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The metasomatic record in the shallow peridotite mantle beneath Grenada (Lesser Antilles arc)

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Abstract

The composition and geochemical signatures of the mantle wedge beneath the Lesser Antilles arc are documented by the ultramafic xenoliths included in alkali basalts (M-series) on Grenada. Xenoliths consist of harzburgites, lherzolites, dunites and subordinate wehrlites and pyroxenites. Primary minerals phases are olivine, low-Al and high-Al orthopyroxene, clinopyroxene and Cr-Spinel. In addition to the primary assemblage, Grenada xenoliths contain metasomatic phases such as Al-rich clinopyroxene, plagioclase, Al-rich spinel, pargasitic amphibole and Si- and Al-rich glasses. The trace-element signatures of pyroxenes and glasses have been determined on selected samples by LA-ICP-MS. Pyroxenes from both lherzolite and harzburgite xenoliths have U-shaped rare earth element (REE) profiles, unusually high Th, U and Sr concentrations and large negative Nb, Ta and Zr, and Hf anomalies. The geochemical signatures of metasomatic clinopyroxene are different from those reported for clinopyroxene from fluid-metasomatised mantle wedge, and are clearly distinct from those of clinopyroxene in equilibrium with host lavas. Si-rich glasses show a narrow compositional range, with trace-element characteristics closely similar to those of reacted pyroxenes. This, along with the general lack of chemical gradients of LILE and LREE over more compatible elements suggests dacitic glasses represent the products of in-situ melting caused by temperature increase before and during the uptake of xenoliths by host lavas. Dacitic melts are believed to represent local re-melts of regions metasomatically enriched by earlier arc magmas that had stalled, fractionated, and solidified in the upper mantle. These local re-melts thus reflect the metasomatic component formed by earlier arc-related metasomatic agents and liable to be re-mobilised. This also appears to be the easiest way to explain the compositional similarities between erupted arc lavas and the metasomatised peridotites.

The results of this study suggest that the mantle wedge beneath the Lesser Antilles underwent complex peridotite–melt reaction processes operated by sub-arc melts and, later on, by magmas similar in compositions to the host alkali basalts. The majority of the compositional range of erupted Grenada magmas, but adakites found at surface, can be obtained by the interaction of basalts, possibly formed by hydrous melting of MORB-source mantle, with the overlying mantle wedge.
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Keywords: Sub-arc mantle; Mantle xenoliths; Metasomatism; Clinopyroxene; Glasses; Lesser Antilles; LA-ICP-MS

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Table 1
Representative major element (wt.%) compositions of olivine

Rock type	Wh	Du	Du	Du	Hz	Hz	Hz	Hz	Hz	Hz	Hz	Hz	Lh	Lh	Lh	Wb	Wb	Wb	Py
Sample	gr 7–1	gr 7–2	gr 1	gr 20b	gr 20–22	gr 20–15a	gr 20–8a	gr 1–2	gr 5–1	gr 20–9c	gr 20–15	gr 20–90	gr 20–21	gr 20–15b	gr 20–2	gr 20–10	gr 20–13	gr 20–13	gr 20–8c
SiO_2	39.49	40.94	40.90	40.30	41.62	40.86	40.54	40.43	41.38	41.91	40.68	40.15	40.72	41.30	41.01	41.17	41.70	40.78	41.67
TiO_2	–	0.02	0.05	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cr_2O_3	–	0.06	–	–	–	0.06	–	–	–	–	–	–	–	–	–	–	–	–	–
FeO_{tot}	16.64	10.13	12.70	10.14	9.92	11.09	10.36	13.56	8.63	9.84	10.12	12.22	9.94	10.32	12.71	10.74	11.00	12.29	9.52
MnO	0.15	0.03	0.11	–	–	–	0.04	0.06	0.01	0.03		0.08	–	–	0.02	–	–	0.05	–
NiO	0.37	0.10	0.19	0.40	0.23	0.29	0.39	0.15	0.39	0.32	0.75	0.24	0.64	0.78	0.11	0.29	0.24	0.13	0.35
MgO	43.57	47.74	46.55	49.14	47.21	47.63	47.72	45.99	50.20	48.54	48.64	47.03	48.71	47.47	45.64	48.11	46.94	46.89	47.80
CaO	0.26	0.06	0.04	0.03	0.01	0.03	–	0.01	0.03	0.05	0.11	0.03	–	–	0.16	0.16	0.03	0.15	0.04
Na_2O	–	–	0.08	–	–	–	–	0.15	–	–	–	–	–	–	–	–	0.04	0.01	0.01
Sum	100.5	99.08	100.6	100.0	98.99	99.96	99.05	100.4	100.6	100.7	100.3	99.75	100.0	99.87	99.65	100.5	99.95	100.3	99.39
Fo	0.82	0.88	0.86	0.90	0.87	0.87	0.88	0.85	0.91	0.88	0.89	0.87	0.89	0.87	0.85	0.88	0.86	0.86	0.875

– Below detection limits; Wh = wehrlite; Du = dunite; Hz = harzburgite; Lh = lherzolite; Wb = websterite; Py = pyroxenite.

1. Introduction

Mantle xenoliths are relatively rare in the magmatic products of volcanic arcs, thus preventing direct chemical information on the composition of the mantle wedge and on the role of slab-derived fluids and/or melts in the modification of the mantle's original geochemical signatures. Sub-arc xenoliths from intra-oceanic island arcs, excluding fore-arc and back-arc xenoliths, have been described from Lihir and Simberi Islands, Papua New Guinea (McInnes and Cameron, 1994; Eiler et al., 1998; McInnes et al., 1999, 2001; Grégoire et al., 2001), Batan Island, Philippines (Vidal et al., 1989; Maury et al., 1992; McInnes and Cameron, 1994; Eiler et al., 1998; McInnes et al., 1999, 2001; Grégoire et al., 2001), Kurile, Russia (Swanson et al., 1987; Kepezhinskas et al., 1995, 1996; Kepezhinskas and Defant, 1996, 2001; Kepezhinskas et al., 2002), Grenada, Lesser Antilles (Arculus and Wills, 1980; Defant et al., 2000; Parkinson et al., 2003), Marelava Volcano, Vanuatu Arc (Barsdell and Smith, 1989; Parkinson and Arculus, 1999) and the Aleutian Arc (DeLong et al., 1975; Conrad and Kay, 1984; Debari et al., 1987; Swanson et al., 1987).

On Grenada two major groups of mafic lavas occur: i) the C-series basalts (calcic and clinopyroxene-phyric, broadly corresponding to ankaramites; Thirlwall and Graham, 1984; Thirlwall et al., 1996), which give rise by differentiation to calc-alkaline andesites and dacites; and ii) M-series basalts (magnesian and olivine-microphyric) from which a series of low-Ca, low-Fe, high-SiO_2 basalts and mafic andesites derives.

Microphyric alkali olivine basalts from the M-series occasionally contain Na-metasomatised mantle xenoliths and present us with the opportunity to acquire petrologic and geochemical data for the sub-arc mantle. We believe the xenoliths are a key to understanding the nature and composition of subduction-related metasomatic agents, and the chemical effects of their interaction with sectors of the mantle wedge. Moreover, these xenoliths may also offer precious insights into the possible links between lithospheric mantle, erupted adakites, and alkali basalts in the arc environment.

A summary of the petrology, mineralogy and geochemistry of the Grenada xenolith suite has been presented recently by Parkinson et al. (2003), along with a discussion of the implications of the data with respect to sub-arc mantle processes. We present in this paper new results of detailed in-situ laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) investigations of pyroxenes and glasses from Grenada xenoliths. The data presented here provide additional

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