Mineralogical heterogeneity of UHP garnet peridotite in the Moldanubian Zone of the Bohemian Massif (Nové Dvory, Czech Republic)

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Previous reports on Nové Dvory garnet peridotites indicated that they lacked primary spinel, and prograde metamorphism evidence was uncommon. This study revealed the presence of Al–and Cr–rich spinels, clinopyroxenes with a lower content of Na and Fe than what has been previously reported, and chemical heterogeneity in garnet in Nové Dvory garnet peridotites. Cr-poor (0.06–0.12 a.p.f.u.) and Cr-rich (0.10–0.27 a.p.f.u.) garnet populations were identified, and they had contrasting coronas around garnet. The garnet peridotite samples were classified into three types on the basis of the chemical composition of garnet and constituent minerals: type A that includes Cr-rich spinel and Cr-rich garnet; type B that includes Cr-poor garnet and no spinel; and type C that includes both Al– and Cr-rich spinel and both Cr-rich and Cr-poor garnet. The finding of spinel relics {Cr# = [100 Cr/(Cr + Al)] ~ 60–70} in garnet from type A peridotite suggests that the Nové Dvory peridotite body may have been located at relatively shallow depths prior to the ultrahigh-pressure metamorphic stage of >4 GPa. Suitable geothermobarometers were used to establish the P–T history of the rocks. The core compositions of clinopyroxene inclusions in garnet and host garnet yielded 978–1002 °C, 4.87–5.12 GPa (type B) and 1034 °C, 4.93 GPa (type C); stage I. Garnet porphyroblasts in type A peridotite lack clinopyroxene inclusions. The core compositions of garnet and pyroxenes yielded 1005–1072 °C, 4.42–4.46 GPa (type A); stage II. The innermost garnet rims and cores of matrix pyroxenes surrounding garnet yielded 1222–1325 °C, 5.03–5.67 GPa (type B) and 1189–1267 °C, 5.59–6.97 GPa (type C); stage II. Thus, Nové Dvory peridotite has experienced an increase in the P–T conditions, and its chemical heterogeneity (especially in the Cr content of garnet) in type C peridotites may have been created by the mechanical mixing of different rock types (i.e., Cr-rich and Cr-poor types) during the compression and/or decompression stage(s).

Keywords: Bohemian Massif, Garnet peridotite, Primary spinel, Phlogopite, Ultrahigh-Pressure

INTRODUCTION

Over the last three decades, ultrahigh-pressure (UHP) metamorphism has been intensively studied, and consequently, many UHP localities have been identified. The studies on these rocks are essential for understanding the Earth’s mantle processes (Chopin, 1984; Brown, 2014). Early and primary mineral properties are easily obliterated during later metamorphism. Thus, the origin and history of peridotite in UHP metamorphic belts are not easy to study. Nevertheless, ample evidence of the metamorphic history of peridotite can be preserved in the form of chemical and textural zoning in impervious minerals such as garnet; therefore, the zoning of garnet and inclusions in it contain important information that is useful for decoding the provenance of the host rock (e.g., Brown, 2014; Xia and Zhou, 2017).

The Gföhl unit, one of the units in the Moldanubian Zone of the Variscan orogenic belt, is a metamorphic belt that mainly consists of felsic granulite along with ortho-and paragneisses that enclose numerous small bodies of garnet and spinel peridotites, pyroxenites, and eclogite. Past studies indicate crust–mantle interaction in the Gföhl unit and suggest varying origins of the UHP lithologies on the basis of geochemical and thermobarometrical investi-
The Bohemian Massif is located at the eastern end of the Variscan orogenic belt that was formed by the Paleozoic continent-continent collision. The Variscan orogenic belt is divided into the northern Saxothuringian Zone and the southern Moldanubian Zone. The southern part of the Bohemian Massif is situated in the Moldanubian Zone and is further divided into three tectonostratigraphic units, i.e., the Gföhl, Monotonous, and Varied units (Fig. 1a). The Gföhl unit is located in the uppermost tectonic level and mainly consists of felsic granulite and metamorphic rocks such as garnet peridotite and eclogites (e.g., Medaris et al., 1990), whereas the basal Monotonous and Varied units mainly consist of medium–T and high P metamorphic rocks (Medaris et al., 1995) and are generally devoid of UHP rocks (Fig. 1b).

The Nové Dvory peridotite body is a lenticular body (approximately 1 x 3 km) enclosed within Gföhl migmatic gneiss in the eastern part of the Moldanubian Zone (Fig. 1b). It contains abundant eclogite and minor amounts of pyroxenite. High temperature and pressure conditions (>1000 °C, >4.5 GPa) have been reported on the basis of garnet peridotite and associated kyanite-bearing eclogite (e.g., Medaris et al., 1990), whereas the basal Monotonous and Varied units mainly consist of medium–T and high P metamorphic rocks (Medaris et al., 1995) and are generally devoid of UHP rocks (Fig. 1b).

The Nové Dvory peridotite body was located in the Gföhl unit and is regarded as ‘mantle-derived’ and hosted within Gföhl migmatic gneiss; however, it is unclear how the peridotite body was emplaced in the crustal material (e.g., Medaris et al., 1990; Nakamura et al., 2004; Medaris et al., 2005). This is a long-term issue in the Bohemian Massif. There exists a pressure gap of about 2 GPa between the crustal material and the coexisting high-grade rocks (Carswell and O’Brien, 1993; Cooke and O’Brien, 2001; Štípská and Powell, 2005). An intrusion model suggests that the Nové Dvory peridotite body represents the fragments of a deep mantle wedge that was transported along the convection flow to depths of more than 120-km, and then it was exhumed to crustal levels (Brueckner and Medaris, 2000; Medaris et al., 2005)

The evidence of prograde metamorphism in Nové Dvory garnet peridotite is rare, and it has been previously indicated by the lack of primary spinel (e.g., Medaris et al., 2005). The presence of primary spinel and phlogopite inclusions in garnet porphyroblasts from Nové Dvory peridotite has been reported (Nakamura et al., 2012; Baba et al., 2015). However, detailed petrological descriptions have not yet been performed on these peridotites; therefore, we re-analyzed and examined these spinel and phlogopite-bearing samples. In addition to these findings, we observed slightly Fe- and Na-poor clinopyroxene inclusions in garnet compared with those in matrix clinopyroxene. These mineralogical and chemical characteristics support the idea that the inclusion phases in garnet were originally formed at relatively low-pressure conditions. Furthermore, we focus on the variation and chemical zoning of trace elements (e.g., Cr, Ti, and Na) in garnet. Pressure-temperature (P-T) conditions were estimated by applying garnet-clinopyroxene geothermometers (Krogh-Ravna, 2000; Nakamura, 2009), a garnet-orthopyroxene geothermometer (Harley, 1984), two–pyroxene geothermometers (Brey and Köhler, 1990; Taylor, 1998), a Cr-in-clinopyroxene barometer (Nimis and Taylor, 2000), and garnet-orthopyroxene geobarometers (Nickel and Green, 1985; Taylor, 1998) to various compositional pairs of garnet, clinopyroxene, and orthopyroxene. Thus, spinel- and Cr-rich garnet-bearing type A samples yielded relatively low P-T conditions compared to spinel-free and Cr-poor garnet-bearing type B samples. In this paper, we present petrological descriptions and thermobarometric studies of Nové Dvory garnet peridotite, complemented by detailed textural and chemical compositions of these peridotite samples and discuss their significance.

Mineral abbreviations used in this study follow those of Whitney and Evans (2010).
peridotites. While Nové Dvory peridotite is enclosed in gneiss, Hamry peridotite is enclosed by felsic granulite. Nevertheless, Gföhl gneiss is thought to be a retrograde equivalent of felsic granulite, and it is stipulated that peridotites enclosed by gneiss are located in the lower level of the Gföhl unit (Matte et al., 1990; Fiala, 1995).

Geochronological studies indicate the Carboniferous age of the high-grade $P-T$ event in the Gföhl unit. The reported U–Pb zircon ages, ~340 Ma, are relatively concordant with the Sm–Nd isochron ages estimated for pyroxenites and eclogites, which range is from 324 to 344 Ma. These ages are interpreted as the age of the peak metamorphic stage even though older ages have been obtained for some pyroxenite samples (Carswell and Jamtveit, 1990; Beard et al., 1992; Becker, 1997; Kröner et al., 2000). More recently, Lu–Hf isochron ages of 336–338 Ma of pyroxenites overlapping the Sm–Nd ages of 324–344 Ma have been reported, which suggests the assimilation of the HT–HP rocks (Ackerman et al., 2016).

However, the U–Pb zircon ages of Gföhl orthogneiss and granulites range from 500 to 390 Ma for magmatic protolith of the Gföhl unit, which is interpreted to represent the age of igneous crystallization (Friedl et al., 2004; Schulmann et al., 2005).

**Figure 1.** (a) Geological sketch map of the Moldanubian Zone (modified from Matte et al., 1990; Urban and Synek, 1995). The shaded region in the inset at the top left shows the position of the Moldanubian Zone in the Bohemian Massif. (b) Simplified geological map of the eastern margin of the Moldanubian Zone (after Dudek, 1990; Medaris et al., 1995).
PETROGRAPHY

The investigated samples are strongly serpentinized and have an inequigranular texture, in which large porphyroblastic garnet (up to 17.5 mm in length) occurs in fine-grained (0.3–1.5 mm diameter) polygonal matrix that mainly consist of serpentine. Garnet in type C shows varying grain sizes; the large garnet grain is shown as L-Grt, and the relatively small garnet grains are shown as S-Grt1 and S-Grt2. The latter small garnet grains are surrounded by pale-yellowish coronas like those in type B, and much smaller garnet grains are surrounded by kelyphite. CpxII is matrix clinopyroxene.

Type A

Two samples (ND8 and ND108) were classified as type A. These samples contain Cr–rich spinel and Cr–rich garnet. Garnet is spheroidal and relatively small in size (<3 mm diameter), whereas CpxII is relatively large (~2 mm diameter) and abundant (Figs. 2a and 2b). Garnet grains are surrounded by thin rims of kelyphite. Kelyphite is fibrous and consists of pyroxenes and spinel. The matrix mainly consists of garnet, clinopyroxene, orthopyroxene, and olivine but no spinel. In sample ND8, rutile, Cr–rich spinel, and amphibole occur as inclusions in garnet, while spinel grains in sample ND108 are identified in kelyphite after garnet (Figs. 3a–3c). The spinel inclusions are surrounded by thin rims of symplectite along the grain boundaries with garnet (Fig. 3b). Garnet with spinel grains is generally Cr–rich compared to its counterparts that lack spinel inclusions.

Type B

Five samples (ND105, ND106, ND304, ND2008, and ND2009) were classified as type B. The main mineral constituents are garnet, clinopyroxene, orthopyroxene, phlogopite, amphibole, and olivine. These samples include Cr–poor garnet and no spinel. Garnet has a relatively large (>5 mm diameter) irregular shape with some embayments (Fig. 2c); clinopyroxene (CpxI and CpxII) is smaller (0.5 mm diameter) than that in type A samples. Garnet grains are surrounded by coronas dominated by serpentine polymorphs. Phlogopite and clinopyroxene occur as inclusions in garnet in samples ND105, ND106, ND304, and ND2009. However, in sample ND2008, amphibole and phlogopite grains occur in the matrix (Fig. 3d).

Type C

Two thin sections (ND101b and ND101B) prepared from sample ND101 were examined. The main mineral constituents include garnet, clinopyroxene, orthopyroxene,
olivine, spinel, rutile, amphibole, and phlogopite. The Cr-rich and Cr-poor varieties of garnet as well as Cr-rich and Al-rich varieties of spinel are present.

In ND101B, large garnet that was initially identified as a single porphyroblast turned out to be an amalgamation of three smaller garnet grains. Garnet grains in this thin section exhibit two contrasting textures (Fig. 2d). The first texture is fine-grained garnet grains that are similar to those in type A and are generally surrounded by thin rims of kelyphite, and the other texture is large garnet grains similar to those in type B and are surrounded by pale-yellowish coronas that mainly consist of serpentine like those in type B (Fig. 2d). CpxII is abundant and mainly occurs at the margins of the large garnet grain (L-Grt on Fig. 2d). Orthopyroxene is rare and restricted to the margins of the large garnet grain. Cr-rich spinel occurs in the matrix, whereas Al-rich spinel (Figs. 3e and 3f), phlogopite, and rutile occur together with serpentine as inclusions in a relatively small garnet porphyroblast (S-Grt1 in Fig. 2d).

In ND101b, phlogopite and CpxI are present in garnet, and no spinel was observed. In general, garnet grains are surrounded by pale-yellowish coronas that mainly consist of serpentine, which are similar to garnet grains in type B (Fig. 2c).

**MINERAL CHEMISTRY**

The minerals were analyzed using an electron probe microanalyzer (JEOL JXA 8230) equipped with four X-ray spectrometers (WDS) at Okayama University. Quantitative analyses were carried out with a 15-kV acceleration potential, 20-nA beam current, 3-μm beam diameter, and the counting times on peak and background were 10 s and 5 s, respectively. The applied matrix corrections followed the procedures of Bence and Albee (1968). The detection
limits (in ppm) of one sigma level for Ti, Na, and Cr were 107, 82, and 119 ppm, respectively. The standards used were natural or synthetic oxides and silicates.

Garnet, clinopyroxene, spinel, phlogopite, amphibole, orthopyroxene, and olivine compositions in the samples were analyzed, and the representative analyses are listed in Tables 1-4.

**Garnet**

Garnet grains in types A, B, and C are pyrope with significant amounts of Cr and compositional range: uvarovite (Uv$_{0.03-0.12}$), spessartine (Sp$_{0.006-0.01}$), pyrope (Pr$_{0.66-0.74}$), almandine (Alm$_{0.13-0.20}$), and grossular (Gr$_{0.00-0.08}$) by mole fraction (Table 1). The garnet end-member components were calculated according to the method of Locock (2008). Garnet in types A, B, and C is relatively homogenous, whereas chemical zoning is distinct near the rim or around the Cr-spinel inclusions (Figs. 4-6).

Garnet in type A samples is on average richer in Cr content (0.10-0.27 a.p.f.u. on the basis of O = 12) than that in type B samples (0.06-0.12 a.p.f.u.). Garnet in type C samples is heterogeneous and shows grain-to-grain variations, as described below. The garnet grain containing Cr-rich spinel inclusions shows a decrease in the Mg content from 2.1 a.p.f.u. to 1.9 a.p.f.u. and an increase in the Cr and Fe contents (from 0.15 a.p.f.u. to 0.34 a.p.f.u. in Cr and from 0.56 a.p.f.u. to 0.64 a.p.f.u. in Fe) near the inclusions. However, garnet grains without spinel inclusions in type A are chemically homogeneous. Irrespective of the presence or absence of spinel inclusions, both garnets show approximately the same core composition of Mg$\# = [100 \text{Mg/(Mg + Fe)}] = 78$ (Figs. 4a and 4c).

In type B samples, garnet grains with phlogopite inclusions have homogeneous cores, but the Fe content increases and Mg content decreases near the rims. Mg$\#$ of garnet are about 82 in the core and about 78 in the rim (Fig. 5a). These rim compositions are approximately the same as the Mg$\#$ in the core regions of the homogenous types.

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Table 1. Mean representative chemical compositions of garnet in the studied peridotite samples

| S-name | Type A | Type B | Type C |
|--------|--------|--------|--------|
|        | ND8d   | ND8d   | ND108  |
| G-No.  | 1 2    | 1 2    | 1 2    |
| Texture| M M    | M M    | M M    |
| SiO$_2$| 41.89  | 42.92  | 42.58  |
| TiO$_2$| 0.17   | 0.14   | 0.17   |
| Al$_2$O$_3$| 20.64 | 22.28  | 22.35  |
| Cr$_2$O$_3$| 4.40 | 1.83   | 2.17   |
| FeO*   | 10.07  | 9.30   | 8.79   |
| MnO    | 0.45   | 0.49   | 0.37   |
| MgO    | 18.75  | 19.81  | 19.54  |
| CaO    | 4.90   | 4.47   | 5.50   |
| Na$_2$O| 0.02   | 0.07   | 0.03   |
| K$_2$O | 0.00   | 0.01   | 0.00   |
| Total  | 101.29 | 101.31 | 101.49 |

O 12 12 12 12 12 12 12 12 12 12 12 12 12
Si 3.00 3.03 3.00 3.00 2.99 2.99 2.99 2.98 2.99 2.98 3.00
Ti 0.01 0.01 0.01 0.01 0.02 0.02 0.02 0.02 0.01 0.01 0.01
Al 1.74 1.85 1.86 1.78 1.85 1.84 1.89 1.89 1.87 2.00 1.81
Cr 0.25 0.10 0.12 0.19 0.10 0.12 0.09 0.10 0.11 0.06 0.16
Fe 0.60 0.55 0.52 0.55 0.43 0.48 0.52 0.46 0.45 0.47 0.49
Mn 0.03 0.03 0.02 0.03 0.02 0.02 0.02 0.02 0.02 0.02 0.02
Mg 2.00 2.08 2.05 2.01 2.23 2.15 2.10 2.15 2.16 2.09 2.09
Ca 0.38 0.34 0.42 0.43 0.37 0.38 0.38 0.39 0.39 0.35 0.41
Na 0.00 0.01 0.00 0.00 0.01 0.01 0.01 0.01 0.01 0.00 0.00
K 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
Total 8.00 7.99 8.00 8.01 8.02 8.02 8.01 8.01 8.01 7.98 8.00
Uv 0.12 0.05 0.06 0.10 0.05 0.06 0.05 0.05 0.05 0.03 0.08
Sps 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
Prp 0.66 0.68 0.68 0.67 0.74 0.72 0.70 0.72 0.72 0.70 0.70
Alm 0.20 0.18 0.17 0.18 0.13 0.14 0.16 0.14 0.14 0.16 0.16
Grs 0.00 0.05 0.07 0.03 0.04 0.04 0.07 0.07 0.06 0.08 0.04
Cr$\#$ 12.56 5.13 6.06 9.64 5.13 6.12 4.55 5.03 5.56 2.91 8.12

S-name, sample name; G-No., grain number; M, Matrix; Cr$\#$, [100 Cr/(Cr + Al)]; FeO*, total Fe is assumed to be Fe$^{2+}$.
garnet in type A. Additionally, these garnet grains including phlogopite inclusions do not show large chemical variations near the inclusions, and the Mg content is approximately flat at 2.20 a.p.f.u. (O = 12). Both garnets with and without clinopyroxene or phlogopite inclusions are relatively homogenous in the cores (Figs. 5b and 5c).

In ND101B from the type C sample, a large garnet grain (L–Grt in Fig. 2d) shows Cr# = \[\frac{100 \text{ Cr}}{(\text{Cr} + \text{Al})}\] (~ 3), which is comparable to garnet in the type B sample (Figs. 5 and 6a), and the other relatively small garnet grain in the matrix (S–Grt1 in Fig. 2d) is more chromferous and shows Cr# (~ 8) that is comparable to garnet in type A samples (Figs. 4 and 6b). Mg# of the Cr–poor and Cr–rich garnet grains are about 84 in the cores and about 78 in the rims (Figs. 6a and 6b).

The X-ray maps of representative garnet grains in the three types are shown in Figure 7. Garnet with Cr-spinel inclusions (Fig. 3a) in type A is characteristically rich in Cr in the core region (Fig. 7a), and an amphibole inclusion is clearly recognized in the Ca map. The traverse from A to B represents the compositional profile shown in Figure 4a. Garnet with Cpx inclusions in type B is shown in Figure 7b, and the traverse from C to D represents the compositional profile shown in Figure 5c. The large garnet grain (L–Grt in Fig. 2d) in type C appears to be an amalgamation of about three smaller garnet grains (shown by the broken lines in the Cr, Fe, Mg, and Mn maps), and the Cr content increases at the rims (Fig. 7c). The traverse from E to F shown in the Cr map represents the compositional profile shown in Figure 6a. The matrix of this sample is Cr–rich, and Cr–spinel grains in the matrix and a relatively Cr–rich garnet grain (not mapped) were identified. Cpx grains are abundant at the margins of the Grt grain, as shown in the Ca element map (Fig. 7c).

There is a weak and positive correlation between Mg# and the grossular content (Fig. 8a) for type B and C samples. Type B garnet is richer in the Ti content compared to the other types, and a positive correlation is recognized between Ti and Na contents (Fig. 8b). In general, type B garnet is richer in Ti (up to 0.03 a.p.f.u.), while types A and C are relatively poor in Ti (<0.02 a.p.f.u.) (Figs. 8b and 8c).

| Table 2. Representative chemical compositions of clinopyroxene in the studied peridotite samples |
|-------------------------------------------------------------|
| **S-name, sample name; G-No., grain number; CpxI, Inclusion in garnet; CpxII, Matrix; Mg#, [= 100 Mg/(Mg + Fe)]; FeO*, total Fe is assumed to be Fe2+:** |
| **Type A** | **Type B** | **Type C** |
|-------------------------------------------------------------|
| S-name | ND8d | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| G-No. | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 0 | 4 | d |
| Texture | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII | CpxII |
| SiO2 | 55.26 | 55.85 | 55.32 | 55.22 | 55.18 | 54.74 | 55.42 | 55.56 | 55.01 | 54.83 | 55.82 |
| TiO2 | 0.17 | 0.10 | 0.21 | 0.17 | 0.18 | 0.20 | 0.18 | 0.16 | 0.20 | 0.18 | 0.15 |
| Al2O3 | 2.60 | 2.21 | 2.80 | 2.42 | 2.62 | 3.07 | 2.81 | 2.38 | 2.48 | 2.54 | 2.52 |
| Cr2O3 | 1.33 | 0.55 | 0.62 | 0.86 | 1.31 | 1.00 | 1.10 | 1.33 | 1.15 | 1.38 | 0.79 |
| FeO* | 2.72 | 2.73 | 3.01 | 1.80 | 2.90 | 3.02 | 2.91 | 2.80 | 1.91 | 2.78 | 2.69 |
| MnO | 0.05 | 0.03 | 0.09 | 0.05 | 0.06 | 0.09 | 0.09 | 0.08 | 0.04 | 0.09 | 0.05 |
| MgO | 15.58 | 16.59 | 15.56 | 16.63 | 15.75 | 15.67 | 15.85 | 16.23 | 16.39 | 15.73 | 15.75 |
| CaO | 21.04 | 21.91 | 20.35 | 21.49 | 20.41 | 19.92 | 20.31 | 20.69 | 21.50 | 20.43 | 21.10 |
| Na2O | 2.06 | 1.86 | 2.34 | 1.96 | 2.47 | 2.61 | 2.57 | 2.26 | 2.06 | 2.43 | 2.11 |
| K2O | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| Total | 100.83 | 101.83 | 100.29 | 100.62 | 100.89 | 100.34 | 101.25 | 101.49 | 100.75 | 100.40 | 101.00 |
| O | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Si | 1.98 | 1.99 | 1.99 | 1.98 | 1.98 | 1.98 | 1.98 | 1.98 | 1.97 | 1.98 | 2.00 |
| Ti | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 |
| Al | 0.11 | 0.09 | 0.12 | 0.10 | 0.11 | 0.13 | 0.12 | 0.10 | 0.11 | 0.11 | 0.11 |
| Cr | 0.04 | 0.02 | 0.02 | 0.02 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.02 |
| Fe | 0.08 | 0.08 | 0.09 | 0.05 | 0.09 | 0.09 | 0.09 | 0.08 | 0.06 | 0.08 | 0.08 |
| Mn | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mg | 0.83 | 0.88 | 0.84 | 0.89 | 0.84 | 0.84 | 0.85 | 0.86 | 0.88 | 0.85 | 0.84 |
| Ca | 0.81 | 0.83 | 0.79 | 0.83 | 0.79 | 0.77 | 0.78 | 0.79 | 0.83 | 0.79 | 0.81 |
| Na | 0.14 | 0.13 | 0.16 | 0.14 | 0.17 | 0.18 | 0.18 | 0.16 | 0.14 | 0.17 | 0.15 |
| K | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 4.01 | 4.02 | 4.01 | 4.02 | 4.03 | 4.03 | 4.03 | 4.02 | 4.02 | 4.03 | 4.01 |
| Mg# | 91.21 | 91.67 | 90.32 | 94.68 | 90.32 | 90.32 | 90.43 | 91.49 | 93.62 | 91.40 | 91.30 |
Clinopyroxene in all studied Nové Dvory garnet peridotite samples is diopside (or diopsidic). The compositions of CpxII is in the range of Mg# = 89–93 and Ca = 0.74–0.86 a.p.f.u. (O = 6), and there is a positive correlation between Mg# and the Ca content (Fig. 9a). Furthermore, clinopyroxene in type A samples tends to be higher in Mg# and richer in Ca than that in type B samples (Fig. 9a).

The Cr content in clinopyroxene erratically varies from one grain to another (Fig. 9b), and there is no systematic difference between types A and B. However, CpxI from two type B samples (ND2009 and ND106) shows high Mg# (about 94) and a slightly low Na content compared to the other analyzed clinopyroxene grains (Fig. 9c). Each clinopyroxene grain is nearly homogeneous and does not show any significant chemical zoning.

Orthopyroxene

Orthopyroxene is present as enstatite in all types of samples and shows the range of Mg# = 88–92 and Ca ≤ 0.01 a.p.f.u. (O = 6). The Al2O3 content of orthopyroxene in types A and B is 0.6–1.1 wt%. There is no distinct difference in the Al2O3 and Cr2O3 content of orthopyroxene between types A and B. However, the Al2O3 content in orthopyroxene in type C significantly varies, and orthopyroxene in the thin section ND101B has a lower Al2O3 content (~ 0.4 wt%) compared to that in the thin section ND101B whose Al2O3 content is similar to those in types A and B (Fig. 10). Opx with a low Al2O3 content (~ 0.4 wt%) is classified as OpxI, while the relatively more aluminous Opx with an Al2O3 content of 0.6–1.1 wt% is classified as OpxII.
Table 4. Representative chemical compositions of orthopyroxene and olivine in the studied peridotite samples from Nové Dvory

| Type A | Type B | Type C | Type A | Type B | Type C |
|--------|--------|--------|--------|--------|--------|
| S-name | G-No.  | Texture | SiO₂   | TiO₂   | Al₂O₃  | Cr₂O₃  | FeO*   | MgO    | CaO    | Na₂O   | K₂O    | Total  |
| ND8d   | Op-x-1 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |
| ND108  | Op-x-1 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |
| ND101B | Op-x-1 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |
| ND101B | Op-x-2 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |
| ND101B | Op-x-1 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |
| ND101B | Op-x-1 | M       | 65.49  | 65.11  | 65.94  | 0.18   | 6.12   | 35.82  | 0.28   | 0.00   | 0.01   | 101.92 |

S-name, sample name; G-No., grain number; M, Matrix; Mg#, [= 100 Mg/(Mg + Fe)]; FeO*, total Fe is assumed to be Fe²⁺.

Figure 4. Compositional profiles of representative garnet grains in type A. (a) Garnet in sample ND8d. (i) and (ii) are Cr-spinel inclusions shown by dotted rectangles. (b) Details of inset (i) in (a). (c) A garnet grain in sample ND108.
Phlogopite occurs as inclusions in garnet and matrix phases in the type B sample ND2008 (Fig. 3d). There is a negative correlation between the Si and Al content (Fig. 11a) with a trend of $2\text{Si} + \text{Al} = 14 \text{a.p.f.u. (O = 22)}$, which suggests the Tschermak substitution $[\text{Mg, Fe}]^{2+} + \text{Si}^{4+} = 2\text{Al}^{3+}$. The $\text{Si} + \text{Al} = 8 \text{a.p.f.u. (O = 22)}$ trend indicates the Ti substitution into phlogopite by the substitution mechanism of $[\text{Mg, Fe}]^{2+} + 2\text{Si}^{4+} = 2\text{Al}^{3+} + \text{Ti}^{4+}$ (e.g., Robert, et al.).
Phlogopite in this study has a lower Al and Cr content compared to that in the so-called 'primary phlogopite' from another peridotite locality (Plešovice quarry), which has been studied by Naemura et al. (2009) (Fig. 11b). The Ti content in the studied phlogopite is in the range from 0.1 to 0.8 a.p.f.u. (O = 22) (Fig. 11c).

**Spinel**

The composition of spinel inclusions in garnet from type A is Cr\# = 60–70 and Mg\# = 49–54, and the Cr and Fe content decreases (1.38–1.25 a.p.f.u. for Cr and 0.51–0.47 a.p.f.u. for Fe) toward the rims (Fig. 4b). The composi-
The spinel inclusion in the garnet grain of type C (S–Grt1 in Fig. 2d) is notably Al-rich with Cr# = 9. Spinel in the kelyphite was not analyzed in this study. The obtained results encompass the entire compositional range of spinel from other Bohemian spinel–garnet peridotites studied by Medaris et al. (2005) and Naemura et al. (2009) (Fig. 12). The spinel inclusion in the garnet grain of type C sample is Cr# = 55–60 and Mg# = 48–52 (Fig. 12). The spinel inclusion in the garnet grain of type C (S–Grt1 in Fig. 2d) is notably Al-rich with Cr# = 9. Spinel in the kelyphite was not analyzed in this study. The obtained results encompass the entire compositional range of spinel from other Bohemian spinel–garnet peridotites studied by Medaris et al. (2005) and Naemura et al. (2009) (Fig. 12).

Olivine

Olivine in the studied samples is relatively homogeneous with Mg# of 90–91 even in the vicinity of kelyphite.
Amphibole (Pargasite)

Amphibole in the studied sample [Si = 5.96–6.58 a.p.f.u., Al = 1.85–2.95 a.p.f.u., Cr = 0.11–0.22 a.p.f.u., Ca = 1.47–1.75 a.p.f.u., Na = 0.95–1.1 a.p.f.u. (O = 23), and Mg# = 90–92] is chromian pargasite according to the nomenclature of Leake et al. (1997) and is present as inclusions in garnet and in the kelyphite of the same garnet grain in type A (Fig. 3a). Amphibole is also present in the matrix in the type B sample ND2008 (Fig. 3d). The Al content in amphibole in this study is comparable to that in Plešovice peridotite studied by Naemura et al. (2009) but Na + K of amphibole in this study is relatively high (>1.0 a.p.f.u. on the basis of O = 23) (Fig. 13).
**P-T CONDITIONS**

**Pressure-temperature estimation**

It is difficult to select suitable pairs of geothermobarometers to use as UHP rocks because the rocks bear a complex evolution history. In addition, problems can arise from considerably different diffusion, reactions, and recrystallization rates in different minerals. To estimate the P-T conditions of the garnet peridotite samples, we used the following set of geothermobarometers: Grt-Cpx thermometers (Krogh-Ravna, 2000; Nakamura, 2009), Grt-Opx thermometer (Harley, 1984), two-pyroxene geothermometers (Brey and Köhler, 1990; Taylor, 1998), and Grt-Opx barometers (Nickel and Green, 1985; Taylor, 1998). The total Fe was treated as FeO. The intersections of the obtained equilibrium P-T curves were adopted as the equilibrium P-T conditions of each sample (Fig. 14). The points with the shortest root-mean-squared distances to all the lines plotted on the P-T diagrams were taken as the P-T averages for each sample.

The chemical variations (e.g., variations in the Cr content in garnet and Al content in orthopyroxene) accompanied by changes in the microstructure of principal minerals (e.g., different mineral phase inclusions in garnet and contrasting coronas surrounding garnet) is suggestive of equilibration under different P-T conditions. To establish this, we utilized different compositional pairs of garnet and pyroxenes to obtain the P-T evolution of the studied peridotites, and they were divided into two-stage pairs: stage I and stage II in the order of occurrence from early to late stages, respectively. Garnet grains are homogeneous in the core regions with a distinct narrow zoning at the outermost rims. Clinopyroxene and orthopyroxene are also chemically homogeneous. The core compositions of clinopyroxene inclusions in garnet (Cpxi) and host garnet were used to obtain stage I equilibration conditions for type B and C samples. Clinopyroxene inclusions are absent in type A garnet. Then, the core compositions of matrix garnet, orthopyroxene, and clinopyroxene were used to obtain stage II equilibration conditions for type A. However, stage II for types B and C was tentatively determined using the compositional pairs of innermost garnet rims and cores of matrix orthopyroxene and clinopyroxene because garnet in types B and C is much larger than matrix pyroxenes. Stage II equilibration conditions probably represent the peak P-T conditions.

![Figure 14](image_url)

**Figure 14.** Representative pressure-temperature (P-T) estimates of the Nové Dvory peridotite samples showing the various stages of equilibration. S-I, stage I; S-II, stage II. The ‘low P-T scheme’ conditions (circled) were estimated using the two-pyroxene thermometers and Grt-Opx barometers while the ‘high P-T scheme’ conditions (in rectangles) were estimated using Grt-Cpx and Grt-Opx thermometers, Grt-Opx barometers, and a Cr-in-Cpx barometer for stages I and II.
and Grt–Opx barometers yielded lower P–T conditions, which are referred to as the ‘low P–T scheme’ in Figure 14 and Table 5, compared to the higher P–T conditions, which are referred to as the ‘high P–T scheme’ obtained when Grt–Cpx geothermometers, Grt–Opx thermometer, and Grt–Opx barometers were used. The reason for this difference is not clear, but Medaris et al. (1990) obtained a similar results from Nové Dvory peridotite and reported significantly lower temperatures from the two-pyroxene thermometer (~ 840 °C) compared to temperatures from Fe²⁺–Mg exchange thermometers (~ 1200 °C). In this study, orthopyroxene is rare and small, and the chemical modification of orthopyroxene during cooling may result in the low-temperature estimation by the two-pyroxene thermometer. Therefore, the results obtained by combining two-pyroxene geothermometers and Grt–Opx barometers (‘low P–T scheme’) were not adopted. The P–T equilibration conditions obtained for type A, B, and C samples are summarized in Table 5 and Figure 14 and are discussed below.

Stability of spinel versus pyrope

We performed thermodynamic calculations using the Holland and Powell (1998) data set to constrain the high P stability limit of Spl + Opx association by employing the endmember reaction of Spl + 2 En = Prp + Fo. We calculated the activity of each phase component using the measured compositions of garnet, olivine, orthopyroxene, and spinel in thin sections of ND8d, ND108, and ND101B and determined the equilibrium pressures by the equation shown below. Activity coefficients were mainly expressed by the regular-solution model, and the values of excess interaction parameters given in Holland and Powell (1998) were adopted. Here, we ignored the reciprocal Gibbs free energy.

\[
2 \left[ G_{\text{En}} + \text{RT} \ln \left( \frac{X_{\text{Mg}}^{\text{Opx}}}{X_{\text{Mg}}^{\text{Opx}}} + W_{\text{FeMg}}^{\text{Opx}} (1 - X_{\text{Mg}}^{\text{Opx}})^2 \right) \right] \\
+ G_{\text{Spl}} + \text{RT} \ln \left( \left( \frac{X_{\text{Spl}}^{\text{Spl}}}{} \right)^2 \right) \\
- \left[ G_{\text{Prp}} + \text{RT} \ln \left( \left( \frac{X_{\text{Al}}^{\text{Al}}}{} \right)^2 \right) \right] \\
+ W_{\text{MgCa}}^{\text{Grt}} X_{\text{Grt}} (1 - X_{\text{Prp}}) + W_{\text{FeMg}}^{\text{Grt}} X_{\text{Alm}} (1 - X_{\text{Prp}}) \\
- \left[ G_{\text{Fo}} + \text{RT} \ln \left( \left( \frac{X_{\text{Fo}}^{\text{Fo}}}{} \right)^2 \right) \right] = 0
\]

Then, we determined the positions of equilibrium curves for the abovementioned reaction and obtained four patterns for: ND8d Cr# = 66, ND108 Cr# = 61, ND101B matrix spinel Cr# = 58, and ND101B inclusion spinel Cr# = 9 (Fig. 15). The calculated curves are located from 3.4 to 4 GPa at approximately 1000 °C for Cr–rich spinel (ND8d, ND108, and ND101B matrix spinel). This occurs because the addition of Cr extends the stability of spinel (e.g., O’Neill, 1981; Klemme and O’Neill, 2000). For the Al-rich spinel inclusion in ND101B (type C), the calculated curve was located at 0.55 GPa at approximately 1000 °C, which is outside the garnet peridotite field (Fig. 15). Therefore, we conclude that this Al-rich spinel in the type C sample is not part of equilibrium assemblage. The origin of Al-spinel will be considered below.

Type A. Garnet grains with Cr–rich spinel inclusions exhibit compositional zoning at their core regions in the vicinity of spinel inclusions (Fig. 4a). However, garnet cores without Cr–rich spinel are homogeneous in

| Stage | Type | Sample | High P–T scheme T, °C | P, GPa | Low P–T scheme T, °C | P, GPa |
|-------|------|--------|----------------------|------|----------------------|------|
| Stage I | A    | ND2009 | 1002                 | 4.82 | 733                  | 2.87 |
|        |      | ND106A | 978                  | 5.12 | 814                  | 3.04 |
|        | B    | ND101b | 1034                 | 4.93 | –                    | –    |
| Stage II | A    | ND8d   | 1005                 | 4.46 | 697                  | 2.42 |
|         |      | ND108  | 1072                 | 4.42 | 742                  | 2.77 |
|         |      | ND105A | 1232                 | 5.36 | 755                  | 2.77 |
|         |      | ND106A | 1222                 | 5.67 | 725                  | 2.33 |
|         |      | ND2008 | 1229                 | 5.35 | 767                  | 2.60 |
|         |      | ND2009 | 1225                 | 5.30 | –                    | –    |
|         |      | ND304  | 1225                 | 5.03 | –                    | –    |
|         |      | ND101B | 1189–1228            | 6.57–6.97 | 825            | 4.28–4.29 |
|         | B    | ND101b | 1267                 | 5.59 | 777                  | 2.90 |
their core region (Fig. 4c). Therefore, the compositional pairs of garnet cores without Cr-rich spinel and matrix pyroxene cores were used as equilibration pairs, and we obtained 1005–1072 °C and 4.42–4.46 GPa (stage II) (Table 5). Low P inclusion phases in garnet (e.g., amphibole and spinel) were identified in type A peridotite. Amphibole inclusions in garnet suggest pre-UHP recrystallization at depths not exceeding 100 km (e.g., Liou and Zhang, 1998; Niida and Green, 1999). Furthermore, the stability of Cr-spinel in garnet, as determined in the previous section, was attained at conditions of <4 GPa at 1000 °C. Nevertheless, Cr stabilizes an isolated spinel grain by itself at the higher P side (e.g., O’Neill, 1981). Thus, type A peridotite may have existed at conditions of <3 GPa where amphibole was stable, after which it was re-equilibrated at the peak P conditions of ~4.5 GPa (stage II).

**Type B.** The compositional pairs of clinopyroxene inclusions in garnet and the core compositions of host garnet yielded 978–1002 °C and 4.87–5.12 GPa (stage I). The Cr-in-Cpx barometer (Nimis and Taylor, 2000) was used to obtain the equilibration pressures for stage I because orthopyroxene grains are not present as inclusions in garnet. The compositional pairs of the innermost rims of large garnet and cores of matrix clinopyroxene and orthopyroxene yielded 1222–1325 °C and 5.03–5.67 GPa (stage II).

The chemical compositions (e.g., Ti content in garnet in type B peridotite) support our results of relatively high P-T conditions. In general, the Ti content of garnet increases with an increase in temperature and pressure (e.g., Ackerson et al., 2013), and the Ti content in type B garnet is higher compared to that in type A. In addition, type B garnet has a relatively high Na content and shows a positive correlation between Ti and Na contents (Fig. 8b). The synthetic experiments of Ono and Yasuda (1996) showed that Na in garnet tends to increase with an increase in pressure.

Phlogopite-bearing samples in this study (Table 5) equilibrated at relatively high P-T conditions (T > 1080 °C, P > 4.5 GPa) compared to phlogopite-bearing samples of the Plešovice peridotite body in the Gföhl unit studied by Naemura et al. (2009), which equilibrated at approximately 1030 °C and 3.5 GPa. Arai (1984) suggested that phlogopite in ultramafic rocks derived from deeper regions generally has a lower Al content. Phlogopite in this study has a relatively low Al content compared to that in Plešovice peridotite (Figs. 11a and 11b), which confirms that studied peridotite was equilibrated at higher P conditions.

**Type C.** P-T estimations for the type C samples were more problematic owing to the chemical heterogeneity of garnet in sample ND101B. The compositional pairs of clinopyroxene inclusions in garnet and core compositions of host garnet in ND101b yielded 1034 °C and 4.93 GPa (stage I) equilibration conditions. The Cr-in-Cpx barometer (Nimis and Taylor, 2000) was used to obtain the equilibration pressures for stage I because orthopyroxene grains are not present as inclusions in garnet. The compositional pairs of innermost rims of large garnet and cores of matrix clinopyroxene and orthopyroxene yielded 1189–1235 °C and 5.59–6.97 GPa (stage II). Analogous to types A and B, type C might have also experienced P and T increase and then re-crystallized under relatively low P-T conditions. The estimated pressures in the ND101B sample are relatively high compared to those in other samples (Fig. 15; Table 5). The Al content of orthopyroxene in equilibrium with garnet generally decreases with an in-

**Figure 15.** P-T conditions of studied Nové Dvory peridotite and other lithologies in the Gföhl unit. 1, Mohelno peridotite (Medaris et al., 1990); 2, Kyanite-bearing eclogite from Nové Dvory (Nakamura et al., 2004); 3, Nové Dvory garnet peridotite (Medaris et al., 1990); Cr# = 66 is the stability curve of Cr-spinel included in garnet in sample ND8d (type A), while Cr# = 58 is the stability curve of matrix Cr-spinel of ND101B (type B) and Cr# = 9 is the stability curve of Al-spinel included in garnet in ND101B (type C) on the basis of the data set of Holland and Powell (1998). P-T conditions for stage I (type A) are tentatively shown from the amphibole stability conditions according to Niida and Green (1999). The diamond-graphite equilibrium boundary (Dia/Gr) according to Kennedy and Kennedy (1976) and the spinel-garnet peridotite boundary (Grt/Spl) on the basis of the data set of Holland and Powell (1998) are shown for reference.
crease in the pressure at constant temperature (e.g., MacGregor, 1974), and the Al content of orthopyroxene in ND101B (Opxb) is distinctly low (Fig. 10). Opxb likely represents an extremely high-pressure ($P > 6$ GPa) stage under which Nové Dvory peridotite may have equilibrated once in its $P$–$T$ history.

**DISCUSSION AND CONCLUSIONS**

The chemical compositions of constituent minerals of types A, B, and C are similar to each other, but there are slight differences in their $P$–$T$ conditions and minor components. For example, the Cr and Ti content in garnet (Figs. 8b and 8c) and the Al content in orthopyroxene (Fig. 10) are different. Garnet grains are approximately homogenous in the core and show scarse chemical zonings at the rims (0.5 mm wide) probably owing to the exchanges of elements (e.g., Godard and Martin, 2000) between garnet and other minerals during the decompression. However, Cr-spinel grains are preserved as relics in garnet in samples ND8d and ND108, which suggests that the Nové Dvory peridotite body may have been originally located at relatively shallow depths (<3.0 GPa), under which spinel was stable prior to the UHP stage (e.g., Altherr and Kalt, 1996). The mineral development sequence of Nové Dvory peridotite inferred from type A was first Ol + Cpx + Opx + Spl + Amp and then Ol + Cpx + Opx + Grt followed by several retrograde assemblages. In addition, there is high concentration of Cr in the core of garnet in ND8d around the spinel inclusions (Fig. 7a), which may be attributed to spinel consumption during garnet growth; in addition, it is possible that the spinel inclusion was larger, at least in this sample. In type A samples, no matrix spinel was identified. Therefore, it is likely that matrix spinel was completely consumed to form garnet owing to the pressure increase. Spinel inclusions are more Cr-rich (ND8d) than their matrix counterparts (ND101B) owing to local Cr accumulation during the growth of garnet at the expense of spinel (e.g., Obata and Morten, 1987). Garnet grains with spinel inclusions in type A are also relatively Cr-rich compared to other garnet grains that lack spinel inclusions; it is likely that at least the garnet grains including spinel were not homogenized even under the peak $P$–$T$ conditions, which is indicative of transient heating at peak conditions and subsequent rapid exhumation.

The Al-rich spinel inclusion is surrounded by corona comprised of serpentine (Fig. 3f) and may be a new product formed at retrograde stage. A similar Al-spinel inclusion in garnet has been described in eclogite from Nové Dvory (Faryad et al., 2013). Cr-spinel grains mantled by garnet in type A and those that occur in the matrix of type C show an increase in Mg# and Al/(Cr + Al) ratios from core to rim. This pattern of zoning is a reversal of prograde metamorphism (e.g., Obata and Morten, 1987). The Cr-spinel grains we found are very small (0.03–0.14 mm in diameter) and do not preserve the prograde nature. Prograde zoning was probably erased by high-$T$ metamorphism, and the zoning of spinel found in type A was created during cooling by exchanges of elements with host garnet.

Garnet grains in types B and C excluding the clusters of small kelyphitized garnet grains near the Cr-rich region in ND101B (Fig. 2d) lack kelyphite coronas and are instead surrounded by pale-yellowish coronas that consist of serpentine minerals. The Raman spectra of yellowish coronas revealed a pattern with four major peaks at ~ 690, 390, 230, and 130 cm$^{-1}$ with relative intensities of four peaks that are almost unchanged among the samples that were studied. These bands are characteristic of the main Raman vibrations of serpentine polymorphs—antigorite, chrysotile, and lizardite (Groppo et al., 2006; Frezzotti et al., 2012). Olivine may have reacted with garnet in the presence of water to form these serpentine-rich coronas. However, garnet in type A contains higher Cr content in garnet, and the garnet grains are surrounded by kelyphite that consists of pyroxenes and spinel. Both coronas are interpreted as retrograde products that formed during the exhumation of garnet peridotite. The Cr content in garnet in type A is relatively high; therefore, kelyphite with a Cr-rich phase (i.e., spinel) was probably more likely to form in type A than in type B.

Clinopyroxene coexisting with garnet and spinel in peridotite becomes more Na-rich with an increase in pressure, which can be controlled by the phase equilibria: $6Di + 3Spl = 3Fo + 2Grs + Prp$. When pressure is increased, the reaction proceeds to the right side and consumes diopside, which results in an increase in the Na content in residual clinopyroxene. Thus, the presence of Fe–Na-poor clinopyroxene inclusions (Fig. 9c) suggests that Nové Dvory garnet peridotite might have equilibrated under relatively low $P$ conditions prior to the peak $P$–$T$ conditions. In addition, higher Mg# in clinopyroxene inclusions than in matrix clinopyroxene (Fig. 9) may reflect lower temperature conditions prior to the peak $P$–$T$ conditions estimated from the matrix clinopyroxene compositions. Therefore, clinopyroxene inclusions may be relics of the prograde evolution of studied peridotite.

Type C is heterogeneous especially in the Cr content of garnet (Figs. 6, 7c, and 8c). In theory, such heterogeneity can be created by the (1) mechanical mixing of two different rocks without chemical homogenization, (2) partial and local incomplete metasomatism, or (3) original heterogeneity created by igneous fractionation processes.
and not being homogenized even by high-\( T \) metamorphism at temperatures exceeding 1000 °C. We speculate that type C is a product of mechanical mixing of different rock types: i.e., Cr-rich and Cr-poor types. The Cr-rich type may be type A described in this paper, and the Cr-poor type may be type B in this study. However, there are distinct differences between the Cr-rich part of type C and type A peridotite. A Cr-poor spinel inclusion in garnet is present in the Cr-rich part of type C, while spinel in garnet of type A is Cr-rich. Furthermore, Cr-rich spinel is present in the matrix in type C, whereas spinel in type A is present only as inclusion phases in garnet. Thus, type C peridotite was not produced by the mechanical mixing of types A and B, but it can be a mixture of type B and other varieties similar to type A. Another possibility is that type C may have undergone partial metasomatic effect during high \( P \) metamorphism: type C was originally a Cr-poor type, but Cr-rich metasomatic fluid or melt (e.g., Yasumoto et al., 2018) infiltrated into type C peridotite, which made a part of type C rich in Cr. Nonetheless, type B peridotite corresponds to ‘Type III’ peridotite described by Medaris et al. (2005) whose compositions of constituent minerals and peak \( P-T \) conditions overlap with those of type B peridotite in this study.

The Nové Dvory peridotite body hosts a wide range of mafic and ultramafic rocks of varying origins (Beard et al., 1992; Nakamura et al., 2004; Medaris et al., 2005), and these rocks may have mixed during compression and/or decompression stage(s). Mechanical mixing has been postulated to play a significant role in the petrogenesis of UHP rocks (e.g., Ackerman et al., 2016; Svojtka et al., 2016; Brueckner et al., 2018). The obtained results depict mineralogical heterogeneity in Nové Dvory garnet peridotite. We have also shown that Nové Dvory garnet peridotite was transformed from relatively low-pressure (stage I) to high pressure (stage II) (Fig. 14). The overall impression is that Nové Dvory garnet peridotite has undergone a complex \( P-T \) evolution history, and each type has its own unique petrogenic history. Type A garnet peridotite might have ascended to shallow levels and was then dragged down to the depths of approximately 150 km (4.5 GPa). However, type B samples may have been subducted to deeper levels and then experienced faster decompression compared to that of type A. Subsequently, they were juxtaposed during exhumation. Type C is interpreted to be a product of mechanical mixing of Cr-poor (type B) and Cr-rich rock types (type A or alike) or a partially metasomatized material. However, the relationships between the occurrences of these peridotite types require considerably more research. In addition, eclogite is closely associated with Nové Dvory peridotite, which has been shown to undergo an increase in pressure before the peak \( P \) metamorphic stage (Miyazaki et al., 2016). The occurrence of spinel and amphibole inclusions in garnet as well as our thermobarometric estimations using inclusion clinopyroxene and host garnet data indicate that the Nové Dvory peridotite body has existed as medium \( P/T \) spinel peridotite and then experienced prograde metamorphism equilibrating at higher \( P-T \) conditions followed by the transformation into garnet peridotite after which it was exhumed with significant cooling to crustal levels. The field relationship between different rock types in the Nové Dvory peridotite body is mostly unclear owing to the poor exposure of rocks and strong serpentinitization of peridotite. Type B is the most abundant rock type and it prevails over types A and C. Therefore, spinel is very rare, which is suggestive of extremely high-pressure metamorphism compared to other peridotites in the GÖhl unit such as spinel-rich garnet peridotite from Plešovice.

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