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Short Communication

Three-dimensional distribution of glass and vesicles in metasomatized xenoliths: A micro-CT case study from Nógrád–Gömör Volcanic Field (Northern Pannonian Basin)

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Abstract: In this study, three clinopyroxene-enriched upper mantle xenoliths, petrographically classified as wehrlite, were investigated from the Nógrád–Gömör Volcanic Field with the use of X-ray microtomography. Our main goal was to quantify the volume of the glass phase and the vesicles to reveal their three-dimensional distribution. Among the studied wehrlite xenoliths, one is weakly and two are strongly metasomatized. The two latter wehrlite xenoliths are characterized by higher modal amount of glass and vesicles, which suggests a genetic connection between glass and concomitant vesicles, and the metasomatic agent. The glass, which was a melt at mantle conditions, forms an interconnected network. This may explain the presence of the electromagnetic anomaly with high electrical conductivity beneath the study area. Our study contributes to the better understanding of melt migration and its metasomatic effect in the lithospheric mantle beneath monogenetic volcanic fields.

Keywords: upper mantle xenoliths, wehrlite metasomatism, X-ray microtomography, glass and vesicle distribution.

Introduction

There are several examples worldwide, where upper mantle xenoliths contain glass phase in interstitial textural position. Glass represents solidified melting residues (e.g., Yaxley et al. 1997) or trapped metasomatic melt agents (Coltorti et al. 2000, and references therein). Glass can form either before xenolith entrapment at great depths or during syn- and post-entrapment processes at shallower mantle levels. Alternatively, the heat effect of the migrating metasomatic melt agent can lead to incipient melting (e.g., Demény et al. 2004; Kovács et al. 2007). Prior studies in the literature dominantly focused on the geochemical characteristics of the glass phases in xenoliths and barely dealt with its volumetric and three-dimensional distribution. However, the presence of melts at great depth can significantly influence the geophysical parameters of the mantle such as electrical conductivity (e.g., Selway et al. 2019), seismic wave velocity (e.g., Hammond & Humphreys 2000) and seismic anisotropy (e.g., Bastow et al. 2010). When the melt forms a network, its effect is even more notable (e.g., ten Grotenhuis et al. 2005). X-ray microtomography is an excellent tool to determine volumetric ratio and spatial distribution of different solid phases and vesicles in rocks (Howarth et al. 2015; Bhanot et al. 2017, 2020; Yao et al. 2020). This technique is also able to estimate the presence and distribution for the volatile components in the silicate matrix (Créon et al. 2017), which is impossible to carry out with optical microscopy.

In this study, we investigated three metasomatized wehrlite xenoliths from the Nógrád–Gömör Volcanic Field (NGVF) located in the northern part of the Pannonian Basin (northern Hungary and southern Slovakia) using X-ray microtomography. Two of the studied xenoliths are metasomatized strongly, whereas one shows only weak metasomatic overprint. Our major goal is to reveal the volume and distribution of glass and joint vesicles and, thus, estimate the amount of metasomatic melt agent present in the lithospheric mantle at the time of entrapment of xenolith by the host basalt. We also aimed to compare the degree of metasomatism and the abundance of glass in the xenoliths. The results were interpreted in light of the electrical conductivity images of the local lithosphere. Our study contributes to better understand the effect of magmatism in the lithospheric mantle beneath monogenetic volcanic fields worldwide.

Geological background and sampling

The Pannonian Basin, an extensional back-arc basin (e.g., Horváth et al. 2006), is situated in Central Europe surrounded by the Alpine, Carpathian and Dinaric orogenic belts (Fig. 1a). During the last 21 Ma, widespread and geochemically variable volcanism took place in the Pannonian Basin and surrounding areas (e.g., Szabó et al. 1992; Harangi 2001; Lexa et al. 2010). The NGVF is the northernmost Neogene monogenetic alkali basalt volcanic field of the Carpathian–Pannonian region, where the magma transported numerous upper mantle xenoliths to the surface (Fig. 1a) (e.g., Szabó et al. 2004).

The peridotite xenoliths of the NGVF were intensively studied in the last decades (e.g., Hovorka & Fejdi 1980; Szabó & Taylor 1994; Konečný et al. 1995, 1999; Liptai et al. 2017; Patkó et al. 2020). Lherzolite and wehrlite series were distinguished, based on the petrographic and geochemical characteristics of numerous xenoliths. Lherzolites are assumed to be the precursor of the metasomatized wehrlites (Patkó et al. 2020).

In this study, we examined three wehrlite xenoliths (Table 1), each from different quarries of the Babi Hill (Babský vrch) basalt flow (Trebeľovce [NTB]; Fiľakovské Kováče [NFK]; Ratka [NFR]) (Fig. 1b). Two wehrlites (NFK1110; NFR1117A) were studied in detail by Patkó et al. (2020) and found to have been strongly involved in the metasomatic process. Since none of the weakly metasomatized wehrlites from that study were appropriate for X-ray microtomography due to the lack of material, we selected a xenolith (NTB1114) which was not included in the study of Patkó et al. (2020). The modal composition data of the NTB1114 wehrlite are presented in Table 1. Its texture is fine-grained with an average grain size of 0.2–0.4 mm. These petrographic features resemble those of wehrlite NTB1109, which is one of the least metasomatized xenolith studied by Patkó et al. (2020). None of the examined xenoliths are affected by host basalt infiltration or post-entrapment *in situ* melting.

Method

Cores of 4 mm in diameter and approximately 5 mm in length were extracted by drilling from the three wehrlite xenoliths. The X-ray microtomography was carried out on these drillcores by a Nanotom PHOENIX high-resolution X-ray micro-CT at the IFP Energies Nouvelles in Rueil-Malmaison, France. The instrument operated with conical X-ray beam established by 90 kV accelerating voltage and 170 μA beam current. The detector was a 110×110 mm sized Hamamatsu flat panel detector with 2000×2000 pixels. The beam source–sample and the sample–detector distances were fixed at 8 mm and 200 mm, respectively. With such adjustments, pixel size was 2 μm, whereas the voxel dimension was 8 μm^3. The sample, which was fixed on a rotating support made a 360° rotation with steps of 0.2°. The acquisition time was 1000 ms for each angle. As a result, 1800 pieces of two-dimensional figures were obtained for each sample, which were used to construct three-dimensional images using the Feldkamp algorithm optimized to conical beam source (Feldkamp et al. 1984).

Results and discussion

The absence of the host basalt infiltration and post-entrapment *in situ* melting affecting the rock-forming minerals of the studied xenoliths indicate that the host basalt did not affect the glass and vesicle content and distribution of the xenoliths. The lack of relationship between geochemistry and distance from the host basalt contact (Patkó et al. 2020) further supports this statement. The only slight evidence of interaction between the xenoliths and the host basalt is the appearance of reaction coronas, in the form of black clinopyroxenes (NFR1117A) (supplementary fig. 1c in Patkó et al. 2020) or assemblages of rhönite, augite, magnetite, plagioclase, and glass after amphibole breakdown (NFK1110; NTB1114) (supplementary fig. 1d in Patkó et al. 2020). However, those phenomena are restricted to the margins of the xenoliths. Thus, the petrographic and geochemical characteristics of wehrlite xenoliths, especially in their central part from where the cores for micro-CT were drilled, represent pre-entrapment conditions.

The resolution and contrast of X-ray microtomography allows clear identification of silicate, oxide, sulfide minerals, as well as glass and vesicles in the wehrlite xenoliths (Table 1). In this study, the focus is on the latter two. According to the results, the strongly metasomatized wehrlite xenoliths (NFR1117A; NFK1110) show higher glass contents (5.8 and 3.3 vol. %) compared to the weakly metasomatized wehrlite (NTB1114) (2.0 vol. %) (Table 1). This indicates that the degree of metasomatism is related to the amount of glass. This is in good agreement with the results of trace element modelling carried out by Patkó et al. (2020), which revealed a positive correlation between melt/rock ratio and degree of metasomatism. Accordingly, the glass phase is considered to represent the solidified metasomatic melt agent.

The greater volume of vesicles in the strongly metasomatized xenoliths (0.7 and 1.5 vol. %) compared to that of the weakly metasomatized one (0.4 vol. %) (Table 1) suggests that their formation is also linked to the metasomatic event. Indeed, the vesicles are concomitant with the glass phase (Fig. 2). According to Créon et al. (2017), such vesicles are originally filled with low-density (<1.5 g/cm^3) gas, dominantly CO_2, which is lost during magma ascent or late stage processes. The CO_2 solubility at 1.3–1.6 GPa, i.e., the estimated pressure of wehrlitization (Patkó et al. 2020), is decreasing from basaltic towards rhyolitic melt compositions (Eguchi & Dasgupta 2018). Indeed, andesitic silicate melt inclusions

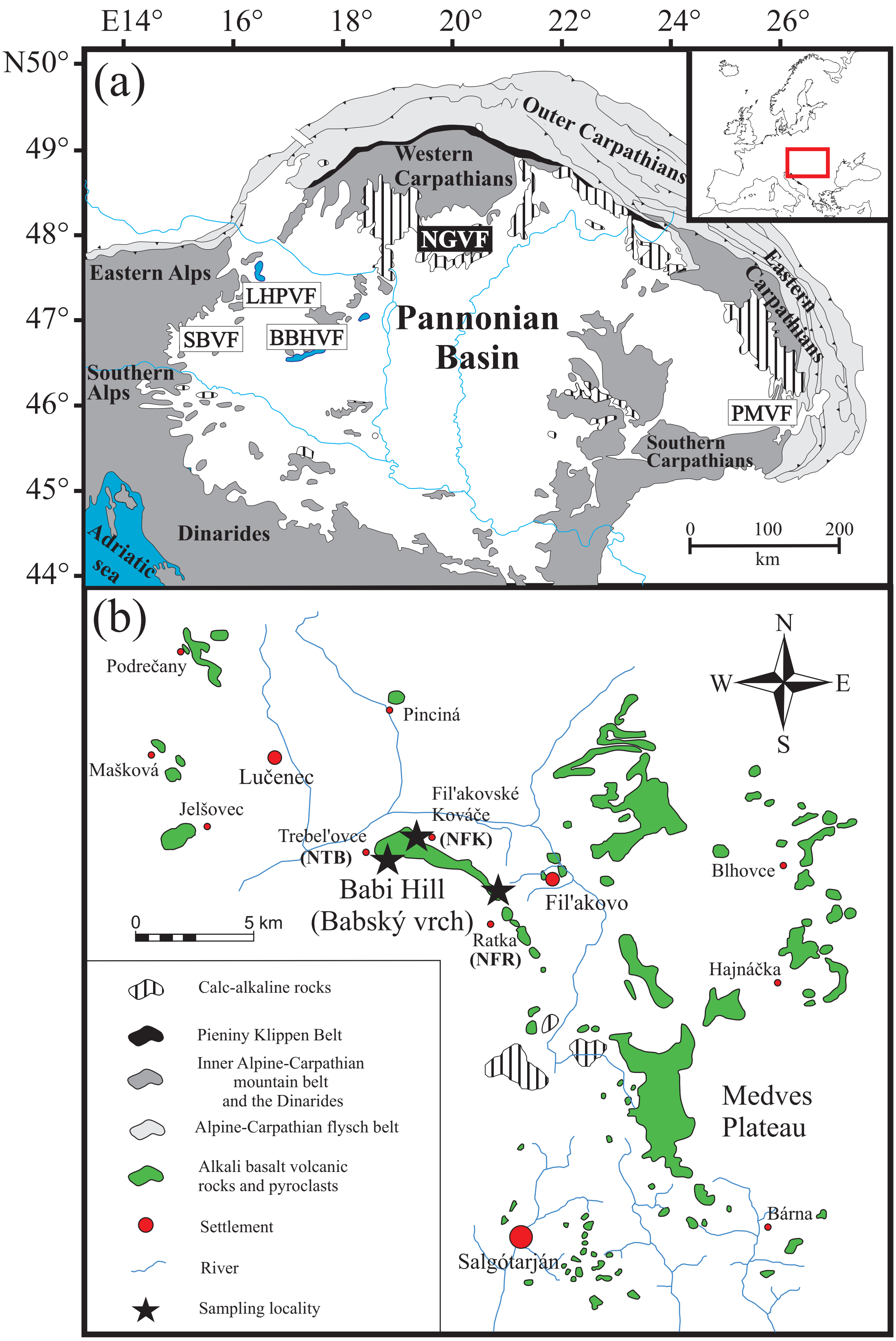

Fig. 1. a — Simplified geological map of the Carpathian–Pannonian region (after Csontos & Nagymarosy 1998, and references therein). Xenolith-bearing Neogene alkali basalt occurrences are depicted using abbreviations: SBVF — Styrian Basin Volcanic Field; LHPVF — Little Hungarian Plain Volcanic Field; BBHVF — Bakony–Balaton Highland Volcanic Field; NGVF — Nógrád–Gömör Volcanic Field; PMVF — Perşani Mountains Volcanic Field. **b** — Alkali basalt outcrops and xenolith sampling locations in the Nógrád–Gömör Volcanic Field (modified after Jugovics 1971 and Konečný et al. 1999).

Table 1: Modal composition of the solid phases and vesicles from the studied xenoliths in vol. % based on the X-ray microtomography and point counting method. Point counting was carried out using the JMicroVision software (Roduit 2006).

	xenolith	**NFK1110**	**NFR1117A**	**NTB1114**
	coordinates	48°17'17.8"N 19°44'32.8"E	48°15'39.8"N 19°47'17.1"E	48°17'25.4"N 19°44'02.2"E
	texture	ol- and cpx-rich patches	ol- and cpx-rich patches	fine-grained
	degree of metasomatism	strongly metasomatized	strongly metasomatized	weakly metasomatized
X-ray microtomography data	melt	3.29	5.78	2.01
	vesicle	1.52	0.74	0.43
	spinel	0.99	1.29	0.96
	sulfide	0.03	0.01	0.03
	silicate minerals	94.17	92.18	96.58
point counting data	olivine	75	76.5	82
	orthopyroxene	0.5	0.5	–
	clinopyroxene	20.5	21	16

in the NGVF show bigger exsolved bubbles, and higher CO_2 contents (1.46–1.94 wt. %) than those occurring in basaltic melt inclusions (1.27–1.30 wt. %) (Szabó et al. 1996). The evolution towards a more felsic melt composition during wehrlitization is explained by the orthopyroxene dissolution process (Patkó et al. 2020). Thus, the metasomatic melt evolution can lead to a decrease in CO_2 solubility, and subsequently, CO_2 exsolution and vesicle formation, especially in the strongly metasomatized portions of the lithospheric mantle.

In the NFK1110 and NFR1117A wehrlite xenoliths, the glass and vesicles form big (~1 mm) patches linked to triple junctions of the rock-forming minerals (Fig. 2a,b). The glass-vesicle patches are connected to each other through thin (5–10 μm) glass network along grain boundaries (Fig. 2a,b). Note that in these xenoliths, olivine- and clinopyroxene-rich patches were observed using optical microscopy, which are typical of the strongly metasomatized wehrlite xenoliths (Patkó et al. 2020). In contrast, in wehrlite NTB1114, which has a fine-grained texture, the glass-vesicle distribution is rather disseminated with smaller (<0.5 mm) interconnected patches (Fig. 2c). This wehrlite is also characterized by the occurrence of several small (~10 μm), rounded bubbles included by silicates. These bubbles are assumed to be CO_2 fluid inclusions (Fig. 2c), since those are abundant in NGVF xenoliths (Konečná 1990; Szabó & Bodnar 1996, 1998). All these suggest that a higher degree of metasomatism is accompanied by more focused melt and glass appearance and a more developed interconnecting network. Thus, it seems that melt distribution has a huge effect on how successful the metasomatism related alteration is.

According to long period magnetotelluric data, there is a low resistivity body (<10 Ωm) occurring beneath the Medves Plateau and Babi Hill (Babský vrch) (Fig. 1b) at a depth range of 30–60 km (Novák et al. 2014). This distribution coincides with the spatial distribution of wehrlites in the xenolith suite of the NGVF, which suggests that the effect of metasomatism is probably responsible for the anomaly, as such low electrical resistivity can be explained by interconnected fluids/melts (Brasse et al. 2002; ten Grotenhuis et al. 2005; Hill et al. 2009). The X-ray microtomography revealed that such a three-dimensional melt network may exist beneath the NGVF.

Conclusions

Based on our X-ray microtomography study of three clinopyroxene-enriched upper mantle xenoliths, we make the following conclusions:

- The degree of metasomatic overprint in wehrlite xenoliths is linked to the abundance and distribution of glass and vesicles inside the rock samples. Strongly metasomatized xenoliths show the highest glass and vesicle contents as well as interconnected vein-like appearance with focused patches at triple junctions.
- The interconnected glass in the xenoliths suggest that melt is likely still present in the mantle, which can explain the low electrical resistivity anomaly revealed by magnetotelluric measurements beneath the NGVF.

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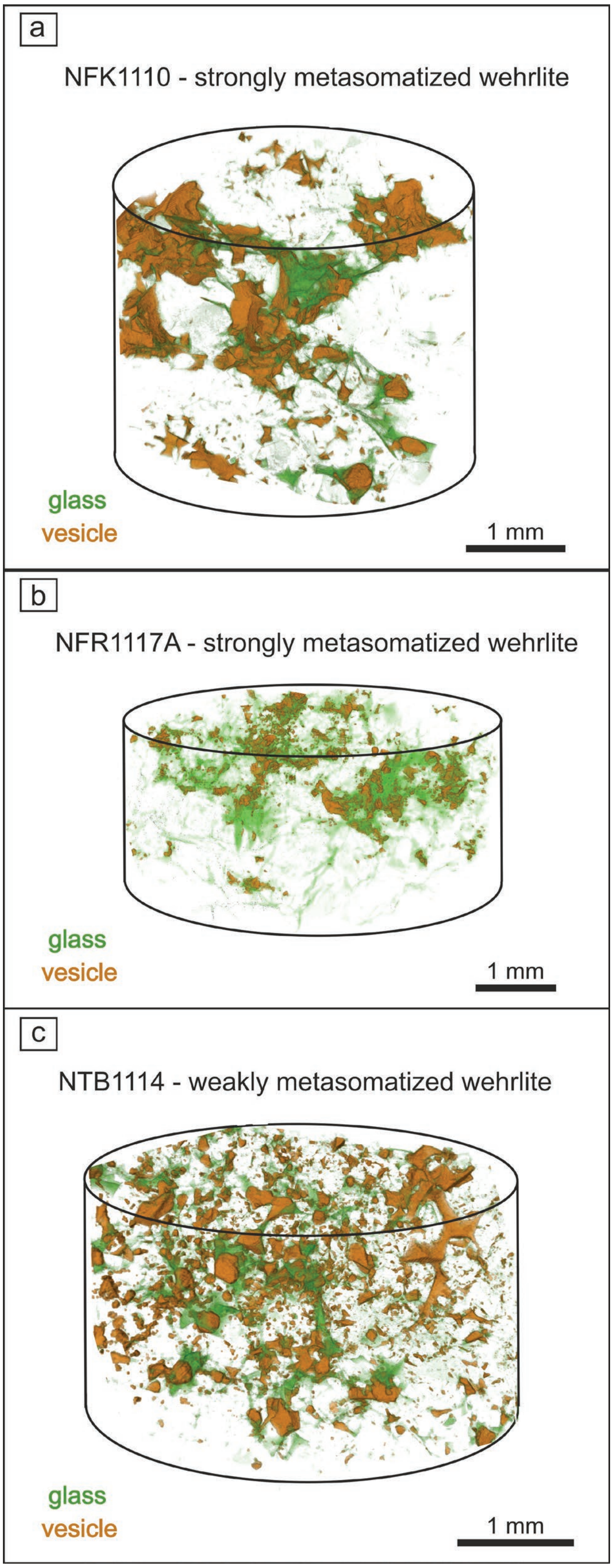

Fig. 2. Three-dimensional images of glass and vesicle distribution of the studied wehrlite xenoliths obtained with X-ray microtomography. The unlabeled parts within the cylinder denote mantle phases (silicates, spinels, sulfides). The cylinder shape of the studied volumes is due to drilling.

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