The Mohelno and Nové Dvory Peridotites: Two Contrasting Types of Peridotite in the Gföhl Unit

L. Gordon MEDARIS, Jr.[1] and Emil JELÍNEK[2]

[1] Department of Geoscience, University of Wisconsin-Madison,1215 W. Dayton St., Madison, Wisconsin 53706, U.S.A.; medaris@geology.wisc.edu
[2] Institute of Geochemistry, Mineralogy and Mineral Resources, Charles University, Albertov 6, 128 43 Praha, Czech Republic

Peridotites in the Gföhl Unit

Peridotites in the Gföhl Unit display diverse characteristics and have been divided into three types, based on their lithologic associations, texture, mineralogy, elemental and isotopic chemical composition, P-T conditions, and calculated cooling rates (Medaris et al., 1990; Medaris et al., 2005; Ackerman et al., 2009). Type I, *e.g.* the Mohelno peridotite, is surrounded by granulite, consists predominantly of Mg-Cr spinel peridotite, and is devoid of eclogite lenses. Garnet, which commonly contains inclusions of spinel, occurs only in the deformed and recrystallized margins of the peridotite body or in closely associated peridotite boudins in granulite. Type II has been identified in the Horní Bory quarry and is represented by a group of Mg-Cr to Fe-Ti spinel-garnet peridotite boudins that are associated with abundant garnet pyroxenite, all of which are hosted by felsic granulite. Type III, *e.g.* the Nové Dvory peridotite, is surrounded by migmatitic gneiss, consists solely of Mg-Cr garnet peridotite, and contains prominent lenses of eclogite.

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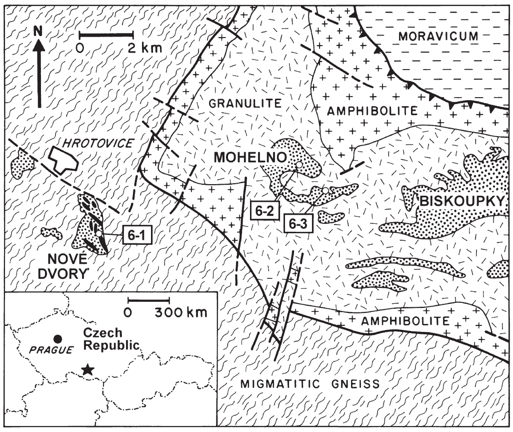
Locations and Field Characteristics

The Mohelno and Nové Dvory peridotites are located in South Moravia approximately 32 km NWN of Znojmo (Fig. 1). The Mohelno peridotite, which is the archetype for Gföhl Type I peridotite, is a folded tabular body, ~300 m thick and 4 km long, that has concordant contacts with the surrounding Náměšť granulite, with which it shares in part a common structural and metamorphic history. Serpentinized spinel peridotiteconstitutes the bulk of the Mohelno body, and garnet peridotite occurs only within a few meters of contacts with granulite, where penetrative deformation has promoted recrystallization during the Variscan Orogen. The Biskoupky peridotite (Fig. 1), which lies ~3 km east of the Mohelno peridotite, exhibits the same characteristics as those of the Mohelno body and is correlative with it.

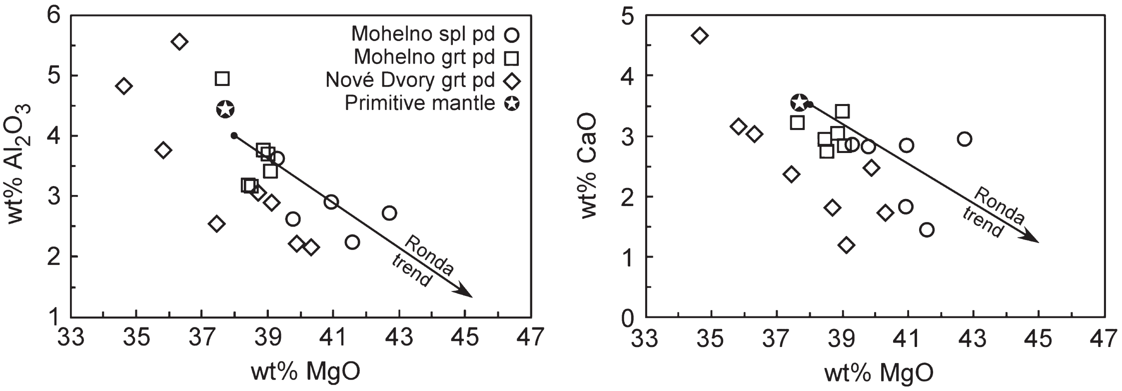
In contrast to Mohelno, the Nové Dvory peridotite (Fig. 1), which is the archetype for Gföhl Type III peridotite, is allochthonous and allofacial with respect to surrounding migmatitic orthogneiss. The ~1 × 2.5 km body consists largely of serpentinized garnet peridotite, which contains prominent lenses of eclogite, up to 15 meters thick.



■ **Fig. 1.** Simplified geological map of the Mohelno and Nové Dvory peridotites and surrounding area. Peridotite bodies are indicated by the stipple pattern, and eclogite lenses in the Nové Dvory peridotite are in black. Excursion localities are indicated by numbers: 6-1, Nové Dvory garnet peridotite and eclogite; 6-2, Mohelno spinel peridotite; 6-3: Mohelno garnet peridotite. Locality of the map area is shown by a star in the inset.

Geochemistry

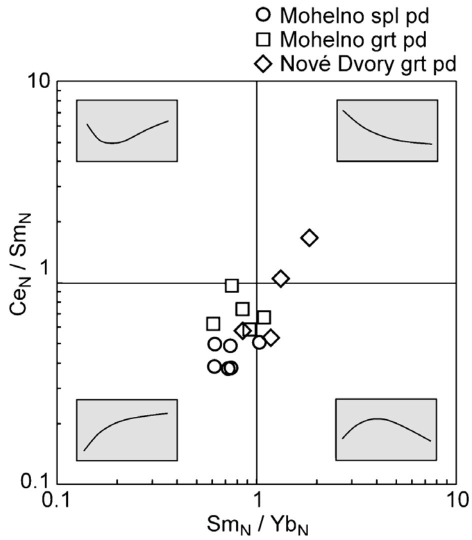
Like many other Mg-Cr mantle peridotites, the Mohelno and Nové Dvory peridotites show a decrease in concentrations of incompatible major elements, such as Al_2O_3 and CaO, with an increase in MgO (Fig. 2). Such compositional variations are commonly ascribed to partial fusion of mantle peridotite and removal of incompatible elements from the residuum by melt extraction. In the Mohelno body, garnet peridotite (MgO ≃ 37.5–39 wt%) is less depleted than spinel peridotite (MgO ≃ 39–43 wt%) , perhaps reflecting some degree of interaction with felsic granulite, with which it is in close proximity. For a given level of MgO, the Nové Dvory peridotite contains lower concentrations of Al_2O_3 and CaO, compared to the Mohelno body (Fig. 2). In addition, three samples of Nové Dvory peridotite contain less MgO (~34.5–36.4 wt%) than does primitive mantle, which may be due to metasomatism by transient melts, from which eclogite and pyroxenite crystallized (Medaris et al., 1995).



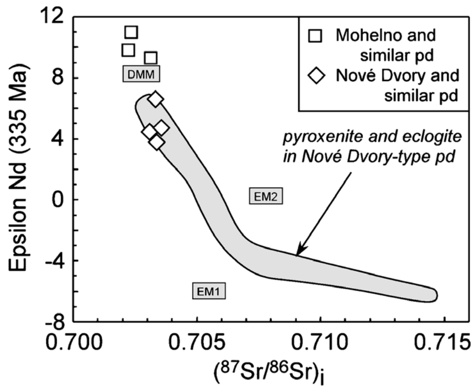
■ **Fig. 2.** Variation in wt. % Al_2O_3 and CaO relative to MgO in the Mohelno and Nové Dvory peridotites. Shown for comparison are the composition of primitive mantle (McDonough and Sun, 1995) and the variation trend for the Ronda peridotite (Frey et al., 1985).

The Mohelno and Nové Dvory peridotites are both depleted in REE, containing less than 1.0 to as little as 0.1 times that in primitive mantle. However, the two peridotites show contrasting REE patterns, with the Mohelno peridotite being consistently light-REE depleted and the Nové Dvory peridotite varying from light-REE depleted to light-REE enriched (Fig. 3). The Mohelno garnet peridotite is not as strongly light-REE depleted as spinel peridotite; again, possibly reflecting interaction with nearby felsic granulite.

With respect to Nd and Sr isotopes, clinopyroxene from the Mohelno and Nové Dvory peridotites falls into two domains (Fig. 4). Clinopyroxene from the Mohelno body and similar peridotites in Austria (Becker, 1997; Medaris, 1999) has ε_{Nd} values of +9.2 to +11.0 (at 335 Ma), which are higher than that for Depleted MORB Mantle (DMM), and relatively low values of $(^{87}Sr/^{86}Sr)_i$, 0.7024 to 0.7032. Clinopyroxene in the Nové Dvory peridotite and similar peridotites in Austria has slightly higher values of $(^{87}Sr/^{86}Sr)_i$, 0.7033 to 0.7034, and lower ε_{Nd} values, +4.1 to +6.6. When the isotopic compositions of clinopyroxene from pyroxenite and eclogite lenses in Nové Dvory-type peridotites are included (Fig. 4; Medaris et al., 2006a), the field for isotopic covariation is seen to be convex downward, with compositions of peridotite clinopyroxene plotting near the top of the pyroxenite and eclogite field. Such a covariation trend has been successfully modelled by mixing between mantle peridotite and oceanic clay (Medaris et al., 1995).



■ **Fig. 3.** Ratios of (Ce/Sm) *vs*. (Sm/Yb) for the Mohelno and Nové Dvory peridotites, normalized to primitive mantle (McDonough and Sun, 1995).



■ **Fig. 4.** Variation in ε_{Nd} and $[^{87}Sr/^{86}Sr]_i$ (at 335 Ma) for clinopyroxene in the Mohelno and Nové Dvory peridotites. The field is for clinopyroxene in garnet pyroxenite and eclogite from Nové Dvory-type peridotite. Abbreviations: DMM, depleted MORB mantle; EM1, enriched mantle 1; EM2, enriched mantle 2 (Hart 1988).

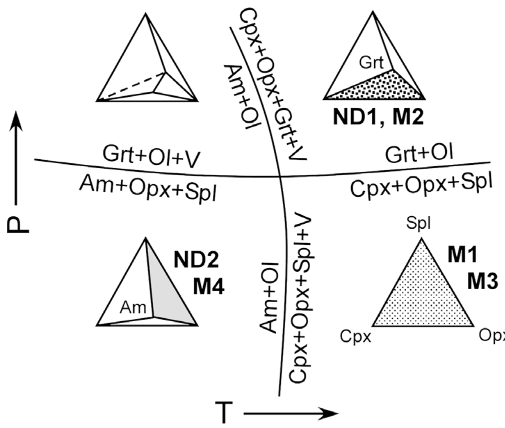
Mineralogy

Minerals in the Mohelno and Nové Dvory peridotites consist of variable proportions of forsterite, pyrope-rich garnet, enstatite, chrome diopside, and $MgAl_2O_4$-rich spinel, reflecting the magnesian composition of their host rocks.

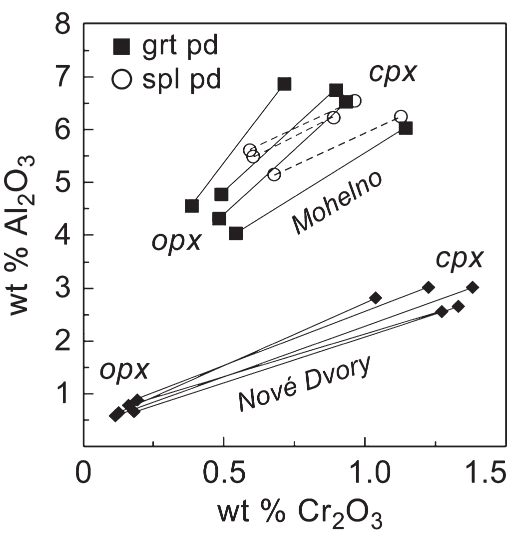
The Mohelno peridotite contains a sequence of four different mineral assemblages (neglecting late-stage serpentinization), whose schematic P-T relations are shown in Figure 5, which is a projection from forsterite and H_2O onto the plane, spl-opx-cpx, in the CMASH system. Assemblage M1, ol+spl+opx+cpx, is the predominant mineral assemblage in the interior and bulk of the peridotite. Assemblage M2, ol+grt+opx+cpx, occurs only within a few meters of the contact with felsic granulite, and spinel inclusions in garnet demonstrate that Assemblage 2 formed later than Assemblage 1. Assemblage 3, spl+opx+cpx, and Assemblage 4, spl+opx+am, occur in kelyphite around garnet, where fine-grained minerals of Assemblage 3 constitute the kelphite rims, and very fine-grained, symplectitic intergrowths of Assemblage 4 minerals are confined to the kelyphite interiors.

In contrast to Mohelno, the Nové Dvory peridotite contains only two mineral assemblages (again, neglecting late-stage serpentinization). The bulk of the body consists of assemblage ND1 (Fig. 5), ol+grt+opx+cpx, followed by assemblage ND2, spl+opx+am, which occurs locally as thin, very fine-grained kelephite rims on garnet.

Additional mineralogical distinctions between the Mohelno and Nové Dvory peridotites are seen in their pyroxene compositions (Fig. 6). Mohelno clinopyroxene and orthopyroxene are both highly aluminous, which is characteristic for pyroxenes in high-temperature and moderate- to low-pressure peridotites. Note however, that orthopyroxene in equilibrium with garnet (assemblage M2) is slightly less aluminous and chromiferous than orthopyroxene in equilibrium with spinel (assemblage M1). In contrast, Al_2O_3 contents and Al_2O_3/Cr_2O_3 ratios are much lower in pyroxenes in the Nové Dvory peridotite (assemblage ND1), which was derived from a different mantle source and equilibrated under different conditions (mainly higher pressure) than those of the Mohelno body.



■ **Fig. 5.** Schematic P-T grid for mineral assemblages in the system, CMASH, projected from forsterite and H_2O on to the plane, $MgAl_2O_4$ - $CaMgSi_2O_6$ - $Mg_2Si_2O_6$. Successive mineral assemblages in the Mohelno (M) and Nové Dvory (ND) peridotites are numbered and indicated by different patterns.

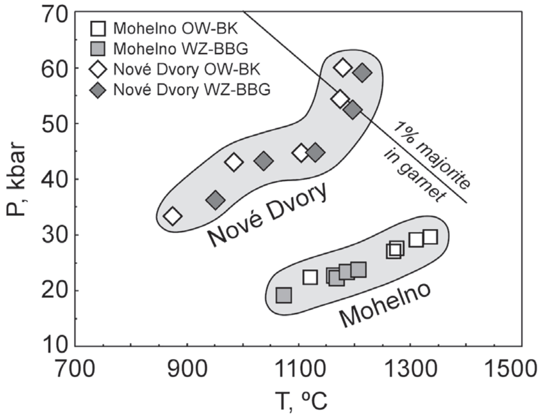


■ **Fig. 6.** Al_2O_3 and Cr_2O_3 contents of coexisting clinopyroxene and orthopyroxene in the Mohelno spinel and garnet peridotites, compared to those in the Nové Dvory garnet peridotite.

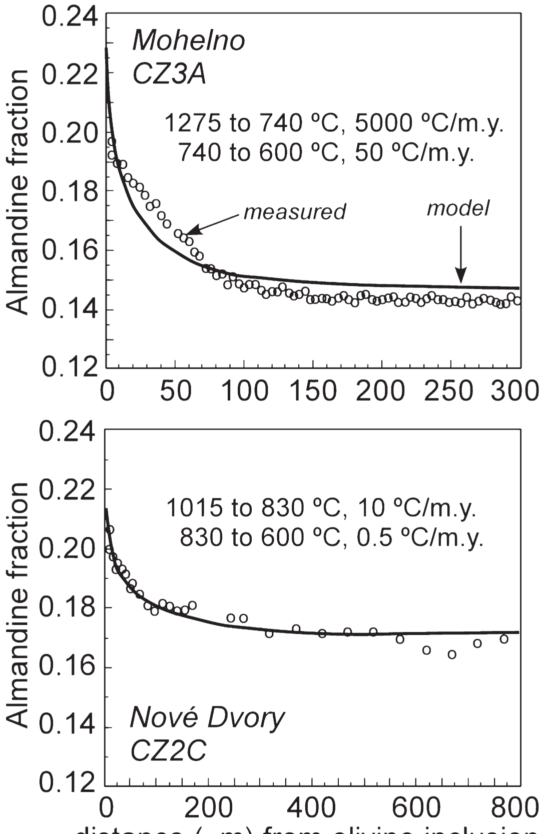
Pressure-Temperature Estimates and History

The P-T equilibration conditions for garnet-bearing assemblages in the Mohelno and Nové Dvory peridotites (assemblages M2 and ND1, respectively) are best estimated by a combination of the Fe-Mg exchange geothermometer for olivine and garnet and the Al-in-orthopyroxene geobarometer . Previously, Medaris et al. (2005) made such estimates by applying calibrations of the olivine-garnet geothermometer by O'Neill and Wood (1979) and O'Neill (1981) and the Al-in-orthopyroxene geobarometer by Brey and Köhler (1990). Results from these previous P-T estimates are shown in Figure 7, where they are compared with newer estimates based on the Wu and Zhao (2007) calibration of the olivine-garnet geothermometer and the Brey, Bulatov and Girnis (2008) calibration of the Al-in-orthopyroxene geobarometer. Compared to the previous P-T results, the newer temperature estimates are significantly lower for the Mohelno samples and slightly higher for the Nové Dvory samples. However, regardless of the specific P-T values obtained from the different calibrations, the Mohelno and Nové Dvory samples still define two contrasting field gradients, i.e., a relatively low P/T array for Mohelno and a relatively high P/T array for Nové Dvory, which extends into the stability field for majoritic garnet.

Cooling rates for garnet peridotite have been calculated by solution of the diffusion equation for compositional zoning in garnet adjacent to olivine inclusions (Medaris et al., 2005; Fig. 8). Bilinear cooling rates are required to achieve acceptable fits between the calculated and measured compositional profile, i.e. to match both the core and rim compositions of the zoned garnet grains. For Mohelno, an extremely rapid initial cooling rate, 5000 °C/m.y., is necessary to preserve the garnet core composition, and slower second stage rates, 1–50 °C/m.y., are required to attain the garnet rim composition. The initial cooling rate may reflect tectonic juxtaposition of hot peridotite and cooler granulite, rather than cooling related to exhumation of the terrane. However, the second stage cooling rates (1 to 50 °C/m.y.) are consistent with those expected during exhumation, and they are comparable to, but slightly slower than, those obtained in the Kutná Hora Complex from eclogite garnet zoning (~100 °C/m.y.) and stratigraphic constraints (100–150 °C/m.y.; Medaris et al., 2006b). Compositional zoning in Nové Dvory garnet has a smaller amplitude and longer decay distance than that in Mohelno garnet, thus yielding a slower initial cooling rate of 10 °C/m.y. and a second stage rate of 0.5 °C/m.y.. Such different model cooling rates for the Mohelno and Nové Dvory peridotites further emphasize the distinction between these two types of Czech peridotite.



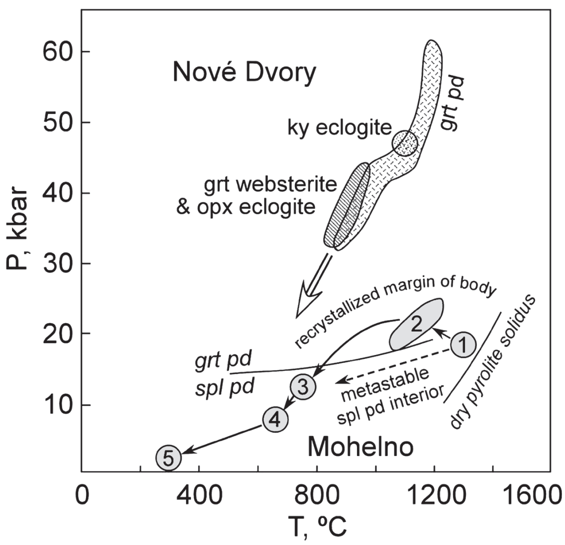
■ **Fig. 7.** Pressure-temperature estimates for the Mohelno and Nové Dvory garnet peridotites, based on the Al-in-orthopyroxene goebarometer (BK, Brey and Köhler, 1990; BBG, Brey, Bulatov and Girnis, 2008) and the olivine-garnet Fe-Mg exchange geothermometer (OW, O'Neill and Wood, 1979; O'Neill, 1980; WZ, Wu and Zhao, 2007).



■ **Fig. 8.** Variation of almandine contents in garnet grains adjacent to olivine inclusions in two samples of garnet peridotite: Mohelno, sample CZ3A, and Nové Dvory, sample CZ2C. Symbols, measured compositions; solid curves, compositional profiles calculated from diffusion modelling. Bilinear cooling rate estimates are given in the insets.

The P-T histories for the Mohelno and Nové Dvory peridotites are summarized in Figure 9. For Mohelno, Stage 1 (assemblage M1, ol+spl+opx+cpx) represents the inferred origin of the peridotites as residua from partial melting of mantle in the spinel stability field. The interior of the peridotite body escaped penetrative deformation during Variscan HP metamorphism, resulting in metastable preservation of assemblage M1, except for intracrystalline re-equilibration and exsolution during cooling. Deformation along the margin of the peridotite promoted recrystallization and development of the garnetiferous assemblage M2 (ol+grt+opx+cpx) in response to Stage 2 Variscan metamorphism at high temperatures and pressures at ~20–25 kbar. Continued deformation and influx of H_2O along the margins of the peridotite promoted development of the Stage 3 (assemblage M3, spl-opx-cpx) and Stage 4 (assemblage M4, spl-opx-am) kelyphites during cooling and exhumation, which can be correlated with retrograde stages in the associated Náměšť granulite.

The bulk of the Nové Dvory peridotite consists of assemblage ND1 (ol+grt+opx+cpx), which yields P-T conditions of ~34–60 kbar, 850–1150 °C (Fig. 9). Such high pressures are consistent with calculated pressures of ~34–47 kbar for garnet websterite, orthopyroxene eclogite, and kyanite eclogite, which occur as lenses in the peridotite (Medaris et al., 2006a; Nakamura et al., 2004). The thin kelyphite rims on garnet, assemblage ND2 (spl+opx+am), represent a limited stage of partial recrystallization at ~8 kbar, 700 °C.



■ **Fig. 9.** Proposed P-T histories for the Mohelno and Nové peridotites. Numbers for the Mohelno body correspond to the mineral assemblages shown in Fig. 5, except for stage 5, which indicates late-stage serpentinization. Stage 1 represents the inferred conditions of origin as the residuum from partial melting of primitive mantle in the spinel stability field. The field for Nové Dvory garnet peridotite includes the range of P-T estimates for assemblage ND1, to which are compared P-T estimates for associated garnet websterite, orthopyroxene eclogite, and kyanite eclogite.

Tectonometamorphic Scenario

Based on elemental and isotopic compositions and P-T conditions, the Mohelno peridotite is interpreted as suboceanic lithospheric and, possibly, asthenospheric mantle, and the Nové Dvory peridotite most likely represents subcontinental lithospheric mantle (Medaris et al., 2005). It was proposed that the Mohelno peridotite originated in Devonian (Frasnian) time in a small ocean basin between Bohemia (Tepla-Barrandia) and Moldanubia (northern Gondwana). With Carboniferous (Tournaisian) closure of the ocean basin and collision of Bohemia and Moldanubia, imbrication of lithospheric/asthenospheric mantle, oceanic crust, and continental crust may have occurred in the vicinity of a subducted spreading center, giving rise to the lithologic association of the Gföhl Nappe and elevating temperatures in the crustal rocks. Further Carboniferous (Viséan) subduction produced the high pressure assemblages in ultramafic (garnet peridotite), mafic (eclogite), and felsic (HP granulite) rocks. Subduction-related melts penetrated the overlying mantle wedge, producing lenses of garnet pyroxenite and eclogite in the Nové Dvory peridotite. Slab breakoff then released the subducted Moldanubian terrane and locally attached fragments of mantle wedge, allowing rapid exhumation and cooling, during which the HP rocks were retrograded to varying degrees over a range of decreasing temperatures and pressures.

Alternatively, the Mohelno peridotite and associated lithologies may have originated in a Devonian back-arc basin between Saxothuringia and Tepla-Barrandia, which was subsequently subducted beneath Tepla-Barrandia (Schulmann et al., 2005; Dörr and Zulauf, 2010). Carboniferous closure of the thermally weakened back-arc basin, due to convergence and eventual collision of Brunia, led to crustal thickening and high-pressure and high-temperature metamorphism in deeper crustal levels, which was followed by orogenic collapse and delamination of mantle lithosphere, leading to rapid exhumation during transpression or elevator tectonics.

Sm-Nd mineral isochrons for nine samples of peridotite-hosted pyroxenite and eclogite in the Gföhl Unit yield a Viséan mean age of 336 ±7 Ma (Medaris et al., 2006a). So, in either tectonometamorphic scenario, exhumation following high-temperature and high-pressure metamorphism must have been rapid, as demonstrated by the presence of Gföhl detritus in Viséan sediments of the Culm foreland basin (Hartley and Otava, 2001).

Stop 6-1 (Day 6). Nové Dvory Garnet Peridotite and Eclogite, ~400 m SW of the Nové Dvory Farmhouse, 2 km WNW of the Town of Rouchovany

Coordinates: N49°04′36.4″ E16°04′56.6″)

This locality is in the southeastern part of the Nové Dvory body, where a low ridge is supported by a large eclogite layer (Fig. 1). Garnet peridotite is exposed along the dirt track leading to the ridge and in outcrop at the western end of the ridge; eclogite is exposed along the top of the ridge and in fallen blocks at the base of the ridge.

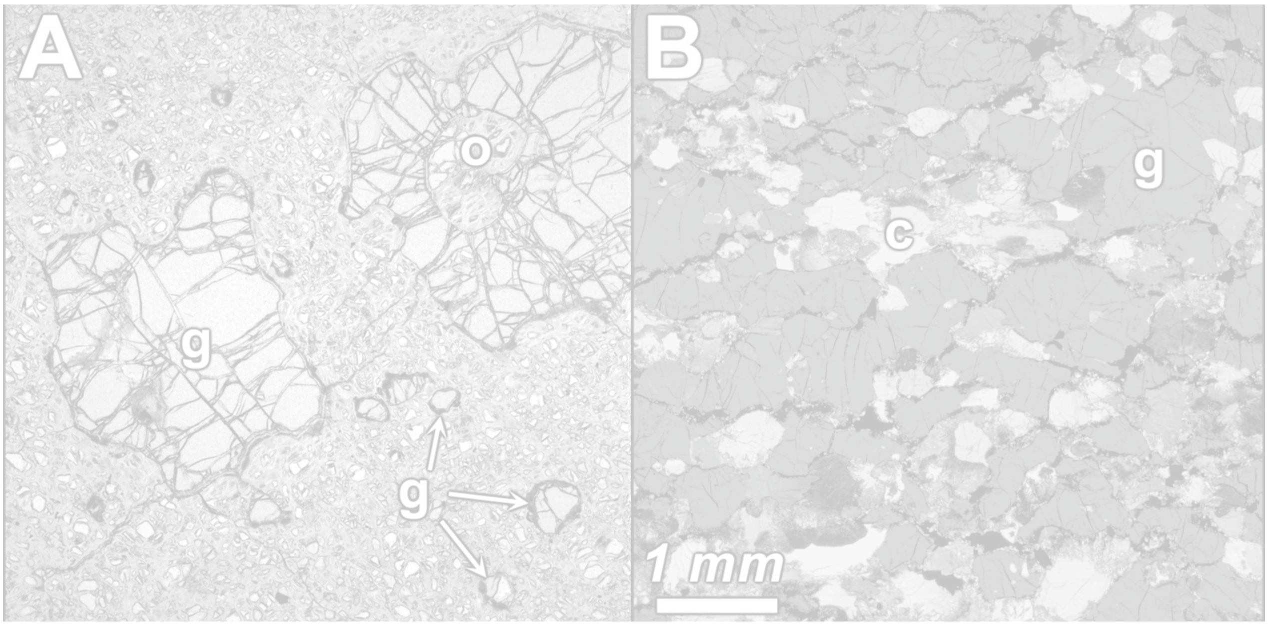


Fig. 10. Photomicrographs of Nové Dvory samples; the scale in each panel is the same. A. Inequigranular garnet peridotite; plane polarized light. Note the two grain size populations of garnet. B. Medium-grained, granoblastic eclogite; partly crossed polarizers. Abbreviations: c, clinopyroxene; g, garnet; o, olivine.