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Carbonated alkali-silicate metasomatism in the North Africa lithosphere: Evidence from Middle Atlas spinel-lherzolites, Morocco

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A B S T R A C T

Mantle xenoliths from Pliocene-Quaternary volcanic diatremes in the Azrou area (Middle Atlas, Morocco) include protogranular to porphyroclastic spinel lherzolites with superimposed metasomatic textures involving pyroxenes and spinel as the main reacting phases.

Thermobarometric estimates on these xenoliths show pressure (*P*)–temperature (*T*) equilibrium conditions in the range 1.1–1.4 GPa and 900–1090 °C.

Bulk rocks have flat heavy rare earth element (HREE) patterns (0.6–2.2 times chondrite) and are variably enriched in light REE (LREE; La_N/Yb_N between 1.1 and 15.6).

The constituent clinopyroxenes are characterized by flat HREE distributions (5.1–11.9 times chondrite) and variable LREE enrichment with La_N/Yb_N from 0.4 to 25, which generally conform to the bulk rock chemistry. Trace elements characteristics of the metasomatised clinopyroxenes suggest that the metasomatasing agents were highly alkaline carbonate-rich melts such as nephelinites/melilitites or, as extreme, silico-carbonatites.

Sr–Nd isotopic composition analyses carried out on clinopyroxene separates yield $^{87}Sr/^{86}Sr = 0.70243–0.70335$, $^{143}Nd/^{144}Nd = 0.51273–0.51325$. The helium isotope composition of olivines ranges from 6.2 to 6.8 R_a. These values, coupled with the radiogenic lead isotopic composition available in the literature, suggest that the Middle-Atlas lithospheric mantle interacted with HIMU-like metasomatic components. These are in turn related to local mantle upwellings along pre-existing tectonic lineaments – located at the northern border of the West African Craton – that were reactivated as far-field foreland reaction of the Africa-Europe collisional system.

1. Introduction

North African Cenozoic intraplate volcanism mainly occurs in Sudan (Jebel Marra), Libya and Chad (e.g. Gharyan, Al Haruj, As Sawda, Tibesti), Tunisia (Les Nefza, Les Mogodos), Algeria (Hoggar) as well as in Morocco (Wilson and Bianchini, 1999). Alkaline volcanics of many of these localities entrained mantle xenoliths that are extremely important to delineate the melt extraction events, the metasomatic enrichments and the thermobarometric evolution that affected the North African lithosphere. The Moroccan occurrences are of particular interest due to an extremely wide range of magmas including highly alkaline and carbonatitic igneous associations (Wagner et al., 2003; Berger et al., 2009; Bouabdellah et al., 2010; El Azzouzi et al., 2010) that testify for the great compositional variability of underlying mantle sources.

Following previous investigation of Gharyan and Hoggar mantle xenoliths (Beccaluva et al., 2007a, 2008a), in this paper we focus the attention on mantle xenoliths from the Azrou area of Middle Atlas which represent one of the best occurrences in terms of xenolith abundance, size and compositional variety (Beccaluva et al., 2008b; Raffone et al., 2009; Wittig et al., 2010a, 2010b). The aim is to provide new geochemical data including major and trace element bulk rock analyses, mineral major element compositions, trace element and Sr–Nd isotope analyses of clinopyroxene as well as olivine helium isotopic composition. These data may highlight the nature of metasomatising components that affected the lithospheric mantle section of the North-West African region.

2. Sampling location

Mantle xenoliths studied in this work have been collected from pyroclastic material in the Ibalrhatene diatreme, in the Azrou-

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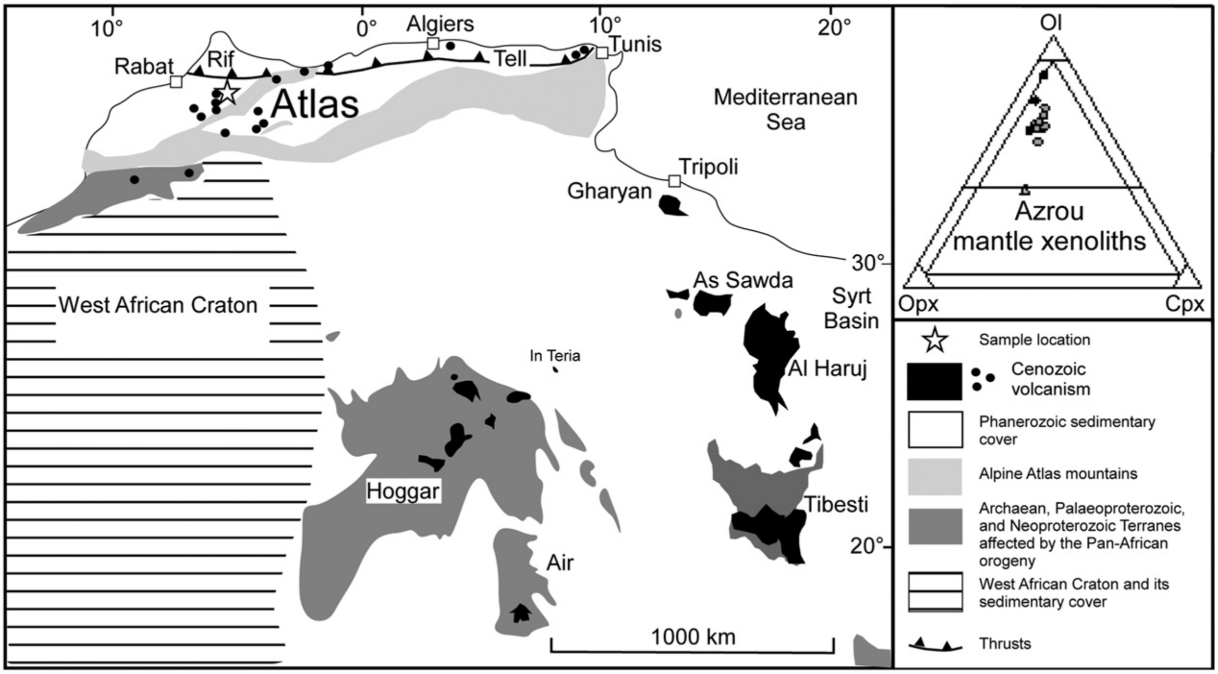

Fig. 1. Simplified geological map of North Africa indicating the locations of the main Cenozoic volcanic fields (after Liégeois et al., 2005, modified). Also reported the modal composition of the Azrou mantle xenoliths in terms of olivine (ol), orthopyroxene (opx), clinopyroxene (cpx); grey and black circles represent lherzolites and cpx-poor lherzolites, respectively.

Timhadite volcanic district (Fig. 1) which formed during Late Pliocene and Quaternary times including hundreds of alkaline monogenic volcanic centres (Harmand and Moukadiri, 1986; Morel and Cabanis, 1993; El Azzouzi et al., 2010). This volcanism, characterized by alkaline basalts, basanites and minor nephelinites, occurs in the Tabular Middle Atlas along NE–SW trending tectonic lineament characterised by transtensional faults (Gomez et al., 1996) in correspondence of a Moho depth of ca. 35 km (Arboleya et al., 2004) and a lithosphere-asthenosphere boundary up to ca. 60 km (Missenard et al., 2006; Missenard and Cadoux, 2011).

3. Analytical methods

The studied peridotite xenoliths are up to 20 cm in size, unaltered and unaffected by host basalt infiltration. Samples were sliced and the freshest portions (weighting between 15 and 30 g) were crushed and then powdered in an agate mill. X-ray fluorescence (XRF) major and trace elements (Ni, Co, Cr, V and Sr) were analysed on powder pellets, using a wavelength-dispersive automated ARL Advant'X spectrometer at the Department of Earth Sciences of the Ferrara University. Accuracy and precision for major elements are estimated as better than 3% for Si, Ti, Fe, Ca, and K, and 7% for Mg, Al, Mn, Na; for trace elements (above 10 ppm) they are better than 10%. REE, Sc, Y, Zr, Hf, Nb, Ta, Th, and U were analysed (after HF–HNO_3 dissolution of rock powders in teflon beakers) by inductively coupled mass spectrometry (ICP-MS) at the Department of Earth Sciences of the Ferrara University, using an X Series Thermo-Scientific spectrometer. Accuracy and precision, based on the replicated analyses of samples and standards, are estimated as better than 10% for all elements well above the detection limit.

Mineral compositions were obtained at the CNR-IGG Institute of Padova with a Cameca SX 50 electron microprobe (fitted with four wavelength dispersive spectrometers) at an accelerating voltage of 15 kV, and specimen current of 15 nA, using natural silicates and oxides as standards. Trace element analyses on pyroxenes were carried out at the CNR-IGG of Pavia by LAM ICP-MS, using an Elan

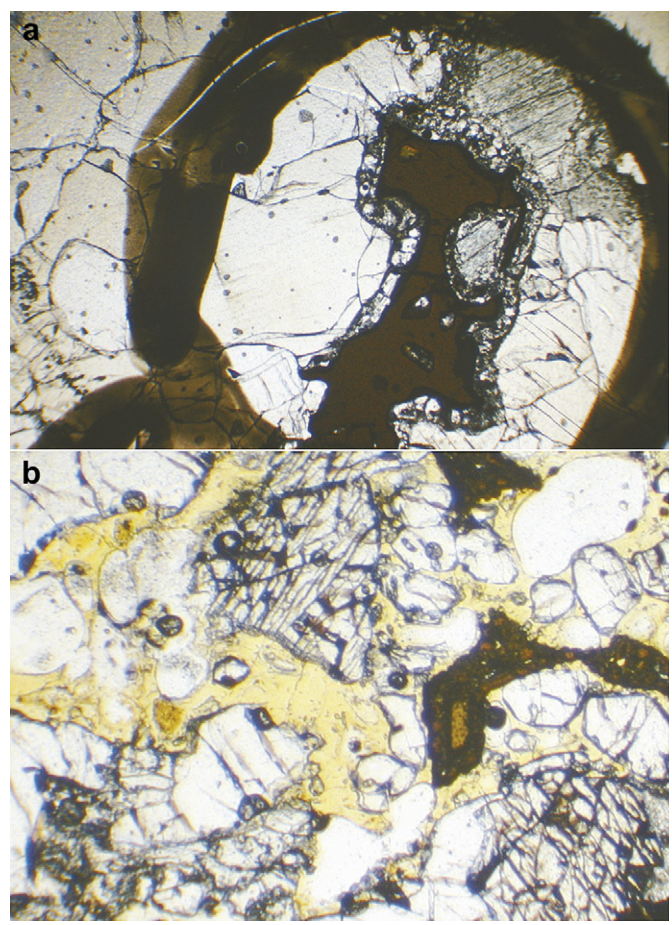

Fig. 2. Photomicrographs of pyrometamorphic textures in mantle xenoliths from Azrou, indicating evidence of metasomatic reactions. (a) destabilized spinel and clinopyroxene crystals developing a reaction aggregate of secondary olivine and clinopyroxene microliths. (b) glassy patches surrounding destabilized orthopyroxene.