites and meta-pyroxenites. Identified mineral assemblage from selected microstructures of massive to sheared meta-pyroxenite and meta-harzburgite is composed of Ol, Opx, Cpx, zoned Amp, Chl, serpentine group minerals Atg/Ctl, spinel group minerals Spl, Hc and rare Tlc. Meta-harzburgites and meta-pyroxenites are members of a subduction complex.

Key words: Eastern Alps, Sieggraben structural complex, meta-harzburgite, meta-pyroxenite, petrography, mineral chemistry

1. INTRODUCTION

The Sieggraben eclogite-bearing structural basement complex at the south-eastern margin of the Eastern Alps contains metaultramafics (e.g., Putiš et al. 2000, 2002). According to Tollmann (1980), the Sieggraben structural complex is a part of the Middle Austroalpine tectonic unit in the Eastern Alps (Fig. 1). Although this complex is most likely a remnant of a pre-Alpine basement, it has a strong Alpine polyphase metamorphic-deformational overprint (Putiš et al. 2000, 2002). The geological and geotectonic evolution of this complex was characterized by Tollmann (1980), Frank et al. (1987), Frisch and Neubauer (1989), Neubauer et al. (1992), Neubauer and Frisch (1993), Neubauer (1994) and Froitzheim et al. (1996). The results of isotopic mineral and whole-rock dating were published by Dallmeyer et al. (1996, 1998), Thöni and Jagoutz (1993), Thöni (1999), Thöni et al. (2008) and Putiš et al. (1994, 2000) reporting Alpine metamorphic overprint ages. Based on the petrological and geothermobarometric data, the evolutionary P–T pathway of the host eclogite-bearing complex was suggested by Putiš et al. (2002) and Kromel et al. (2011).

Data on geological mapping, petrotectonics and petrology were published by Putiš et al. (1994, 2000, 2002) and Korikovsky et al. (1998). A brief characterization of petrography and mineral chemistry of the Sieggraben meta-harzburgites was reported by Hrvanović et al. (2014) from the area of Sieggraben and Schwarzenbach.

The goal of this paper is to present petrographic and mineral chemistry data related to evolutionary stages of a host meta-harzburgite and crosscutting meta-pyroxenite dikes from the Sieggraben structural complex in the area between the Steinbach and Gschorrholz villages in southeastern Austria (Fig. 1a). The studied mineral assemblages of meta-harzburgites and meta-pyroxenites provide rare information on tectonometamorphic evolution of mantle fragments in a subduction zone.

Mineral abbreviations used in our text, tables and figures are after Whitney and Evans (2010): Amp = amphibole, Atg = antigorite, Bt = biotite, Cal = calcite, Chl = chlorite, Chr = chromite, Clc = clinochlore, Ctl = chrysotile, Cpx = clinopyroxene, Di = diopside, En = enstatite, Fs = ferrosilite, Fo = forsterite, Grt = garnet, Hc = hercynite, Jd = jadeite, Mag = magnetite, Mhb = magnesioh hornblende, Ms = muscovite, OI = olivine, Omp = omphacite, Opx = orthopyroxene, Pl = plagioclase, Ph = phengite, Prg = pargasite, Qz = quartz, Rt = rutile, Srp = serpentine group, Spl = spinel, Tlc = talc, Tr = tremolite, Ts = tschermakite, Wo = wollastonite, Zo = zoisite, besides Carb = carbonates.

2. GEOLOGICAL SETTING OF THE SIEGGRABEN STRUCTURAL COMPLEX

The tectonostratigraphy of the Austroalpine (AA) structural complexes is based on the work of Tollmann (1980). Schmid et al. (2004) avoided Middle AA terminology, considering this part of the AA Unit as belonging to the Upper Austroalpine Unit after the Cretaceous collision (Neubauer 1994).
Field geological-structural mapping of the Sieggraben structural complex (SSC) in the area around Sieggraben (Putiš et al. 2000, 2002) determined two main types of thrust-faults and related meso- and microstructures: Early Cretaceous higher-temperature structures are defined by NNW–SSE trending high-pressure D1 mineral lineations reflected in high-pressure phases of Cpx–Omp, Zo and Amp–Prg, and also in the mostly medium-temperature D2 lineations of Qz, Pl, Amp in...
ductile layered mylonites. These higher-temperature structures are recognizable only in the internal parts of the AA SSC, and they are overprinted by D3 lower temperature WSW dipping stretching lineations in ductile blastomylonitic microstructures; particularly evident in the hanging wall. Low-angle normal faults, most likely active during late Cretaceous to Early Neogene, were observed in the footwall of the Austroalpine Metamorphic Series (AMS) and were investigated in 13 selected polished sections by polarized-light microscopy and microprobe analysis at the State Geological Institute of Bratislava. Petrographic studies of the Eocene Omp formation and its host meta-harzburgite were conducted in order to constrain the conditions of emplacement of the Omp Formation within the Austroalpine Metamorphic Series (AMS). The Omp Formation, a Late Cretaceous-Eocene calc-silicate rock (CSR) unit, is a part of the Austroalpine Metamorphic Series (AMS) and is characterized by high-grade metamorphic assemblages of meta-harzburgites and meta-pyroxenites. The Omp Formation is hosted by the Austroalpine Metamorphic Series (AMS) and is characterized by high-grade metamorphic assemblages of meta-harzburgites and meta-pyroxenites. The Omp Formation is a Late Cretaceous-Eocene calc-silicate rock (CSR) unit, which is a part of the Austroalpine Metamorphic Series (AMS) and is characterized by high-grade metamorphic assemblages of meta-harzburgites and meta-pyroxenites. The Omp Formation is a Late Cretaceous-Eocene calc-silicate rock (CSR) unit, which is a part of the Austroalpine Metamorphic Series (AMS), the latter exposed in large km-size block(s) in direct tectonic contact with the SSC (Fig. 1c). The host meta-harzburgite occurs below the described eclogitic complex; their contact is tectonic (sheared) and strongly weathered. The harzburgite is crosscut by at least two systems of pyroxenite dikes. Our study was focused on mineral assemblages of the host meta-harzburgite and the crosscutting meta-pyroxyenitic dikes as well.

3. MATERIALS AND METHODS

Hand specimens were collected from a road cut between the Gschorrholz and Steinbach (Fig. 1b) villages (all GS-2 specimens: N 47° 28.656', E 16°18.571; all GS-3 specimens: N 47° 28.667', E 16°18.552'), and a quarry in Steinbach (all ST specimens: N 47° 28.273', E 16°18.436'). Mineral composition and microstructures were investigated in 13 selected polished sections by polarized-light microscopy and microprobe Leica DM2500P at the Department of Mineralogy and Petrology, Comenius University in Bratislava. Chemical compositions of minerals were determined by a Cameca SX-100 electron microprobe at the State Geological Institute of Dohnýž Štúr in Bratislava. Analytical conditions were at 15 kV accelerating voltage and 20 nA beam current. Cameca Peak Sicht v. 4.2 software was used for data recalculation. We used following standards for calibration of the given elements (in brackets): albite (NaK), wollastonite (SiK, CaK), orthoclase (KK), forsterite (MgK), AlO, (AlK), fayalite (FeK), rhodonite (MnK), metallic Cr (CrK), V (VK), Ni (NK), TiO, (TiK). The beam diameter used was 5 and 10 μm, and/or 1-3 μm for exsolution lamellae and symplectites.

Mineral formulae were calculated on the basis of 4 oxygen anions for olivine, 15 (eNK) cations for amphibole, 4 cations for pyroxene, 3 cations for spinel, 14 oxygen anions for the minerals of serpentine group and chloride. Fe³⁺ was calculated from charge balance.

4. RESULTS

Investigated metaultramafic rocks from Steinbach and Gschorrholz are meta-harzburgites and meta-pyroxenites. Meta-harzburgites are composed of Ol, Opx, Cpx, spinel group minerals, serpentine group minerals Chl and rare Carb. Meta-pyroxenites are composed of Opx, Cpx, Ol, Amp, spinel group minerals, serpentine group minerals Chl and rare Tlc.

Macroscopically meta-harzburgites are dark-green, more or less sheared rocks with fine-grained serpentinized groundmass and visible pale elongated Opx, less Cpx porphyroblasts with size of 0.3 to 0.6 mm across (Fig. 2a). Meta-pyroxenites are pale greenish rocks which occur as dikes in meta-harzburgite. There are two macroscopic varieties of meta-pyroxyenites: 1) coarse grained rocks with compact aggregates of pyroxenes (Fig. 2b); 2) sheared rocks with elongated porphyroblasts of pyroxenes in fine grained metamorphic matrix with amphiboles.

4.1. Petrography and mineral chemistry of meta-harzburgite

Olivine has anhedral grains, clear relief with characteristic high interference colour in typical mesh structure of serpentine minerals (Fig. 3a, b). It occurs in metamorphic matrix and as inclusion
Fig. 2. Cut surfaces of a) meta-harzburgite from Steinbach (sample ST-3), b) meta-pyroxenite from Gschorrholz area (sample GS-2-1).

Obr. 2. Přírez a) vzorky meta-harzburgitu zo Steinbachu (vzorka ST-3), b) vzorky meta-pyroksenitu z Gschorrholzu (vzorka GS-2-1).

Tab. 1. Representative mineral analyses of Ol, Opx, Cpx and Spl in meta-harzburgite.

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Fig. 3. Photomicrographs a–b) and back-scattered electron (BSE) images c–f) of meta-harzburgite. a) Plain-polarized light microscopic image of Opx and Ol porphyroblasts with mesh structure in the metamorphic matrix serpentinite group minerals (sample ST-S1). b) Crossed-polarized light microscopic image of metamorphic Opx, Ol, Spl, Amp, Chl, Atg/Ctl (sample ST-3). c) Granoblastic matrix of Ol, Opx, Cpx and Spl with ingrowing Chl and Atg/Ctl (sample ST-5). d) Exsolution lamellae of low-Al Cpx in the middle part of Mhb grain (sample ST-5). e) Opx porphyroblasts ingrown and overgrown by Cpx and Mhb granoblastic aggregate (sample ST-S1). f) Hydrated and carbonatized domains rich in Tr, Chl and Atg/Ctl (sample ST-S2).

Obr. 3. Fotografie mikroštruktúr meta-harzburgitu a–b) zobrazených aj v spätne rozptýlených elektrónoch c–f). a) Fotografia porfyroblastov Opx a Ol v štruktúre metamorfného matrixu minerálov serpentínovej skupiny (vzorka ST-S1) v polarizovanom svetle pri rovnobežných nikoloch. b) Fotografia metamorfného Opx, Ol, Spl, Amp, Chl, Atg/Ctl (vzorka ST-3) v polarizovanom svetle pri skrížených nikoloch. c) Matrix granoblastického Ol, Opx, Cpx a Spl s prerastujúcim Chl a Atg/Ctl (vzorka ST-5). d) Exsolučné lamely nízkohlinitého Cpx v strednej časti blastov Mhb (vzorka ST-5). e) Porfyroblasty Opx prerastené granoblastickým agregátom Cpx a Mhb (vzorka ST-S1). f) Hydratované a karbonizované mikrooblasti s prevahou Tr, Chl a Atg/Ctl (vzorka ST-S2).
in Opx (Fig. 3c). Grains of Ol have no chemical zoning; they have typical metamorphic composition with 89.14 to 91.62 mol. % Fo found from 19 analyses (Tab. 1).

Orthopyroxene has high relief and no pleochroism. Porphyroblasts are surrounded by metamorphic Ol-rich matrix (Fig. 3a–c). It is low-Al metamorphic Opx with Al₂O₃ 0.5 to 1.8 wt. % (found from 17 analyses), partly altered into Atg, Chl and Ctl along irregular cracks. The Opx has composition of enstatite with Mg from 1.76 to 1.88 apfu found from 17 analyses (Fig. 5a; Tab. 1). Orthopyroxene also occurs as granoblastic grains in the metamorphic matrix. Chemical composition of Opx porphyroblasts and granoblastic Opx from metamorphic matrix is very similar.

Clinopyroxene occurs as anhedral grains in aggregates in metamorphic matrix (Fig. 3c,d). Exsolution lamellae of low-Al Cpx are observable in Amp (Fig. 3d). Some anhedral grains of Cpx often ingrows Ol aggregates, or intergrows with Opx (Fig. 3e). Clinopyroxene has diopside composition with Ca 0.96 to 0.99 apfu found from 32 analyses (Fig. 5a; Tab. 1). The chemical composition of anhedral grains and exsolution lamellae is the similar; both are low-Al Cpx.

Amphibole is porphyrolastic or granoblastic and occurs in metamorphic matrix. Grains show zonal chemical composition. The central part of Amp is composed of zonal magnesio-hornblende which is rimmed by Tr (Figs 3d, 5b). This central part of Amp is surrounded by metamorphic Ol-rich matrix (Fig. 3c,d). Exsolution lamellae of low-Al Opx along irregular cracks. The Opx has composition of enstatite with Mg from 1.76 to 1.88 apfu found from 17 analyses (Fig. 5a; Tab. 1). Magnetite is often present too, but we do not deal with this mineral in detail in this work.

Chlorite grains are flaky, randomly oriented, with different size, produced by alteration of Ol or Opx (Fig. 3b,c,f). According to calculated structural formula it is clinochlore containing ca. 4.5 Mg apfu (Fig. 5d; Tab. 3). Serpentine group minerals form mesh structure of Atg and Ctl along irregular cracks. The Opx has composition of enstatite with Mg from 1.76 to 1.88 apfu found from 17 analyses (Fig. 5a; Tab. 1). Magnetite is often present too, but we do not deal with this mineral in detail in this work.

4.2. Petrography and mineral chemistry of meta-pyroxenite

Olivine occurs as anhedral grains in size 20 μm in the metamorphic matrix characterized by typical metamorphic composition. It has 90.43 to 92.13 mol. % of Fo component found from 14 analyses (Tab. 4). Some of grains are altered in talc and some occur in symplectite with Spl.

Orthopyroxene occurs as anhedral porphyroblasts in the fine grained metamorphic matrix of low-Al Cpx, low-Al Opx and Amp (Fig. 4a,b; Tab. 4). Orthopyroxene porphyroblasts are locally broken down to Opx-Cpx symplectites, partly replaced
Fig. 4. Photomicrograph a–b) and c–f) BSE of meta-pyroxenite. a) Plain-polarized light microscopic image of Opx and Amp porphyroblasts (sample GS-2c). b) Crossed-polarized light microscopic image of Opx porphyroblast in the metamorphic matrix of Opx, Cpx and Amp (sample GS-2-2). c) Prograde-metamorphic Opx-Cpx symplectite in Opx porphyroblast (sample GS-2a). d) Amphibolization (Tr) of Opx-Cpx matrix (sample GS-Px1). e) Cpx, Opx and Mhb porphyroblasts, rimmed by Tr. Central part of Mhb with Cpx exsolution lamellae, and Prg rim (sample GS-3-1). f) Ol-Spl symplectite in matrix of Opx, Cpx and Ol. Tr as a retrograde phase (sample GS-2c).
Fig. 5. Classification diagrams a) pyroxenes after Morimoto et al. (1988), b) amphiboles after Hawthorne et al. (2012), c) the spinel group after Lindsley (1991) and d) chlorite after Zane and Weiss (1998); with e) serpentine group minerals after Bačík (unpublished). Empty symbols: chosen mineral analyses of meta-harzburgites; filled symbols: chosen mineral analyses of meta-pyroxenites.

Obr. 5. Klasifikačné diagramy a) pyroxénov (Morimoto et al., 1988), b) amfibolov (Hawthorne et al., 2012), c) minerálov spinelovej skupiny (Lindsley, 1991) a d) chloritu (Zane a Weiss, 1998); s minerálmi serpentínovej skupiny e) podľa Bačíka (nepublikovaný). Nevyplnené symboly: vybrané analýzy minerálov z meta-harzburgitu; vyplnené symboly: vybrané analýzy minerálov z meta-pyroxenitu.
by Atg or Ctl (Fig. 4c). Low-Al Cpx exsolution lamellae often occur in Opx porphyroblasts and low-Al Opx exsolution lamellae occur in Cpx porphyroblasts. Metamorphic low-Al Opx has enstatitic composition with Mg content between 1.73 and 1.83 apfu found from 44 analyses (Fig. 5a; Tab. 4).

Clinopyroxene is Al-poor and occurs as anhedral grains 0.2 to 0.6 mm in metamorphic matrix (Fig. 4c–e). Low-Al Cpx exsolution lamellae are often observable in the core of Mhb (Fig. 4e). Cpx is diopsidic, containing 0.95 to 1.00 Ca apfu found from 43 analyses (Fig. 5a; Tab. 4).

Amphiboles occur as elongated and randomly oriented porphyroblasts with chemical zoning (Fig. 4a–f). Amphibole is composed of magnesio-hornblende core and pargasitic rim, partly replaced by Tr (Figs 4e, 5b; Tab. 5). The inner zone of magnesio-hornblende core often shows Cpx exsolution lamellae and it is rimmed by outer zone of the similar magnesio-hornblende composition but richer in Al, Na, K and Ti. Pargasite occurs also as individual grains in the metamorphic matrix with Cpx and Opx (Fig. 5b; Tab. 5). Tremolite is younger Amp generation occurring in the metamorphic matrix with Cpx, or it ingrows Cpx and Opx porphyroblasts (Fig. 4c,e,f).

Spinel group minerals occur mainly as rounded inclusion in Opx and as anhedral grains of variable size in the metamorphic matrix. According to crystal-chemical formula, it is Sp with Cr from 0.05 to 0.7 apfu found from 13 analyses(Figs 4b,f; 5c; Tab. 4). Along with Sp, Mag occurs as opaque mineral.

Chlorite occurs as big flakes, replacing Ol or Opx (Fig. 4e). In classification diagram, it falls into the clinochlore composition (Fig. 5d). It is Mg-rich, containing ca. 4.5 Mg apfu.

Serpentine group minerals Atg/Ctl replace Opx or Ol. They also occur in aggregates with tremolitic amphibole (Figs 4c,d, 5e; Tab. 6).

5. DISCUSSION

The Austroalpine Sieggraben structural complex shows three deformation-recrystallization stages (D1 to D3) according to Putiš et al. (2000, 2002), Kromel et al. (2011), Hrvanović et al. (2014). The investigated meta-harzburgites and meta-pyroxenites can also be characterized by three metamorphic stages (D1 to D3).

D1 burial stage is interpretable according to typical metamorphic mineral phases of low-Al Opx and Cpx, Fe-rich Ol and sometimes Cr-rich Sp in both principal lithologies. The D1 stage is characterized by zonal Amp grains with increasing Na and Al from core to rim; the core zones often show low-Al Cpx exsolution lamellae, and all of this indicates a prograde (burial) metamorphic process. The D1 mineral assemblage is consistent with the eclogite facies conditions.

The decomposition of higher-Cr Sp(1) into symplectic Sp(2, Cr-poor) ingrowing Ol might indicate decompression during the D2 exhumation stage. This assemblage is stable in higher amphibolite- to granulite facies conditions.

Aggregates of Atg/Ctl and Mg-Chl as alteration products of Ol, Opx and Sp, and replacement of Sp by Mag, indicate continuing decompression and cooling, therefore interpretable as inferred the D3 exhumation stage. Tremolite as the darkest external part of zonal Amp grains along with Srp, Mg-Chl and Mag indicates a retrograde metamorphic process in amphibolite- to higher greenschist facies conditions.

The D1 to D3 evolution stages most likely occurred in Cretaceous, as reported from other parts of the HP-bearing Austroalpine basement fragments (e.g., Thöni and Jagoutz 1993; Thöni 1999; Thöni et al. 2008).

6. CONCLUSIONS

Investigated ultramafic rocks are composed of typical metamorphic mineral phases: Fe-rich Ol, Al-poor Opx, Al-poor Cpx, zonal Amp (Mhb, Prg to Tr), Cr-poor and Cr-rich...
minerals of the spinel group, Atg/Ctl mineral of the serpentine group and chlorite. Modal estimates speak for original harzburgite crosscut by pyroxenite dikes.

Meta-harzburgites are composed of mainly metamorphic olivine-orthopyroxene aggregates inherited from a harzburgitic protolith. Meta-harzburgites show a distinct metamorphic recrystallization of inferred original harzburgite magmatic phases (Ol, Opx, Spl ±Cpx) transposed to the D1 eclogite-facies Fe-Ol, low-Al Opx and Cpx, Mg-Hbl to Prg, Cr-Spl (D1) during burial in a subduction channel.

Meta-pyroxenite contains mainly metamorphic Cpx and Opx indicating a pyroxenite protolith. Porphyroblasts of low-Al Opx, low-Al Cpx, Fe rich Ol and Cr-Spl suggest eclogite-facies metamorphic conditions characteristics for the D1 metamorphic stage.

The D2 exhumation stage is recognized by the Ol-Spl (after Cr-Spl) symplectites.

The D3 metamorphic stage is determined by the amphibolite-to-greenschist facies mineral metamorphic association composed of the serpentine-group minerals (Ctl/Atg), clinohlore, tremolite and magnetite.
Meta-harzburgites and meta-pyroxenites exposed between the Steinbach and Gschorrhölz villages are the mantle fragments emplaced in subducted lower continental crust during the Cretaceous subduction-collision event.

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7. REFERENCES


