

Genetic relationships between lithospheric mantle, alkaline and calc-alkaline basic volcanoes in the eastern Carpathians (Romania): evidence from trace element and Nd-Sr isotope geochemistry

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The inner part of the Carpathian arc is the site of an intense alkaline (Downes *et al.*, 1995 and references therein) and calc-alkaline (Mason *et al.*, 1996 and references therein) basic volcanism since the Miocene times. Both types of volcanoes are closely associated in space and in time and it is difficult to reconcile the two distinct models for magma petrogenesis, plume- and subduction-related, to explain the synchronous occurrences of both types of volcanoes. The geological data of Csontos (1995) contradict the possibility of an oceanic crust subduction between the European and the Moesian plates since or even before the eruptions occurred. Together with extensive geophysical data (Mocanu and Radulescu, 1994), they provide evidence for the existence of at least two major tectonic sutures along which different continental crust blocks are suboverthrust relative to each other and significantly subducted into the lithospheric mantle. Xenoliths of this mantle were collected by some recent alkaline volcanoes (Persani Mts) closed to calc-alkaline ones (South Harghita Mts), both being active since around 2 Ma (Pécskay *et al.*, 1995). Thus the eastern area of the Transylvanian Basin (Romania) is suitable for exploration of the possible relationships between the subcontinental mantle and basic volcanic rocks of different affinities, and the reasons for such volcanic rock associations. This assumes an exhaustive study of the xenoliths in order to decipher the history of the subcontinental mantle. Based on the results of Vaselli *et al.* (1995) from which major element data on mineral separates and whole-rocks, and Nd-Sr isotopic data on clinopyroxene separates were taken, a petrographical and trace element study was performed on the various mantle lithologies. Our interpretation (Chalot-Prat and Boullier, 1997) makes the assumption that the metasomatism of the subcrustal mantle, initially harzburgitic, was not

linked to the percolation of eruptive magmas but to that of ultrabasic ones coming from partial melting of a basic continental crust. In return, this metasomatized and heterogeneous mantle was likely to be the source of both types of eruptive magmas.

These xenoliths include amphibole- and clinopyroxene-poor lherzolites and amphibole- or clinopyroxene-dominant veins. Lherzolites display porphyroclastic to granoblastic textures correlated to increasing equilibrium T from 970° to 1090°C (two-pyroxene thermometer of Wood and Banno, 1973) and increasing recrystallized olivine grain size. Amphibole and clinopyroxene, unlike olivine and enstatite, are small, undeformed, isolated, located at triple point junctions or along grain boundaries, and do not show a systematic relationship with any other mineral. These interstitial minerals are thus considered to be metasomatic and formed within a harzburgite by percolation of a melt along grain boundaries. The process of grain boundary migration of the dynamically recrystallized olivine was temperature-enhanced. Veins show a granoblastic texture. The clinopyroxene and amphibole crystals are large, undeformed, sometimes poikiloblastic, enclosing deformed olivines or enstatites, or even diopside (for amphibole). They are believed to result from intense metasomatism by impregnation of a disrupted sponge-like peridotite in the process of resorption. The veins underline fracture systems through which the melt was channelled.

In terms of major elements, peridotite whole-rocks correlate more or less between each other displaying a residual mantle feature relative to the Primitive Mantle (PM), while the composition of veins, totally checked by the dominant mineral, is far from that of peridotites. The amphibole and clinopyroxene in peridotites are clearly richer in Mg and Cr and poorer in Ti, Al, Fe and K than in veins.

In terms of trace elements, the PM-normalized spidergrams of whole-rocks of peridotites and veins are fundamentally distinct: peridotites being rather depleted and veins rather enriched in the most incompatible trace elements relative to PM. Mass balance calculations demonstrate that clinopyroxene (or amphibole in veins) are the main trace element bearing phases which thus will focus our attention. On the whole, clinopyroxene (and amphibole) of the peridotites have lower contents in trace elements than those of veins. Their *REE* patterns >1 while it is $= 1$ for clinopyroxene and amphibole in veins. Considering: (1) the physical-chemical process of metasomatism; (2) the distribution of clinopyroxene and amphibole in peridotites; and (3) the low and close values of clinopyroxene and amphibole partition coefficients at mantle depth, the trace element contents of clinopyroxene and amphibole in peridotites result from equilibrium with a melt I rich in the most incompatible elements except Ta and Nb, while the trace element contents of clinopyroxene and amphibole in veins result from equilibrium with a melt II rich in all of the most incompatible elements. Considering now the opposite Th/Ta ratios of both groups of metasomatic minerals, the geometrical relationships between peridotites and veins and the percolation-crystallization process within a fracture, melt I and melt II did not come from each other and percolated within the mantle during two distinct and successive events. Correlations between major and trace element contents in peridotite whole-rocks emphasize that interstitial metasomatism significantly increased their Ca content, and confirm the depleted and residual state of the original mantle. Thus during a first stage, a harzburgitic mantle was transformed into a secondary lherzolite which was transformed, during a second stage, along major fracture systems into monomineral veins.

The neof ormation of clinopyroxene and amphibole from olivine and enstatite required that melts I and II were both Ca-rich and Si-poor. Nevertheless, according to the contrasted clinopyroxene and amphibole compositions in interstitial and vein locations, the melt I was necessarily richer in Mg and Cr, similar in Na but poorer in Ti, Fe, Al and K than the melt II. The trace element composition of each melt, calculated using partition coefficients of clinopyroxene and amphibole at mantle depth, are far from this of carbonatites and rather closed to those of ultrabasic magmas such as Mg-leucitite for Melt I and melanephelinite for Melt II.

In assuming that major and minor phases of the

source respectively control major and trace element composition of the melt, it is deduced that melt I followed by melt II were extracted during a two-stage partial melting from the same source, at high pressure and under increasing temperature conditions. The mineralogical assemblage of this source could have been Cr-rich hydrogarnet (pyrope variety), calcite or dolomite, amphibole, clinopyroxene, apatite, zircon, titanite and/or rutile, i.e. that of a metasomatized carbonate mantle, or perhaps an eclogite of crustal affinity. The Nd and Sr isotopic data on separate clinopyroxenes and amphiboles of peridotites and veins (Vaselli *et al.*, 1995) confirm the previous results. Considering that all these minerals are metasomatic, these data can be interpreted in terms of mixing between a depleted mantle (the initial harzburgite DM then the secondary lherzolite SP) and two liquids (MI then MII) which could have the same isotopic signature at the limit between mantle and crust fields. The likely involvement, during melting, of specifically U-enriched phases, is in favour of eclogites enclosed in a deep and polymetamorphic continental crust. In that case, melting of eclogites could have occurred by suboverthrusting of lower crust into the mantle, as suggested by the structural context described above.

The inferred bulk compositions of Melt I and Melt II are clearly different from those of alkaline and calc-alkaline basic lavas: the relative proportion of major elements is not at all the same and their trace element contents relative to PM are much higher. Nevertheless both contaminant melts show strong positive anomalies in Th, Sr and Zr, and a Ti negative anomaly, which are both present, although attenuated, in the patterns of the two types of lavas. In the same way the melts I and calc-alkaline lavas on one hand, and the melts II and the alkaline lavas on another hand differ from each other by diametrically opposed Ta and Nb contents and different *REE* fractionation. Thus, contaminant melts and basalts can be assumed to have only indirect relationships. A likely hypothesis may be that the lavas originated by melting of peridotites already metasomatized by the melts I and II. This is also supported by the similarity of isotopic ratios (Fig. 1) of alkaline lavas and monomineral veins, and the fact that the isotopic ratios of the most primitive calc-alkaline lavas, although they differ from those of clinopyroxenes of peridotites, lie on the trend defined by the mixing hyperbola DM-M I. This would mean that the mantle source of calc-alkaline lavas was only more metasomatized by the melt I than the mantle brought up as xenoliths.