Journal of South American Earth Sciences 41 (2013) 122–139

Contents lists available at SciVerse ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Petrology of ultramafic xenoliths in Cenozoic alkaline rocks of northern Madagascar (Nosy Be Archipelago)

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A R T I C L E I N F O

Article history:
Received 22 December 2011
Accepted 17 June 2012

Keywords:
Mantle xenoliths
Lherzolite
Harzburgite
Wehrlite
Basanites
Nosy Be Archipelago
Madagascar

A B S T R A C T

Late Miocene basanites of Nosy Be and Nosy Sakatia islands (Nosy Be Archipelago, northern Madagascar) carry spinel-facies anhydrous ultramafic xenoliths (lherzolites, harzburgites and wehrlites). Geothermobarometric estimates indicate that these xenoliths derive from shallow mantle depths of 35–40 km, with those from Nosy Be island showing equilibration *T* (averages in the range of 945–985 °C) lower than the Nosy Sakatia analogues (averages ranging from 1010 to 1110 °C). One Nosy Sakatia mantle xenolith exhibits relatively fertile lherzolite composition, with trace and major element mineral chemistry consistent with a residual character after low degrees (1–2%) of mafic melt extraction. We interpret this composition as that resembling a depleted mantle (DM)-like lithospheric composition before metasomatic overprints. The other lherzolites and harzburgites display petrochemical characters consistent with variable extent of partial melting (up to 18%), associated with pronounced metasomatic overprints caused by migrating melts, as highlighted by enrichments in highly incompatible trace elements (e.g. light rare earth elements, LREE and Sr), together with the abundant occurrence of wehrlitic lithologies.

The variability of petrochemical features points to different styles of metasomatism and metasomatic agents. The estimated composition of the parental melts of wehrlites matches that of host basanites. The combination of this evidence with the petrographic features, characterized by coarse-granular to porphyroclastic textures and by the presence of olivine without kink-banding, suggests that wehrlites are veins or pockets of high pressure cumulates within the mantle peridotite. The same melts also metasomatized via porous-flow percolation some lherzolites and harzburgites. Distinctly, a group of lherzolites and harzburgites was metasomatized by a different alkaline melt having markedly lower incompatible trace element contents.

Late infiltration of metasomatic fluids is responsible for the spongy texture of some clinopyroxenes of lherzolites, harzburgites and wehrlites.

1. Introduction

Mantle xenoliths hosted in mafic alkaline lavas often represent one of the few proxies for the composition and thermal condition of the lithospheric mantle in many Earth's regions (e.g., Rocco et al., 2012, and references therein). The texture of the xenoliths, as well as their chemical and isotopic composition, offers a precious opportunity to evaluate enrichment/depletion processes which acted in the uppemost mantle. Very little is known on the chemical composition and history of the Madagascar lithospheric mantle, but the geological history of northernmost Madagascar points to a complex evolution, being the Nosy Be lithosphere involved in several orogenic cycles and rifted during the Madagascar-Somali and Madagascar-India separation (e.g., de Wit, 2003; Melluso et al., 2009 and references therein). This complexity implies mineral and chemical heterogeneity of the local sub-continental mantle.

The Cenozoic mantle-derived volcanic rocks of Madagascar range in composition from olivine melilitite to tholeiitic basalt (e.g., Melluso and Morra, 2000; Melluso et al., 2007a,b, 2011; Cucciniello et al., 2011), and the most mafic alkali-rich terms often host ultramafic xenoliths. The mafic volcanic rocks of northern Madagascar are known for many xenolith-rich localities, most of them located in the Nosy Be archipelago and in the Massif d'Ambre.

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0895-9811/$ – see front matter
http://dx.doi.org/10.1016/j.jsames.2012.06.012

The Nosy Be Archipelago is formed by the Nosy Be island, formed by sedimentary rocks pierced by volcanic vents and plutonic intrusions, and several islets, many of which are volcanic (Fig. 1), with the bulk of the volcanic rocks being represented by spatter cones and tuff rings of basanite/tephrite composition (Melluso and Morra, 2000). Slightly peraluminous rhyolite lavas (e.g. at Sakatia island), nepheline syenites (Lokobe, SE Nosy Be) and gabbroic/syenitic/phonolitic intrusions (Nosy Komba island) are also known in the archipelago. These rocks are the northwesternmost part of the igneous activity of the Ampasindava peninsula, of Late Cenozoic age, which penetrates within northern Madagascar with large intrusions and volcanic fields. The northernmost tip of Madagascar is also covered by a large composite volcano (the Massif d'Ambre) and penetrated by a basanite/phonolite dyke swarm (Cucciniello et al., 2011; Melluso et al., 2007a,b). The nodules subject of this study were collected in necks and tuff rings on the southeastern sector of Nosy Sakatia island and the eastern sector of Nosy Be island (Fig. 1).

2. Analytical techniques

Xenolith samples from necks and tuff cones were cut, and polished thin section were prepared. Modal analyses of 24 samples were determined by using the Leica QwinPlus software image-analysis, by subdividing the thin section in a variable number of points (from 300 to 3000 depending on the grain size). Mineral chemical analyses were obtained using a CAMECA SX50 electron microprobe at CNR, Rome, operating in Wavelength Dispersion Spectrometry (WDS) at 15 kV and 15 nA, using an electron beam ranging from 2 to 5 μm, and a JEOL JSM-5310 at Centro Interdipartimentale di Servizi per Analisi Geomineralogiche (CISAG) of the University of Napoli equipped with an Energy Dispersion Spectrometry (EDS) INCA X-act detector and an operating at 15 kV and 50–100 mA, with a spot size of 15–17 μm and a net acquisition time of 50 s. Further details are reported in Melluso et al. (2010).

Trace element concentration in clinopyroxene (La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb, Sc, V, Sr, Y, Zr, Nb, Ti and Ba) was obtained on selected gold-coated thin sections with a Cameca IMS 4f ion microprobe (SIMS) at IGG-CNR, Pavia (Italy). The primary beam consisted of mass analysed $^{16}O^-$ and was focalized on spots of 15–20 μm diameter. Analytical conditions were typically 10 nA beam current and 17 keV total impact energy. The sputtered ions were transferred to the mass spectrometer by the 25 μm optics and energy filtered by applying −100 V offset voltage, with an energy band width by ±25 eV. Quantification was done using an empirical calibration based on a number of well-characterized natural minerals and using ^{30}Si as internal standard. Further details on the analytical and quantification procedures are reported by Bottazzi et al. (1994). Estimated accuracy is better than 10% for element concentration at the ppm level. Detection limits for REE, Sr, Zr, Nb and Ba are at 10 of ppb level or lower.

3. Petrography and modal composition of host lavas and xenoliths

Mantle xenoliths collected from Nosy Sakatia and Nosy Be islands are ~5 cm large, with rectilinear or rounded edges. Modal composition is characterized by anhydrous assemblages containing variable amount of olivine, orthopyroxene, clinopyroxene and spinel. The Nosy Sakatia xenoliths can be modally classified as lherzolites, harzburgites and wehrlites, whereas those from Nosy Be are represented by two lherzolites and one harzburgite (Fig. 2 and Table 1).

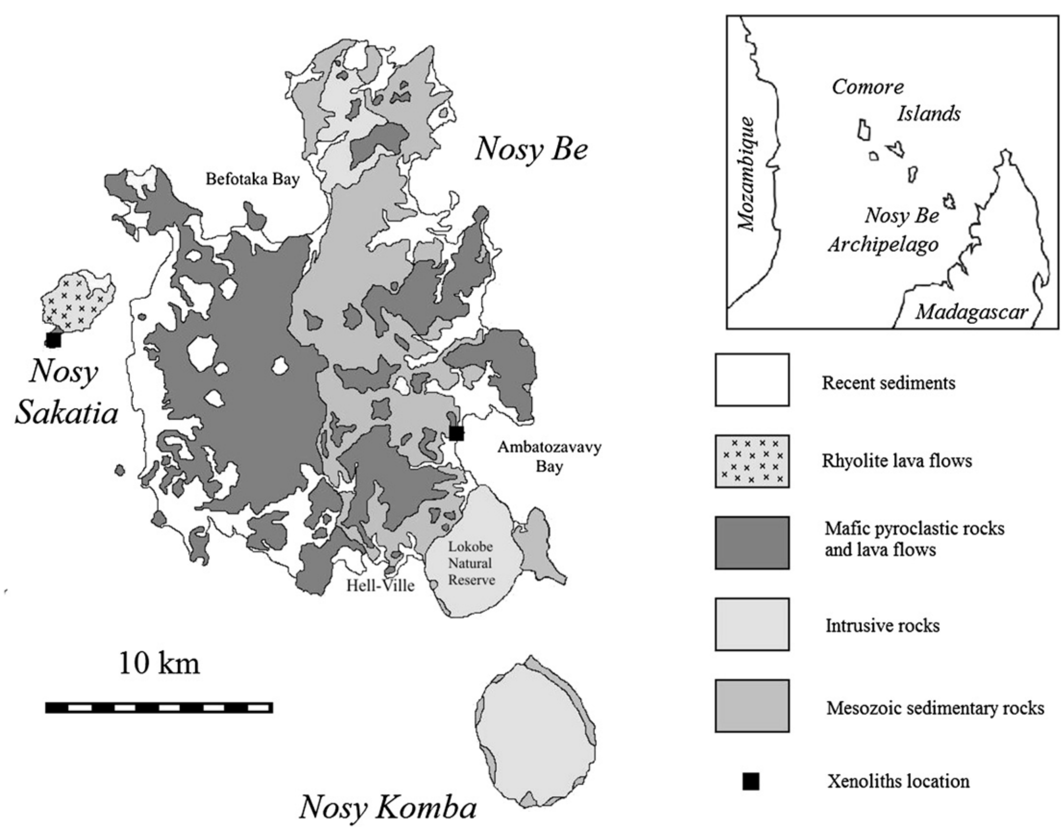

Fig. 1. Sketch map of Nosy Be Archipelago with the location of mantle xenoliths.