Coeval calc-alkaline, potassic, and ultra-potassic mafic melts from northern Greece: implications for the genesis of a “Leopard-Skin” mantle source

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Introduction

Mantle derived melts in subduction-related magmatic suites commonly display large compositional variations often due to variable enrichments of incompatible chemical elements that are thought the be introduced into the upper mantle by fluids released by subducting oceanic lithosphere (e.g. Foley, 1992; Peccerillo, 1999). This feature is also observed for mafic magmas associated with the main granitic bodies that intrude the Serbomacedonian and Rhodope massifs in Northern Greece during Tertiary (e.g. Perugini et al., 2003). In this paper, considering the geochemical variability of coeval mafic rocks (mafic microgranular enclaves and dykes), we suggest the presence of a metasomatised “leopard-skin” mantle wedge with high variable geochemical composition whose partial melting may explain the wide compositional spectrum of mafic magmas in northern Greece. Our hypothesis is corroborated by numerical simulations of infiltration of metasomatic fluids into a lithospheric mantle wedge.

Calc-alkaline, potassic and ultra-potassic mafic melts

Figure 1A-C shows SiO2 vs. K2O diagrams (Peccerillo and Taylor, 1976) for some representative granitoids and associated mafic products outcropping in northern Greece. It shows that mafic melts ranging from calc-alkaline to shoshonitic are ubiquitous in almost all plutons indicating the coeval occurrence of mantle derived melts with different enrichments of K2O. This is also evident in the frequency histogram of K2O (Fig. 1D) constructed with magmas with SiO2<60% where a wide spectrum of melts with different enrichment in K2O is shown. It is to note that the enrichment of K2O in these mafic melts is mirrored, in general, by incompatible elements. These mafic rocks display a continuous variation between two extreme compositions (Figure 2A): (i) potassic, ultra-potassic rocks (lamprophyres) having high K2O, and low Al2O3, low Na2O and CaO, and (ii) more typical calc-alkaline rocks showing low K2O, high Al2O3 (high Na2O and CaO). In Figure 2B are shown spider diagrams performed using average compositions of mafic rocks selected on the basis of their K2O enrichment. The diagrams show that all samples have a clear enrichment in LILE coupled with HFSE depletion, and Nb, Ta and Ti negative anomalies, typical of subduction related magmas. Striking is the similarity, both in absolute values and relative enrichment of the elements between the high potassium rocks and lamprophyres, with respect to the low potassium rocks that show lower contents of LILE and some HFSE.
Figure 1. A-C) K₂O vs. SiO₂ diagrams for some representative granitic bodies from northern Greece and associated mafic rocks. D) Frequency histogram of K₂O for mafic rocks (SiO₂<60%).

The coeval occurrence of mantle derived melts showing geochemical compositions ranging from lamprophyric to calc-alkaline suggests that a heterogeneous mantle, able to generate a rich compositional variability of melts between these two end-members, existed during Tertiary beneath the Serbomacedonian and Rhodope massifs. The first end-member can be interpreted to be derived by partial melting processes of a strongly metasomatized mantle source where K-rich phases, such as phlogopite, played a key role. The low Al, Na, Ca, and high compatible elements argue for a restitic peridotitic source (e.g. Foley, 1992).

Figure 2. A) Al₂O₃ vs. K₂O plot showing the geochemical variation of mafic rocks. B) Spider diagram showing the trace element patterns of mafic low-K₂O, high-K₂O rocks, and lamprophyres from northern Greece normalised to primordial mantle (Wood et al. 1979).

These considerations are corroborated by the fact that lamprophyric mafic products are commonly associated with a metasomatized lithospheric mantle wedge above a subducting slab, the latter being the engine acting to produce the metasomatic process itself (e.g. Mitchell and Bergman 1991). The second mantle end-member shows higher Al, Na, Ca, and lower compatible elements, suggesting a derivation from a fertile metasomatized lherzolitic mantle source. How-
ever, these two mantle source compositions have to be considered just as two extreme end-
members occurring in a mantle wedge able to generate melts spanning all intermediate com-
positions (Figure 2A). The main question arises as to what processes may generate such an inho-

geneous mantle wedge.

Figure 3. A) Sketch of a subduction zone in which metasomatic fluids released by a dipp-
ing oceanic slab infiltrate into a fractured mantle wedge. B-C) Contour plots of succes-
Law steps of the simulation showing the development of metasomatism induced by dif-
sion of the “metasomatic agent” from fractures to the surrounding mantle. D) Gray shaded
plot of the system after time $t_0$. In (B-D) gray values are considered as a proxy for concen-
tration of the “metasomatic agent”.

Genesis of a “leopard-skin” mantle source

In order to understand the possible causes responsible for the development of in-homogeneities
in a mantle wedge overlying a subducting oceanic slab, numerical simulations have been per-
formed. We consider a fractured lithospheric mantle wedge (Fig. 3A) in which metasomatic fluids,
released by dehydration of the oceanic slab, infiltrate. For the sake of simplicity we consider that
fluids are constituted by only one “metasomatic agent” (e.g. K$_2$O). The fracturing of the mantle is
assumed to be random. We also assume that fractures are always saturated with the me-
tasomatic fluids and that metasomatism is developed by diffusion of such fluids from fractures to
the surrounding mantle. Simulations are performed in grey values, considered as a proxy for the
centration for the “metasomatic agent”; in particular, the black colour (grey value=0) is the
pure “metasomatic agent” and the white colour (grey value=255) is the mantle wedge unaffected
by metasomatism. Intermediate grey values represent intermediate degrees of metasomatism.
Figure 3B and C displays contour plots of the concentration of the “metasomatic agent” during the development of metasomatism and shows that the efficiency of the process is directly proportional to the density of fractures. In detail, the higher the density of fractures, the higher the metasomatism suffered by the mantle wedge. Figure 3D shows a shaded representation of the simulated system and evidences that, in the same system, portions of mantle that suffered very variable degrees of metasomatism, indicated by different shades of grey, coexist. This is better evidenced by the frequency histogram of Figure 4 in which the high compositional variability of the mantle wedge after the metasomatic process can be observed. Partial melting of such an heterogeneous mantle wedge would produce mafic melts with highly variable degree of enrichment of the “metasomatic agent”.

The modelled “metasomatic agent” is conceptually analogous to the chemical elements (mainly incompatible elements) that constitute metasomatic fluids responsible for the production of metasomatism of mantle wedges overlying subduction zones. On the basis of these considerations, we suggest that our model may explain the occurrence in northern Greece of coeval and compositionally different mantle derived melts. It is noteworthy that, although the numerical simulation presented above keeps into account the essential features of the development of metasomatic processes in fractured lithospheric mantle it needs to be refined by introducing appropriate length and time scales. Results are encouraging and work is in progress to develop more reliable models to be tested on natural systems.

References


