History of metamorphism preserved in the UHP Śnieżnik eclogites (NE Bohemian Massif)

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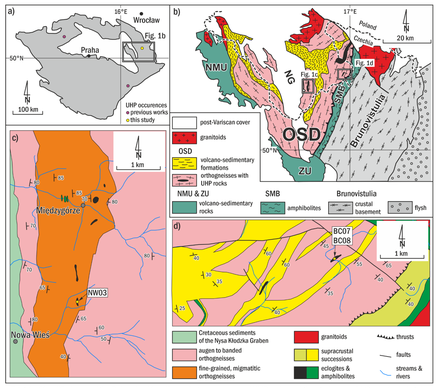
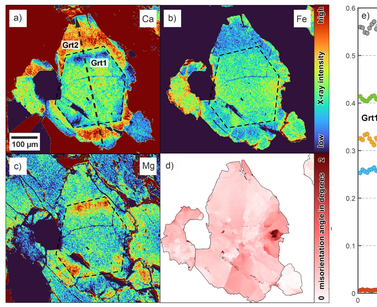
1 Introduction and geological setting



The Orlica-Śnieżnik Dome (OSD) is located in the Central Sudetes in SW Poland, which form the NE margin of the Bohemian Massif (Fig. 1). The OSD represents the deeply eroded root zone of the European Variscan Belt in the northeastern corner of the Bohemian Massif. In this study, we present the **first direct documentation of coesite** in both omphacite and garnet from two eclogite localities in the OSD: Nowa Wieś (Ph-bearing eclogite) and Bielice (Ph-free eclogite). This discovery provides conclusive evidence of UHP conditions, finally resolving the long-standing controversy. To better constrain the PT conditions related to the pressure-peak of metamorphism and the onset of decompression, we apply **thermodynamic modelling, conventional geothermobarometry, Zr-in-rutile thermometry, and quartz-in-garnet elastic barometry**. Furthermore, we place these results in the context of geodynamic scenarios that may have led to the formation of these rocks and UHP metamorphism in the OSD.

Fig. 1 (a) Simplified map of the Bohemian Massif showing occurrences of UHP rocks and the study area. (b) Geological sketch map of the Orlica-Śnieżnik Dome. Abbreviations: NG – Nysa Graben, NMU – Nove Město Unit, OSD – Orlica-Śnieżnik Dome, SMB - Staré Město Belt. ZBU - Zábřeh Unit (c,d) Detailed geological maps of the areas of interest based on various sheets of the Detailed Geological Map of the Sudetes

2 Petrography and mineral chemistry



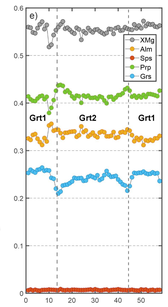


Fig. 2 (a-c) Compositional map of a garnet grain in sample NW03; (d) Map of misorientations in the same grain; (e) Compositional profile through the studied garnet grain (line marked on map a).

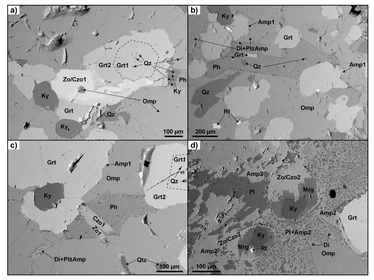


Fig. 5 Back-scattered electron images of the Ph-bearing eclogite from Nowa Wieś showing mineralogical textures and associations of sample NW03. (a-c) Textural relations between minerals from the peak-pressure mineral assemblage with local occurrences of Zo/Czo1. The distinction between Grt1 and Grt2 on maps a and c was made based on the Ca-content map of the area. Quartz inclusions occur mostly within the Grt1 parts of garnet grains. (d) Reaction of Ky to Mrg and Zo/Czo2 as seen on the boundary of the Amp-Pl vein.

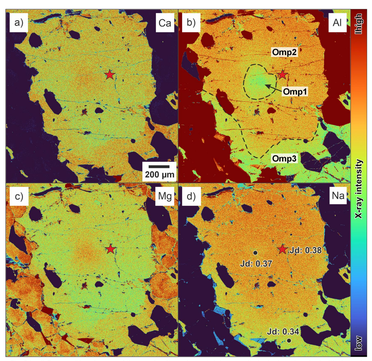


Fig. 3 (a-d) Compositional maps of the omphacite grain containing coesite inclusions (marked with the red star). Sample NW03 from Nowa Wieś.

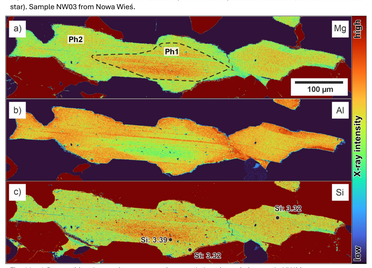


Fig. 4 (a-c) Compositional map of a representative zoned phengite grain in sample NW03.

The Ph-bearing eclogite (NW03) is a fine-grained, equigranular eclogite and it macroscopically exhibits well-developed, locally folded foliation marked by alternating omphacite- and garnet-rich layers. The foliation is locally enhanced by the shape preferred orientation of white mica flakes. The rock comprises omphacite and garnet with accessory phengite, kyanite, quartz, rutile, amphibole, plagioclase and rare zoisite/clinozoisite, pyrite, hematite, apatite, zircon and coesite.

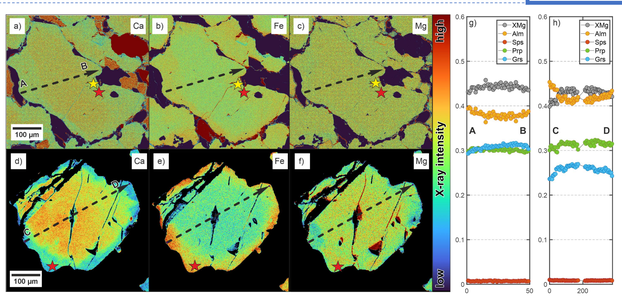


Fig. 6 (a-d) Compositional maps of the omphacite grain in BC08 sample containing quartz (yellow stars) and coesite (red stars) inclusions.

The Ph-free eclogite (BC07, BC08) is a medium-grained eclogite. The rock consists of omphacite, garnet and quartz with accessory rutile, kyanite, amphibole, zoisite/clinozoisite, plagioclase, zircon, ilmenite, titanite, apatite, K-feldspar, orthopyroxene, spinel (hercynite). Additionally, coesite was observed as inclusions in garnet and omphacite.

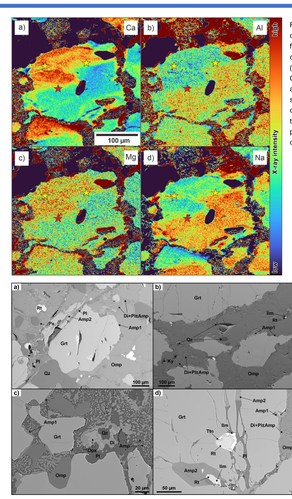


Fig. 7 (a-c) Compositional maps of Ca, Fe, Mg content in garnet from sample BC08 with marked coesite (red star) and quartz (yellow star) inclusions. (d-f) Compositional maps of Ca, Fe and Mg content in garnet from sample BC07. Location of the coesite inclusion is marked with the red star. (g-h) Compositional profiles through garnets shown on maps a-f.

Fig. 8 Back-scattered electron images of the Ph-free eclogite from Bielice showing characteristic petrographic features of samples BC08 and BC07. (a) Peak-pressure mineral assemblage (Grt, Omp) crosscut by Amp-Pl vein. Omp is surrounded by Di+PtcAmp symplectite, transforming to Px rims on the boundaries with Qz (b-c) Textural relations between the symplectite and the peak-pressure mineral assemblage. (d) Ti-bearing phases in one inclusion in Grt crosscut by Amp-Pl vein.

3 Coesite discovery

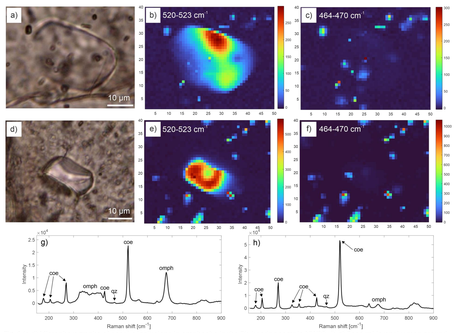


Fig. 9 (a,d) Microphotographs of coesite inclusions in omphacite in the Ph-bearing sample NW03. (b,e) Spectral intensity map around the 521 cm^{-1} Raman band characteristic for coesite. (c,f) Map of intensity around the 464 cm^{-1} Raman band characteristic for quartz. (g,h) Raman spectra of coesite inclusions shown in a and d, respectively.

Coesite forms small, reaching up to 20 µm in diameter, inclusions in garnet (Fig. 10a) and omphacite (Fig. 9a,d; 10b). All the coesite inclusions examined were located beneath the surface of the thin section. **Inclusions in garnet were located in the rim parts of the grains. No consistent pattern was observed in the location of coesite inclusions within omphacite**.

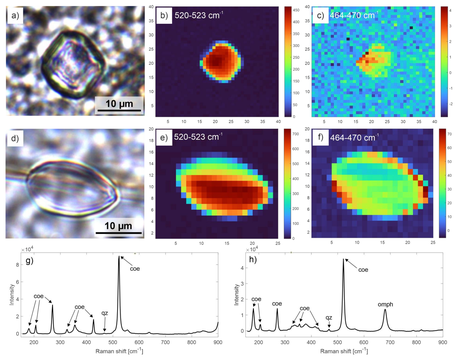


Fig. 10 Microphotographs of coesite inclusions in (a) garnet and (d) omphacite in the Ph-free sample BC08. (b,e) Spectral intensity map around 521 cm^{-1} Raman band characteristic for coesite. (c,f) Map of intensity around 464 cm^{-1} Raman band characteristic for quartz. (g,h) Raman spectra of coesite inclusions shown in a and d, respectively.

4 PT conditions of metamorphism

The eclogites from the Orlica-Śnieżnik Dome experienced UHP metamorphic conditions, as evidenced by coesite inclusions in garnet and omphacite. Peak-pressure conditions, reconstructed based on composition of garnet, omphacite ± phengite in both studied samples reached **2.9-3.2 GPa at 750-830°C.** These results are consistent, within the margin of error, with those obtained using conventional geothermobarometry and Zr-in-rutile thermometry for rutile inclusions in garnet. The UHP metamorphic event was followed by **nearly isothermal decompression to approximately 2.0-2.2 GPa at 680-770°C.**

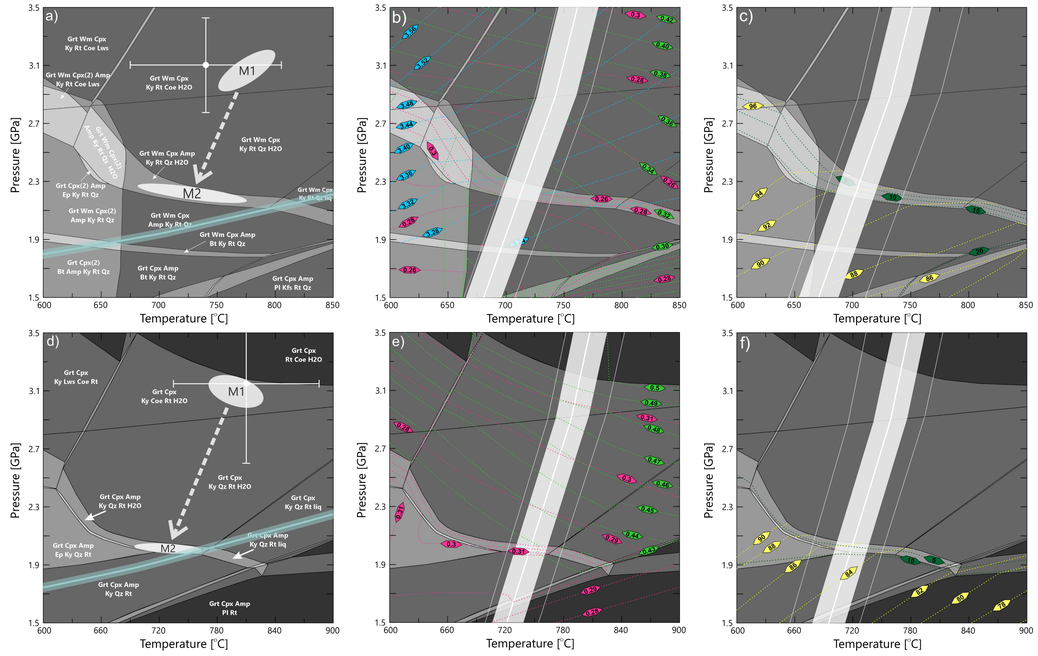


Fig. 11 (a) Phase diagram for the Ph-bearing eclogite sample NW03 from Nowa Wieś, and (d) for the Ph-free eclogite sample BC08 from Bielice with the results of phase diagram modelling (circles M1 and M2), conventional geothermobarometry (white dot with error bars) and max. entrapment pressure calculated using QuiG (light blue lines). (b,e) Modelled isopleths for X_{Ca} in omphacite (green), X_{Ca} in garnet (pink) and Si in phengite (blue). White lines mark the results of Zr-in-rutile thermometry calculated for inclusions in garnet (min – mean – max, shaded area showing ± std). (c,f) Modelled isopleths for X_{Ab} in amphibole (yellow) and %vol. of amphibole (dark green). White lines mark the results of Zr-in-rutile thermometry calculated for matrix rutile (min – mean – max, shaded area showing ± std).

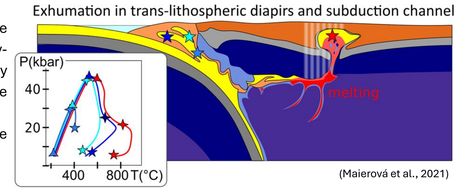
5 Discussion and further plans

Is the Orlica-Śnieżnik Dome part of the Saxothuringian or the Moldanubian Zone?

Saxothuringian Zone: ★★

- complex exhumation along plate interface, involving bouyancy-driven exhumation followed by ductile thinning, crustal-scale folding and vertical shortening
- all rock units derived from the lower plate

Exhumation in trans-lithospheric diapirs and subduction channel



(Maierová et al., 2021)

Moldanubian Zone: ★

- exhumation by trans-mantle diapirism
- mostly felsic granulite bodies, often bordered by mantle-derived mafic complexes
- lower plate-derived rocks mixed with mantle rocks and emplaced into the upper-plate crust
- spatial correlation with ultra-K magmatic bodies

Orlica-Śnieżnik Dome:

1) all rock units derived **from the lower plate**, with detrital zircon affinity to Saxothuringian Zone and only minor occurence of ultra-K magmatic dykes
2) bouyancy-driven exhumation of UHP eclogites in a subduction channel, as evidenced by extensive partial metling in the neighbouring orthogneisses and polyphase inclusions of Qz+Kfs±Pl present in UHP garnet in Bielice eclogite;
3) continuation of fabrics observed in lower-grade rock units from the OSD advocates for a subsequent, joint exhumation by crustal-scale folding (e.g. Chopin et al., 2012, Štípská et al., 2012);

→ This indicates a **closer geodynamic affinity** of the OSD **to the Saxothuringian Zone** of the European Variscan Belt. Additionally, migmatisation under confinment ("autoclave effect") may have facilitated the formation of UHP rocks at shallower depths than those predicted by the lithostatic model.

Further plans:

- Mesostructural analysis of the eclogites and neighbouring orthogneisses to further study the geodynamic evolution of the unit;
- Combined Lu-Hf and Sm-Nd grt-cpx-whole rock dating and U-Pb in-situ dating of zircon from this and two other eclogite locations in the OSD.

References:
Chopin, F., Schulmann, K., Skrzypek, E., Lehmann, J., Dujardin, J. R., Martelat, J. E., Lexa, O., Corsini, M., Edel, J. B., Štípská, P., & Pitra, P. (2012). Crustal influx, indentation, ductile thinning and gravity redistribution in a continental wedge: Building a Moldanubian mantled gneiss dome with underthrust Saxothuringian material (European Variscan belt). *Tectonics*, *31*(1)
Maierová, P., Schulmann, K., Štípská, P., Gerya, T., & Lexa, O. (2021). Trans-lithospheric diapirism explains the presence of ultra-high pressure rocks in the European Variscides. *Communications Earth & Environment*, *2*.
Štípská, P., Chopin, F., Skrzypek, E., Schulmann, K., Pitra, P., Lexa, O., Martelat, J. E., Bollinger, C., & Žáčková, E. (2012). The juxtaposition of eclogite and mid-crustal rocks in the Orlica-Śnieżnik Dome, Bohemian Massif. *Journal of Metamorphic Geology*, *30*(2), 213–234.

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