NOBLE GAS ISOTOPE SYSTEMATICS IN CENOZOIC ALKALINE VOLCANIC ROCKS AND MANTLE XENOLITHS OF THE BOHEMIAN MASSIF – IMPLICATIONS FOR THE EVOLUTION OF THE EUROPEAN SUB-CONTINENTAL LITHOSPHERIC MANTLE

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The structure and chemical composition of Earth's upper mantle is most efficiently inferred from mantle-derived xenoliths and primitive magmas with a source in the upper mantle. In this respect, noble gases provide valuable insights into the chemical evolution of Earth's mantle and the subsequent evolution of distinctive terrestrial reservoirs, including the mantle, crust and atmosphere. Different mantle reservoirs have diagnostic noble gas compositions. For example, He isotope ratios ($^3He/^4He$) in the depleted mid-ocean ridge basaltic (MORB) mantle (DMM) are uniform at 8 ± 1 R_A ($R_A \equiv$ atmospheric $^3He/^4He$ at 1.39×10^{-6}), the sub-continental lithospheric mantle (SCLM) has the estimated $^3He/^4He = 6.1 \pm 2.1$ R_A, whwreas $^3He/^4He$ in ocean island basalts (OIB) are typically >9 R_A, but may extend to values as high as ~50 R_A. In addition, heavier noble gases (Kr, Xe) can potentially reveal important information about volatile recycling through subduction zones, interactions with shallow-sourced fluids or hydrothermal overprints.

Alkaline volcanic rocks often are generated following major tectonic events in intra-plate settings, such as in the early phases of continental rifting and, occasionally, in back-arc settings, or may erupt along first-order transform faults. Contrary to MORB and OIB, continental intra-plate volcanic rocks have seldom been characterized for their noble gas inventory, and the measurements of He, Ne and Ar abundances and isotope ratios in xenoliths from the European SCLM are particularly infrequent, despite the importance of this reservoir for the evolution and stabilization of the continental areas.

Previous studies of mantle xenoliths from the Massif Central (France), Eifel (Germany), and Kapfenstein (Austria) provided evidence for a homogeneous He isotope signature of the European SCLM at ~6 R_A which was later confirmed by analyses of mantle xenoliths [1–3]. The $^3He/^4He = 6.3 \pm 0.4$ R_A for the European SCLM [2] and is also consistent with continental intra-plate alkaline volcanic rocks worldwide at 5.9 ± 1.2 R_A [4]. Similar values were reported for gas exhalation systems (mofettes, mineral springs) in Massif Central, Eifel, Eger Rift and Pannonian Basin [e.g., 5 and references therein].

Here, we report the noble gas elemental and isotope data for olivine and clinopyroxene from Cenozoic alkaline basaltic rocks of the Bohemian Massif. Samples were collected in the northern part of the Bohemian Massif across the main crustal sutures and tectonic zones with the aims to (i) characterize the noble gas systematics in SCLM domains beneath the Bohemian Massif, and (ii) reveal potential differences in noble gas systematics for discontinuous mobile zones versus thick intact lithospheric sections. In addition, peridotite xenoliths from a stratified mantle beneath the Kozákov volcano were also analyzed to identify any variability associated with vertical distribution of noble gases in the mantle column.

Most samples from this study have $^3He/^4He$ ratios that are similar to, or lower than, the SCLM signature inferred elsewhere [2,4]. This is manifested in samples FG32 and FG34 in particular, which have a similar $^3He/^4He$ of ~6.2 R_A and by several other samples with $^3He/^4He$ close to this value (5.5–5.9 R_A; $n = 6$). The ubiquity of this latter type of mantle source is supported by the He systematics of the xenolithic olivine FG32x, which is similar to the He isotope signature of olivine from the host basanite FG32 although the mantle xenoliths are much more degassed and thus much more susceptible to air contamination and radiogenic ^4He addition than host alkaline lavas. Lower $^3He/^4He$ ratios away from SCLM values documented in the within-rift volcanic rocks suggest a metasomatic input of volatiles during the Variscan subduction into the lithospheric mantle.

The SCLM-like $^3He/^4He = 7.2$ R_A measured in olivine nephelinite from the Devil's Wall dyke swarm may provide additional information on the evolution of the SCLM. The swarm likely originates from greater depths at >100 km, at or below the asthenosphere/lithosphere boundary. This is different to most other occurrences of alkaline volcanic rocks in the Bohemian Massif, which are sourced from shallower depths at ~80 km.

The Ne isotope results provide several important observations for the central European lithosphere. It is apparent that differences exist in terms of the Ne isotope ratios for samples collected in mobile zones (Ohře/Eger rift, the Lusatian Fault and the Labe/Elbe

Fault Zone) versus samples collected in largely intact blocks (Teplá Highland, Devil's Wall, Lusatia). The xenoliths and basaltic rocks erupted along main sutures have air-like Ne isotope compositions ($^{20}Ne/^{22}Ne$: 9.57–9.95) whereas higher Ne isotope ratios ($^{20}Ne/^{22}Ne$: 9.96–10.17) tending toward MORB and/or asthenospheric mantle compositions are typical of basaltic rocks (and mantle xenoliths brought by them) erupted through larger intact blocks within the Saxothuringian and Moldanubian units. We also note that these samples have less air contamination and thus are more relevant for tracking their ultimate mantle source. There is no evidence that the $^{21}Ne/^{22}Ne$ variation is related to nucleogenic effects from $^{18}O(\alpha,n)^{21}Ne$ and $^{24}Mg(n,\alpha)^{21}Ne$ reaction, respectively. Instead, a trend following the air–MORB–SCLM line appears to provide the first-order explanation for the Ne isotope systematics. This is similar to the results for samples from other Cenozoic volcanic areas in Europe, such as Massif Central, Eifel, Dreiser Weiher, Pannonian Basin and Spitsbergen [1–3] although the extent of atmospheric contamination appears to be more pronounced in samples from this study.

The difference in Ne isotope compositions between samples from mobile zones versus intact blocks is also observed for Ar systematics, where all samples related to the rift settings and mobile zones, including most mantle olivines, show air-like (or slightly radiogenic) $^{40}Ar/^{36}Ar$ values (<642) over the two orders of magnitude variation in [^{40}Ar], suggesting >99% atmospheric contribution, while samples from intact blocks display a clear trend toward radiogenic $^{40}Ar/^{36}Ar$ values (>3000; ~7% mantle Ar) with increasing [^{40}Ar].

Collectively, abundances and isotope systematics of noble gases can provide the first-order information about the structure of the mantle from which chemically more evolved melts are derived and the processes which modified European SCLM.

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