Source components of the Gran Canaria (Canary Islands) shield stage magmas: evidence from olivine composition and Sr-Nd-Pb isotopes

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Abstract – The Canary Island primitive basaltic magmas are thought to be derived from a HIMU-type upwelling mantle containing isotopically depleted (NMORB) component and having interacted with an enriched (EM)-type component whose origin is still a subject of debate. We have studied the relationships between Ni, Mn and Ca concentrations in olivine phenocrysts (85.6-90.0 mol.% Fo, 1722-3915 ppm Ni, 1085-1552 ppm Mn, 1222-3002 ppm Ca) from the most primitive subaerial and ODP Leg 157 high-silica (picritic to olivine basaltic) lavas with their bulk rock Sr-Nd-Pb isotope compositions ($^{87}Sr/^{86}Sr$ = 0.70315-0.70331, $^{143}Nd/^{144}Nd$ = 0.51288-0.51292, $^{206}Pb/^{204}Pb$ = 19.55-19.93, $^{207}Pb/^{204}Pb$ = 15.60-15.63, $^{208}Pb/^{204}Pb$ = 39.31-39.69). Our data point toward the presence of both a peridotitic and a pyroxenitic component in the magma source. Using the model [Sobolev et al. (2007) The amount of recycled crust in sources of mantle-derived melts. Science 316: 412-417] in which the reaction of Si-rich melts originated during partial melting of eclogite (a high pressure product of subducted oceanic crust) with ambient peridotitic mantle forms olivine-free reaction pyroxenite, we obtain an endmember composition for peridotite with $^{87}Sr/^{86}Sr$ = 0.70337, $^{143}Nd/^{144}Nd$ = 0.51291, $^{206}Pb/^{204}Pb$ = 19.36, $^{207}Pb/^{204}Pb$ = 15.61, $^{208}Pb/^{204}Pb$ = 39.07 (EM-type endmember) and pyroxenite with $^{87}Sr/^{86}Sr$ = 0.70309, $^{143}Nd/^{144}Nd$ = 0.51289, $^{206}Pb/^{204}Pb$ = 20.03, $^{207}Pb/^{204}Pb$ = 15.62, $^{208}Pb/^{204}Pb$ = 39.84 (HIMU-type endmember). Mixing of melts from these endmembers in proportions ranging from 70% peridotite and 30% pyroxenite to 28% peridotite and 72% pyroxenite can generate the compositions of the most primitive Gran Canaria shield stage lavas. Combining our results with those from the low-silica rocks from the western Canary Islands [Gurenko et al. (2009) Enriched, HIMU-type peridotite and depleted recycled pyroxenite in the Canary plume: a mixed-up mantle. EPSL 277: 514-524], at least four distinct components are required. We propose that they are (1) HIMU-type pyroxenitic component (representing recycled ocean crust of intermediate age) from the plume center, (2) HIMU-type peridotitic component (ancient recycled ocean crust stirred into the ambient mantle) from the plume margin, (3) depleted, MORB-type pyroxenitic

component (young recycled oceanic crust) in the upper mantle entrained by the plume, and (4) EM-type peridotitic component from the asthenosphere or lithosphere above the plume center.

Keywords: Canary Islands, Gran Canaria, ODP Leg 157, olivine, mantle plume, peridotite, pyroxenite, radiogenic isotopes, ocean crust, recycling

Introduction

Decompression melting of a HIMU-type (high time-integrated $^{238}U/^{204}Pb$, resulting in radiogenic Pb isotopic composition) mantle plume containing a component of the recycled oceanic crust may have generated the magmas feeding volcanoes on the Canary Islands (Hoernle and Tilton, 1991; Hoernle et al., 1991, 1995). The trace element and isotope compositions of mafic, low-silica (<46 wt.% SiO_2) lavas from throughout the Canary Islands form arrays between HIMU-like and depleted mid-ocean-ridge-basalt (MORB)-source-type mantle endmembers. These arrays were interpreted to reflect (1) interaction of plume melts with depleted upper mantle in the shallow asthenosphere or lithosphere (Hoernle et al. 1991, 1995), or (2) mixing between older (HIMU-like) and younger (NMORB-like) recycled oceanic crustal components either within the plume (Widom et al. 1999; Gurenko et al. 2006) or in the upwelling asthenospheric mantle (Geldmacher et al. 2005). Mafic, more silica-rich (>46 wt.% SiO_2) and evolved magmas erupted on the eastern Canary Islands (i.e. Lanzarote, Fuerteventura, Gran Canaria and Anaga Massif on Tenerife) show evidence for the presence of the third, enriched (EM)-type mantle component (Hoernle and Tilton 1991; Hoernle et al. 1991, 1995; Widom et al. 1999; Simonsen et al. 2000; Abratis et al. 2002; Lundstrom et al. 2003). EM-type mantle components worldwide are generally interpreted to be derived from recycled continental lithosphere, in the form of lithospheric splinters beneath ocean islands or seamounts, terrigenous sediments or recycled subcontinental lithospheric mantle incorporated into the upper mantle beneath the volcanic structures closest to the continents (Hawkesworth et al. 1986; Gerlach et al. 1988; Hoernle and Tilton 1991; Hoernle et al. 1991, 1995, 2002; Widom et al. 1997, 1999; Geldmacher and Hoernle 2000; Lundstrom et al. 2003; Doucelance et al. 2003; Escrig et al. 2005; Geldmacher et al. 2005, 2008). Within the Atlantic lithosphere, these components not only occur in rocks from the eastern Canary Islands, but are also recognized in the seamounts belonging to the older parts of the Madeira and Canary hotspot tracks (Geldmacher and Hoernle 2000; Geldmacher et al. 2001, 2005).

Identification of source components is one of the major geochemical challenges of igneous petrology. Sobolev et al. (2005, 2007) proposed a model to determine the amount of recycled component in the ascending mantle assuming its presence in the form of silica-oversaturated eclogite, which partially melts during decompression and reacts with ambient peridotitic mantle converting it into olivine-free “reaction pyroxenite”. Consequently decompression melting of a two-component source consisting of peridotitic and reaction pyroxenitic lithologies yields a “hybrid melt” with element and radiogenic isotope signatures based on mixing of different proportions of peridotite and pyroxenite counterparts (Sobolev et al. 2008; Gurenko et al. 2009). Based on Ni, Ca and Mn concentrations in olivine phenocrysts, the chemical and isotopic composition of peridotite and pyroxenite constituents of the plume and their relative contributions to magma genesis can be inferred. It has been shown for the western Canary Islands (Hierro, La Palma, La Gomera and the massif Teno on Tenerife) that the peridotitic component has a HIMU-like isotopic signature and the pyroxenitic component a more depleted, MORB-like composition (Gurenko et al., 2009). The HIMU-type peridotitic component is interpreted to reflect the upwelling Canary plume material and the pyroxenitic component is interpreted to be derived from entrained upper MORB-source mantle.

Whereas only alkali-rich, low-silica lavas and their derivatives (primarily compositions on the basanite/alkali basalt boundary extending to phonolite) outcrop on the western Canary Islands, both low-silica (trachytes and phonolites with rare evolved basanites and nephelinites) and high-silica lavas (picrites, tholeiites, transitional and alkali basalts through trachyte to peralkaline rhyolite) are present on the eastern Canaries (Lanzarote, Fuerteventura, Gran Canaria and Anaga Massif on Tenerife (Fúster et al., 1968; Ibarrola et al. 1970; Hernandez-Pacheco 1971; Schmincke 1976, 1982; Hoernle and Schmincke, 1993a,b). Although no primitive (olivine-bearing) low-silica lavas representing the parents of the evolved late shield stage volcanism on Gran Canaria have been found thus far, the similarity in incompatible element characteristics and Sr-Nd-Pb isotopic compositions of the late shield silica-undersaturated lavas from Gran Canaria to the HIMU-type lavas from the western Canary

Islands suggests that they are derived from a common peridotitic component of the Canary hot spot. The high-silica group lavas (including primitive tholeiites, transitional basalts and picrites) from the eastern islands, however, show evidence for the involvement of an enriched EM-type component (Hoernle and Tilton 1991; Hoernle et al. 1991, 1995, 2002; Widom et al. 1999; Simonsen et al. 2000; Abratis et al. 2002; Lundstrom et al. 2003; Gurenko et al. 2006).

In the present study, we focus on the compositions of olivines from the most primitive Miocene picritic to olivine basaltic lavas representing the mafic part of the high-silica group in the Gran Canaria shield stage lavas. Based on new, high-precision determinations of Ni, Mn and Ca in olivines, combined with whole rock radiogenic isotope data, we demonstrate that the enriched (EM)-type isotopic signature is hosted in peridotite, along with HIMU-like signature carried by deep mantle plume, being probably a signature of the African subcontinental lithosphere. This component could be entrained into the plume as it ascended through the upper mantle or possibly was incorporated due to thermal erosion and detachment of the base of the lithospheric mantle during continental breakup. We propose that at least four distinct components i.e., (1) HIMU-1-type peridotitic component probably resulted from stirring of ancient recycled ocean crust into the ambient mantle, (2) HIMU-2-type pyroxenitic component representing recycled ocean crust of intermediate age located in the plume center and probably representing main component of the Canary plume, (3) depleted, MORB-type pyroxenitic component – young recycled oceanic crust – entrained by the plume, and (4) EM-type peridotitic component from the asthenosphere or lithosphere above the plume center, are required to explain the isotopic signature of the shield stage volcanism on the Canary Islands.

Gran Canaria volcanic history and samples selected for the study

The subaerial eruptive history of Gran Canaria, Canary Islands (**Fig. 1**), is subdivided into three periods: (1) Miocene (~15–8.5 Ma); (2) Pliocene (~5.5–1.5 Ma); and (3) Quaternary (~1.5 Ma to present) (e.g. Hoernle and Schmincke, 1993a,b). The oldest subaerially exposed picritic and alkali basalt lavas (Guigui and Hogarzales formations of ca.15-14 Ma) underlie several hundred meters of dominantly ignimbrites, the peralkaline rhyolitic Mogan Group (14-13.3 Ma) and the later phonolitic Fataga Group (13.3-8.5 Ma). The Late Miocene El Tablero formation is represented dominantly by nephelinites (ca. 5.5 Ma). The thick Pliocene Roque Nublo group (~4.1–3.5 Ma) consists of a complete suite of alkali basalt through trachyte and basanite to phonolite. The volcanic rocks of the Llanos de la Pez formation (~3.2–1.8 Ma) comprise dominantly nephelinites, while the thick Quaternary and more recent lavas (~1.8–0 Ma) are dominantly basanites, with rare alkali basalts and local tephrites.

Basaltic volcaniclastic rocks drilled during the ODP Leg 157 in the lower parts of Site 953 represent the upper seamount and subaerial shield stage of Gran Canaria (Shipboard Scientific Party 1995; Gurenko et al. 1998; Schmincke and Segschneider 1998; **Fig. 1**). The oldest volcaniclastic sediments at Sites 953 consist of green to dark green hyaloclastite tuffs, lapillistones, and breccias interbedded with minor calcareous claystone and nannofossil ooze. The hyaloclastite tuffs are composed of angular vesicle-free to strongly vesicular sideromelane shards, now completely smectized, crystallized basalt rock fragments, abundant clinopyroxene, rare relics of olivine preserved in pseudomorphs composed of layer silicates, rare plagioclase, and minor biogenic debris. Fresh olivine phenocrysts were found only in scattered basalt clasts concentrated at the base of the debris flow deposits.

We analyzed olivine crystals from three subaerially-erupted picrobasalts of the oldest Guigui formation on Gran Canaria. Three other samples (i.e., 93R-5, ODP label 157-953C-93R-5, 13-27 cm; 93R-4, ODP label 157-953C-93R-4, 18-24 cm and 101R-5, ODP label 157-953C-101R-5, 116-123 cm) are from the Gran Canaria volcaniclastic apron drilled during ODP Leg 157 (Gurenko et al. 1998; Schmincke and Segschneider 1998). The main criteria for sample selection was presence of Mg-rich (Fo>85 mol%) olivine phenocrysts. Major, trace elements and radiogenic isotopes in subaerial lava samples were previously studied by Hoernle et al. (1991), Hoernle and Schmincke (1993a) and Gurenko et al (2006), while the compositions of ODP drilled samples are new data presented in this paper.

Analytical techniques

Analyses of olivine were performed at the Max Planck Institute for Chemistry (Mainz, Germany) using JEOL Superprobe JXA-8200 electron microprobe following the technique described by Sobolev et al. (2007). Olivine phenocrysts were analyzed at 20 kV accelerating voltage and 200-300 nA of primary beam current. Peak and background counting times were 60 s during analysis of major elements, 120 s during analyses of Ca, Cr, Mn and Co, and 180 s during analysis of Ni. The intensity of the CoK_{α} line overlapping with the shoulder of FeK_{β} second order line was corrected off-line using linear regression equation from Sobolev et al. (2007). A set of reference materials i.e., San-Carlos olivine (SCO) USNM 111312/444 (Jarosewich et al. 1980), pure Al_2O_3, NiO, Co metal, natural rhodonite for Mn and wollastonite for Ca (Micro-Analysis Consultants Ltd, Cambridgeshire, UK) were used for routine calibration and instrument stability monitoring.

The details of the techniques used for analyses of major and trace elements and radiogenic isotopes in subaerial lava samples are given in Gurenko et al. (2009). The original Sr-Nd-Pb isotopic compositions of three ODP samples were obtained at IFM-GEOMAR (Kiel, Germany) following the established standard procedure (Hoernle at al. 2008, Duggen et al. 2008). Because all studied ODP samples are strongly altered, we analyzed clinopyroxene separates in sample 93R-5 and fresh hand-picked groundmass fragments in samples 93R-4 and 101R-5. Isotopic ratios were determined by thermal ionization mass spectrometry (TIMS) on a TRITON (Sr-Nd) and Pb by double-spike (Pb-DS) on a MAT262 RPQ^{2+} TIMS. Both instruments operate in static multi-collection mode. Sr and Nd isotopic ratios are normalized within each run to $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$ respectively and all errors are reported as 2-sigma of the mean. Reference material measured along with the samples were normalized and gave $^{87}Sr/^{86}Sr = 0.710250 \pm 0.000007$ (N = 4) for NBS 987 and $^{143}Nd/^{144}Nd = 0.511850 \pm 0.000008$ (N = 4) for La Jolla standards. Pb isotope ratios were determined using a

^{204}Pb-^{207}Pb double-spike. The long-term reproducibility of double spike corrected NBS981 values (N = 45) are ^{206}Pb/^{204}Pb = 16.9416 ± 0.0024, ^{207}Pb/^{204}Pb = 15.4998 ± 0.0024, ^{208}Pb/^{204}Pb = 36.7231 ± 0.0063 and compare well with published double and triple spike data for NBS981 (Baker et al. 2004; Galer and Abouchami 1998; Thirlwall 2000, 2002). For better comparability with the Pb isotopic data previously published by Gurenko et al. (2006, 2009), the new Pb-DS data were renormalized to the NBS981 values of Todt et al. (1996). The Sr-Nd-Pb replicate analyses of ODP Leg 157 101R-5 sample are within the above mentioned external errors of the standards. Total chemistry blanks are $<$50 pg for Sr-Nd and $<$30 pg for Pb and thus are considered negligible.

Bulk-rock Sr-Nd-Pb isotopic composition

The Sr-Nd-Pb isotopic compositions of the studied samples are listed in **Table 1**. The samples are characterized by restricted ranges of ^{87}Sr/^{86}Sr (0.70315-0.70331), ^{143}Nd/^{144}Nd (0.51288-0.51292) and ^{207}Pb/^{204}Pb (15.60-15.63) ratios but display a relatively large range in ^{206}Pb/^{204}Pb (19.55-19.93) and ^{208}Pb/^{204}Pb (39.31-39.69) ratios. As shown in **Fig. 2**, the lavas from Gran Canaria and ODP Leg 157 require the admixture of an isotopically enriched (EM)-type component with elevated ^{87}Sr/^{86}Sr and ^{207}Pb/^{204}Pb (for their ^{206}Pb/^{204}Pb) ratios and overall slightly lower ^{143}Nd/^{144}Nd compared to the HIMU-type (or LVC = low velocity component found in intraplate volcanic rocks throughout the eastern Atlantic, western Mediterranean and Western Europe; Hoernle et al. 1995) endmember for the western Canary Islands.

Composition of olivine phenocrysts

Olivine (OL) compositions are summarized in **Table 1**; individual OL analyses are available in **Table S1, Online Supplementary information**. Olivine compositions range from $Fo_{78.9}$ to $Fo_{89.4}$ in drilled Miocene basaltic lapilli and from $Fo_{75.2}$ to $Fo_{90.1}$ in subaerially erupted lavas. Similarly as in Sobolev et al. (2007) and Gurenko et al. (2009) and in order to be consistent with previously obtained results, we consider here a restricted number of olivines (323 of 560 grains) defined by 3 mol.% of the highest Fo value in each individual sample.

The Gran Canaria olivines (both subaerial and ODP) are characterized by the highest Fo contents and strong variations of Ca and Ni concentrations and Mn/FeO ratios compared to olivines from the lavas erupted on the western Canary Islands of Hierro, La Palma and Tenerife but similar to those on La Gomera. The variations in Ca, Ni and MnO/FeO overlap almost the entire range known from the Canary Islands (**Fig. 3**). The ODP samples are characterized by relatively low Ca concentrations (1227-1965 ppm) similar to those of El Hierro, whereas the subaerially erupted lavas (1608-3002 ppm Ca) overlap almost the entire range from La Gomera, La Palma and Tenerife (**Fig. 3A**). Nickel concentrations (2466-3915 ppm Ni in olivines from ODP samples and 1722-3521 ppm Ni from subaerial lavas on Gran Canaria) generally decrease with decreasing Fo contents (**Fig. 3B**). The concentrations of Ni normalized to FeO and MgO contents (Ni×FeO/MgO used to eliminate the effect of magma fractionation) vary significantly at any given Fo content (**Fig. 3C**), similar to variations observed for La Gomera and, to a lesser extent, for El Hierro lavas. The concentrations of Mn strongly correlate with Fo contents (not shown). When normalized to FeO contents (also to minimize the effects of Ol fractionation), they show significant scatter at any given Fo content (**Fig. 3D**). These strong variations of Ni×FeO/MgO and Mn/FeO ratios imply that the studied olivines have crystallized from different batches of melts with significant differences in Ni and Mn concentrations.

Averaged Ni×FeO/MgO, Mn/FeO ratios and Ca concentrations are shown in **Fig. 4**, together with bulk rock Sr, Nd and Pb isotopic ratios of the host lavas. $^{87}Sr/^{86}Sr$ isotope ratios form a trend sub-parallel and above the field formed by the western Canary Islands (Gurenko et al., 2009). This more radiogenic signature is consistent with increasing role of the anticipated enriched (EM)-type component in the Gran Canaria lavas (**Fig. 4A-C**). It is worth emphasizing that the trends on diagrams of Ni×FeO/MgO, Mn/FeO and Ca versus $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ overlap or cross the trends defined by the western Canary Islands and have different slopes (**Fig. 4D-I**). Similar relations can be observed for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ isotope ratios (not shown).

Source components of the Canarian magmas inferred from radiogenic isotopes

Three main types of mantle components, i.e. HIMU (or LVC; Hoernle et al. 1995), DMM (or N-MORB) and EM (Zindler and Hart 1986), were previously recognized in the source of magmas erupted on the Canary Islands (Sun 1980; Cousens et al. 1991; Hoernle and Tilton 1991; Hoernle et al. 1991; Marcantonio et al. 1995; Thirlwall 1997; Thirlwall et al. 1997; Hoernle 1998; Widom et al. 1999; Simonsen et al. 2000; Geldmacher et al. 2001, 2005; Abratis et al. 2002; Lundstrom et al. 2003; Gurenko et al. 2006). Shield stage lavas from the four westernmost Canary Islands (Teno Massif on Tenerife, La Gomera, La Palma and El Hierro) require the presence of a HIMU (or LVC) -type component with relatively radiogenic Pb (e.g. $^{206}Pb/^{204}Pb$ >20.0). The trend extends towards a depleted (NMORB)-like endmember with non-radiogenic Sr and Pb but radiogenic Nd isotope ratios (Hoernle and Tilton 1991; Hoernle et al. 1991, 1995; Gurenko et al. 2006). The lavas from the Gran Canaria shield, both subaerially erupted and drilled, as well as those from the other eastern islands of Fuerteventura and Lanzarote (Hoernle and Tilton 1991; Hoernle et al. 1991, 1995, 2002; Thirlwall et al. 1997; Widom et al. 1999; Gurenko et al. 2006) require a third, enriched (EM)-type component with high $^{87}Sr/^{86}Sr$ and $\Delta 8/4Pb$, some of them lying above the Northern Hemisphere Reference Line (*NHRL*; Hart et al. 1984) (**Fig. 2**).

The nature of EM component has been extensively debated, especially after it was demonstrated that HIMU- and EM-type volcanism are often geographically associated, indicating a genetic link (Hart et al. 1986; Chauvel et al. 1992). Several different models for the origin of the EM component have been proposed during the last decades: (a) derivation from near-primitive lower-mantle, (b) metasomatism by devolatilization of mantle peridotite, (c) metasomatism by carbonatitic melts, (d) recycling of oceanic crust containing aged pelagic or terrigenous sediments, (e) involvement of subcontinental lithospheric mantle, (f) addition of lower continental crust to the mantle, (g) recycling of a subduction-modified mantle wedge, (h) any combination of the above (see Geldmacher et al. 2008 and references therein). The origin of the EM-type component that primarily occurs in the lavas from the eastern Canary Islands, from the seamounts belonging to the older parts of the Madeira and Canary hotspot tracks, and from the southeast Cape Verde Islands was ascribed to interaction of plume-derived magmas with (a) the crust beneath Gran Canaria (Thirlwall et al. 1997) and/or (b) enriched, recycled African subcontinental lithospheric material present in the upper mantle beneath the African continental margin (Hoernle and Tilton 1991; Hoernle et al. 1991, 1995, 2002; Widom et al. 1999; Geldmacher and Hoernle 2000; Geldmacher et al. 2005; Lundstrom et al. 2003). In particular, Hoernle et al. (2002) and Geldmacher et al. (2005) proposed that a lithospheric mantle with an EM-type signature could be eroded from the African subcontinental root and incorporated into the upper asthenospheric mantle by edge-driven convection. It can potentially reside within the lithosphere or deeper in the upper mantle, where it can be entrained by rising plumes. Recently, Geldmacher et al. (2008) have confirmed a shallow origin for at least some of the EM-type component in the northern Atlantic and provided evidence for the origin of the EM-type mantle through recycling of subcontinental lithosphere globally, so that the origin of the EM-type components in the lavas representing intraplate volcanism in the eastern Atlantic could be ascribed to the plume-upper mantle (lithosphere and/or asthenosphere) interaction.

Composition of peridotite and pyroxenite components and implications for the origin of Gran Canaria shield stage magmas

As shown by Gurenko et al. (2009), the shield stage lavas from Teno Massif on Tenerife, La Gomera, La Palma and El Hierro form good correlations between their bulk rock isotopic ratios and X_{px} values, i.e. weight fraction of pyroxenite component in the magma source (dashed line in **Fig. 5**), inferred from the olivine chemistry. The inferred isotopic composition of the peridotite endmember is very close to the low velocity component (LVC), which was proposed by Hoernle et al. (1995) as a potential source composition for intraplate volcanism in the eastern North Atlantic, the western Mediterranean and Europe (**Fig. 2**). The Gurenko et al. (2009) data indicated that the HIMU-type component in the source of the western Canary Islands does not appear to be physically represented by eclogite (derived from recycled oceanic crust, Si-rich eclogite partial melt or reaction pyroxenite) but instead by peridotite. A similar conclusion was reached concerning HIMU-type intraplate volcanic rocks from New Zealand (Timm et al., 2009). The isotopic signature of such peridotite might have been inherited either directly from the old (≥1 Ga) recycled crust, implying that the old ocean crust was stirred into/reacted with the ambient mantle so that there is no significant eclogite left, or derived from the subcontinental lithosphere, metasomatized by melts or fluids generating high μ ($^{238}U/^{204}Pb$) sources in accordance with Halliday et al. (1995). The HIMU-like component is quite common and widely recognized in many ocean island basalts (OIB) and associated seamounts and mid-ocean ridge basalts (MORB) throughout the Atlantic, being generally interpreted as a signature of a deep mantle plume (e.g. Ito et al. 1987; Dosso et al. 1991; Kamenetsky et al. 1998; Kurz et al. 1998), which fits well with our conclusion. The second (pyroxenite) component of the western Canary Island lavas was interpreted to be young (<1 Ga) recycled oceanic crust preserved as eclogite with depleted MORB-type isotopic signature (Gurenko et al. 2009). Similar to Gurenko et al. (2009), we interpret the observed relationships between Ni and Mn concentrations in olivine phenocrysts and bulk rock radiogenic isotope compositions of the studied lavas (**Fig. 4**) as mixing trends defined by the compositions of melts derived from partial melting of peridotite and pyroxenite components in the magma source. We used the parameterization modified after Sobolev et al. (2008) to infer the fraction of pyroxenite-derived melt in the composition of each individual lava (given in **Table 1**). The following equation was applied:

$$X_{px} = 6.705\text{E}{-}04 \times Ni \times FeO/MgO - 1.332\text{E}{-}02 \times Mn/FeO + 1.524 \qquad (1)$$

where X_{px} = weight fraction of pyroxenite-derived melt so that melts originating from pure peridotitic mantle have X_{px} = 0 and those from reaction pyroxenite have X_{px} = 1. Ni and Mn are element concentrations given in ppm; FeO and MgO are given in wt.%.

The inferred proportions of pyroxenite-derived melt were then related to bulk rock ^{86}Sr/^{87}Sr, ^{143}Nd/^{144}Nd, ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb and ^{208}Pb/^{204}Pb isotopic ratios for each individual lava (**Table 2, Fig. 5**). In contrast to the western Canary Islands, the Gran Canaria lavas with the most radiogenic Sr and Nd and least radiogenic Pb isotopic composition appear to have formed through a mixture of ~70% peridotite and ~30% reaction pyroxenite (derived from eclogite), agreeing well with the proportion of recycled oceanic crust or eclogite (25-35%) estimated from the Os and Pb isotopic data (Widom et al. 1999). Both peridotite and pyroxenite counterparts differ in Sr, Nd, Pb isotope compositions from those proposed for the western Canary Islands by Gurenko et al. (2009). Calculating the regression lines through the data on the plots of X_{px} versus Sr, Nd and Pb isotope ratios yields the following compositions for the endmember components (**Table 3**):

1. Peridotite with ^{87}Sr/^{86}Sr = 0.70337 ± 0.00003, ^{143}Nd/^{144}Nd = 0.51291 ± 0.00001, ^{206}Pb/^{204}Pb = 19.36 ± 0.07, ^{207}Pb/^{204}Pb = 15.61 ± 0.01, ^{208}Pb/^{204}Pb = 39.07 ± 0.07;
2. Pyroxenite with ^{87}Sr/^{86}Sr = 0.70309 ± 0.00003, ^{143}Nd/^{144}Nd = 0.51289 ± 0.00001, ^{206}Pb/^{204}Pb = 20.03 ± 0.07, ^{207}Pb/^{204}Pb = 15.62 ± 0.01, ^{208}Pb/^{204}Pb = 39.84 ± 0.07.

In contrast to the western Canary Islands, the pyroxenite endmember on Gran Canaria exhibit HIMU-like composition (e.g. radiogenic Pb isotope ratios: ^{206}Pb/^{204}Pb = 20.0 and ^{208}Pb/^{204}Pb = 39.8) instead of the peridotite endmember. The pyroxenite endmember has very similar Sr, Nd and Pb isotopic compositions to the low-silica Gran Canaria late shield stage rocks (as illustrated by the composition of the most mafic Fataga sample, an evolved nephelinite; **Fig. 2**) and the most HIMU-like low-silica shield stage lavas from the western Canary Islands (Hierro, La Palma and Teno massif on Tenerife), suggesting a genetic link between these different rock groups. We think that these results indicate that the Canary Island plume is heterogeneous both lithologically/mineralogically (containing peridotite and pyroxenite) and compositionally (in major and trace elements and isotopic composition). Source lithology/mineralogy primarily controls the major and trace element contents of the melts (low-silica melts being derived from a primarily peridotite source and high-silica rocks primarily from a pyroxenitic source), whereas the isotopic composition is likely to reflect the age of the recycled component (Gurenko et al. 2009). Older recycled ocean crust (eclogite) is likely to have more radiogenic Pb isotopic compositions. Because it is older, it is also likely generally to be stirred into the surrounding mantle peridotite. Later mixing of the peridotite, for example on the margin of the upwelling plume, with younger recycled ocean crust (still in the form of eclogite) in the upper mantle, can generate the observed range in isotopic composition of the low-silica rocks from the western Canary Islands and within the post-erosional or rejuvenated stages on the older eastern islands such as Gran Canaria that have isotopic compositions similar to those of El Hierro (e.g. Hoernle et al. 1991).

The Gran Canaria pyroxenite endmember also falls within the edge of the field for the ubiquitous LVC component found in volcanic rocks from the eastern North Atlantic, western Mediterranean and Europe, interpreted to reflect the composition of the sublithospheric (presumably plume) mantle upwelling beneath these areas (Hoernle et al. 1995; Duggen et al. 2009). It is quite surprising that the low-silica rocks from the western Canary Islands (and by analogy possibly also from Gran Canaria), which are formed by mixing of peridotite with old (>1 Ga) recycled ocean crust (eclogite) stirred into it and younger recycled oceanic crust (also originally eclogite) in the form of reaction pyroxenite, has a similar composition to the reaction pyroxenite in the source of the high-silica rocks on Gran Canaria. Our results, however, indicate that the LVC component does not represent a single physical component, but rather a common composition that is generated through (a) mixing of HIMU-type peridotite containing stirred in ancient (1-2 Ga and possibly older) oceanic crust (or melts from such material) with melts from reaction pyroxenite derived from younger recycled ocean crust (as proposed by Gurenko et al. 2009) or (b) melts from reaction pyroxenite formed from recycled oceanic crust of intermediate age (probably in the range of 1-1.5 Ga; Widom et al. 1999). Therefore the similarity between the pyroxenitic endmember in the Gran Canaria high-silica rocks and the most radiogenic low-silica melts from the western Canary Islands is most likely fortuitous, suggesting that the Canary plume is lithologically and compositionally heterogeneous.

The EM-type endmember for the Gran Canaria high-silica rocks appears to be derived from a peridotitic source and could potentially reflect African subcontinental lithospheric mantle recycled into the upper asthenospheric mantle along the African continental margin, as has been proposed by Hoernle and Tilton (1991), Hoernle et al. (1991, 1995, 2002), Widom et al. (1997, 1999), Geldmacher and Hoernle (2000), Geldmacher et al. (2005) and Lundstrom et al. (2003). The enriched component could be entrained into the plume as it ascends through the upper mantle, incorporated into the upper mantle through thermal erosion of the base of the African lithosphere through edge-driven convection (Hoernle et al. 2002; Geldmacher et al. 2005; Lustrino 2005) or through physical detachment of the subcontinental lithospheric mantle during continental breakup (Hoernle and Tilton, 1991; Hoernle et al. 1991; Hanan et al. 2004). In summary, at least four distinct endmembers (two peridotitic: HUMU-1- and EM-type and two pyroxneitic: HIMU-2- and MORB-type; **Fig. 5 and 6**) are required to explain shield stage volcanism in the Canary Islands. Distinct peridotitic and pyroxenitic endmembers are required to generate both the low-silica and the high-silica mafic rocks.

A question that remains to be answered is why there is minimal interaction between the endmembers for the different primitive rock groups. The easiest way to minimize interaction between the low-silica and high-silica source endmembers is if the sources (source components) are physically separated. Sobolev et al. (2005) proposed that there is more pyroxenite in the plume center and less in the periphery. Therefore the high-silica lavas may preferentially sample pyroxenite in the plume center as compared to low-silica lavas derived from the edges of the plume, consistent with the models of Cousens et al. (1990), Hoernle and Schmincke (1993a,b) and Hoernle (1998) for the evolution of the Gran Canaria shield stage.

The pyroxenitic component, having an isotopic composition that most closely represents that of the composition of the regionally-distributed LVC component of Hoernle et al. (1995) may therefore represent the dominant plume component. If the pyroxenite is located in the plume center and the EM component is a shallowly recycled rather than a plume component from depth, then the EM material is most likely to be located in the lithosphere beneath Gran Canaria, as has been argued by Hoernle et al. (1991) based on the presence of the EM component in melts that have undergone high pressure fractionation within the lithospheric mantle. The high-silica melts will be the hottest if generated from the plume (or blob) center and are the most voluminous forming Gran Canaria (Hoernle and Schmincke, 1993a,b). Therefore they are likely to cause the most melting and assimilation of the surrounding lithosphere during their ascent. In addition, the high-silica melts have lower abundances of incompatible elements than the low-silica melts and will be more sensitive indicators of lithospheric interaction (Hoernle et al. 1991). The low-silica melts generated from the peridotite from the margins of the plume both in the early and late stages of ocean island volcano growth are more likely to interact with material entrained at the margins of the plume, such as reaction pyroxenite melts formed from young recycled oceanic crust in the upper mantle. This material is unlikely to reach the center of the plume where the high-silica melts are generated. Due to their lower temperatures and thus lower degrees of melting, the low-silica lavas have significantly higher incompatible element abundances and thus require significantly more assimilation to affect their isotopic compositions. Due to their lower temperatures of generation in the plume margins, the low- silica melts are not as likely to interact as extensively with the lithospheric mantle. In conclusion, a zoned plume with a pyroxenitic-rich core with a composition similar to the LVC component, and more peridotitic margins having a distinct isotopic composition (more HIMU-like composition), with the melts from the core interacting more extensively with the lithosphere (or asthenosphere directly above the center of the plume) and the melts from the margins with recycled oceanic crust in entrained upper mantle, could explain why the high- and low-silica rocks in the Canary Islands appear to involve distinct source components.

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Figure captions

Fig. 1. Schematic map outlining the position of Gran Canaria, Tenerife and Fuerteventura (Fu.) with an inset map of the Canary Islands, showing the locations of the ODP Leg 157 Sites 953 to 956 (filled circles) and of the sample locations from subaerial shield stage lavas of Gran Canaria (open circles), simplified lithology of Site 953 and the position of the selected samples in the drill core based on the Site description taken from Shipboard Scientific Party (1995). The numbers in parenthesis after/below the island names in the inset map refer to the oldest ages in million years obtained for the shield stage volcanism from these islands (after Geldmacher et al. 2005).

Fig. 2. Whole rock isotopic compositions of the studied Gran Canaria and ODP Leg 157 shield stage lavas on $^{206}Pb/^{204}Pb$ versus (A) $^{87}Sr/^{86}Sr$, (B) $^{143}Nd/^{144}Nd$, and (C) $^{207}Pb/^{204}Pb$ diagrams. The *shaded field* represents the compositions of lavas from the western Canary Islands (Tenerife, La Gomera, La Palma and El Hierro) taken from Gurenko et al. (2009). *Fataga nephelinite* represents the isotopic composition the most primitive Fataga nephelinite (11.8 Ma) from Hoernle et al. (1991), illustrating the similarity of the low-silica group lavas erupted on the eastern Canary Islands, the low-silica lavas from the western Canary Islands and the *LVC* component, while the high-silica group lavas (i.e., studied samples) require the involvement of an enriched, EM-type component, with intermediate $^{206}Pb/^{204}Pb$ but elevated $^{87}Sr/^{86}Sr$. In this figure and Fig. 5, *HIMU-1* and *EM Peridotite* and *MORB* and *HIMU-2 Pyroxenite* endmember compositions for low-silica rocks from the shield stage volcanism from the western four Canary Islands (from Gurenko et al. 2009) and for high-silica shield stage rocks from Gran Canaria (this study) are shown. The arrows point to the compositions of *DMM*, *HIMU*, *EM1* and *EM2* mantle components taken from Zindler and Hart (1986); N-MORB is taken from the literature; *LVC* is an ubiquitous sublithospheric, low-velocity component beneath the eastern Atlantic, Europe and the western Mediterranean hosting the enriched (HIMU)-like isotopic signature (Hoernle et al. 1995).

Fig. 3. Compositions of olivine phenocrysts from the Miocene shield stage lavas subaerially erupted on Gran Canaria and drilled during the ODP Leg 157. Olivines are shown on plots of Fo content (mol. %) vs. element concentrations (given in ppm) of (A) Ca, (B) Ni, and normalized concentrations of (C) Ni given as Ni×FeO/MgO and (D) Mn (Mn/FeO), demonstrating the wide Ni and Mn ranges despite elimination of the effects of magma fractionation on Ol composition. *SCO* = San Carlos olivine USNM 111312/444 (Jarosewich et al. 1980) was multiply analyzed as an unknown (N = 49) together with the samples of interest (after every 30-50 analyses) to provide the analytical error in olivine composition. Note that the variations of unknown olivines significantly exceed ±2σ SD analytical errors (±0.1 mol% Fo, ±70-80 ppm for Ca and Ni, and ±40 ppm for Mn based on replicate measurements of SCO; black filled circles in all panels). Reference fields of olivine compositions labeled as Tenerife, La Gomera, La Palma and El Hierro are from Gurenko et al. (2009).

Fig. 4. Relationships between $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ isotopic ratios of the Gran Canaria shield stage lavas (measurements on whole rocks) and average Ni×FeO/MgO (A, D, G), Mn/FeO (B, E, H) ratios and Ca concentrations (C, F, I) of olivine phenocrysts, calculated for the olivine from each sample with the highest three Fo-numbers. Small filled circles in the shaded fields are related whole-rock isotopic and olivine elemental compositions obtained for the western Canary Island lavas using the same approach (Gurenko et al. 2009). The Gran Canaria olivine-whole rock compositions deviate from the trends defined for the western Canary Islands, suggesting that both peridotite and pyroxenite components involved in partial melting might have a wider compositional range or distinct compositions compared to those from the western Canary Islands.

Fig. 5. Sr-Nd-Pb isotopic compositions of peridotite and pyroxenite endmembers melted to form the Gran Canaria shield stage lavas, inferred from the relationships with X_{px}, weight fraction of pyroxenite-derived melt determined from the olivine chemistry, and (A) $^{87}Sr/^{86}Sr$, (B) $^{143}Nd/^{144}Nd$ and (C) $^{206}Pb/^{204}Pb$, (D) $^{207}Pb/^{204}Pb$, (E) $^{208}Pb/^{204}Pb$ isotopic ratios of the whole-rock host lavas. *Shaded field* including small filled circles and *dashed line* connecting

peridotite and pyroxenite endmembers represents a two-component source model suggested by Gurenko et al. (2009) for the western Canary Islands. *Solid lines* fitting the peridotite and pyroxenite endmembers represent the solutions for the presently studied Gran Canaria subaerial and ODP drilled lavas. The inferred “eastern Canaries” peridotite component has less radiogenic Pb but more radiogenic Sr and Nd isotope ratios, while the reaction pyroxenite also has relatively high Sr and low Nd isotopic ratios but substantially more radiogenic $^{206}Pb/^{204}Pb$ ratios of ~20, corresponding to the compositional field of the HIMU-type low-velocity component defined by Hoernle et al. (1995). [provide updated figure; 18-aug-09]

Fig. 6. Cartoon illustrating a model where the enriched (EM)-like component (with $^{87}Sr/^{86}Sr$ = 0.70337, $^{143}Nd/^{144}Nd$ = 0.51291, $^{206}Pb/^{204}Pb$ = 19.36) of the Canary hotspot could be entrained into the plume as it ascends through the upper mantle. A viable mechanism could either be thermal erosion of the base of the African lithosphere or physical detachment of the subcontinental lithospheric mantle caused by edge-driven convection during breakup of the Pangea supercontinent (Hoernle and Tilton 1991; Hoernle et al. 1991, 2002; Hanan et al. 2004; Geldmacher et al. 2005; Lustrino 2005). The EM component(s) required to explain the composition of the eastern Canary Island lavas could be located in the shallow asthenosphere or lithosphere. In accordance with Gurenko et al. (2009), we propose that the upwelling plume consists of HIMU-1-type peridotite (with $^{87}Sr/^{86}Sr$ = 0.70324, $^{143}Nd/^{144}Nd$ = 0.51283, $^{206}Pb/^{204}Pb$ = 20.45) and a HIMU-2-pyroxenitic-rich core (with $^{87}Sr/^{86}Sr$ = 0.70309, $^{143}Nd/^{144}Nd$ = 0.51289, $^{206}Pb/^{204}Pb$ = 20.03). MORB-type pyroxenite (with $^{87}Sr/^{86}Sr$ = 0.70286, $^{143}Nd/^{144}Nd$ = 0.51300, $^{206}Pb/^{204}Pb$ = 19.05) is entrained at the leading (western) edge of the plume. The HIMU-1 peridotite and entrained MORB-pyroxenite represent two main components contributing to the origin of magmas erupted on the western Canary Islands. Canary Islands: EH = El Hierro, LP = La Palma, LG = La Gomera, TF = Tenerife, GC = Gran Canaria, FU = Fuerteventura, LZ = Lanzarote. [provide updated figure; 18-aug-09]

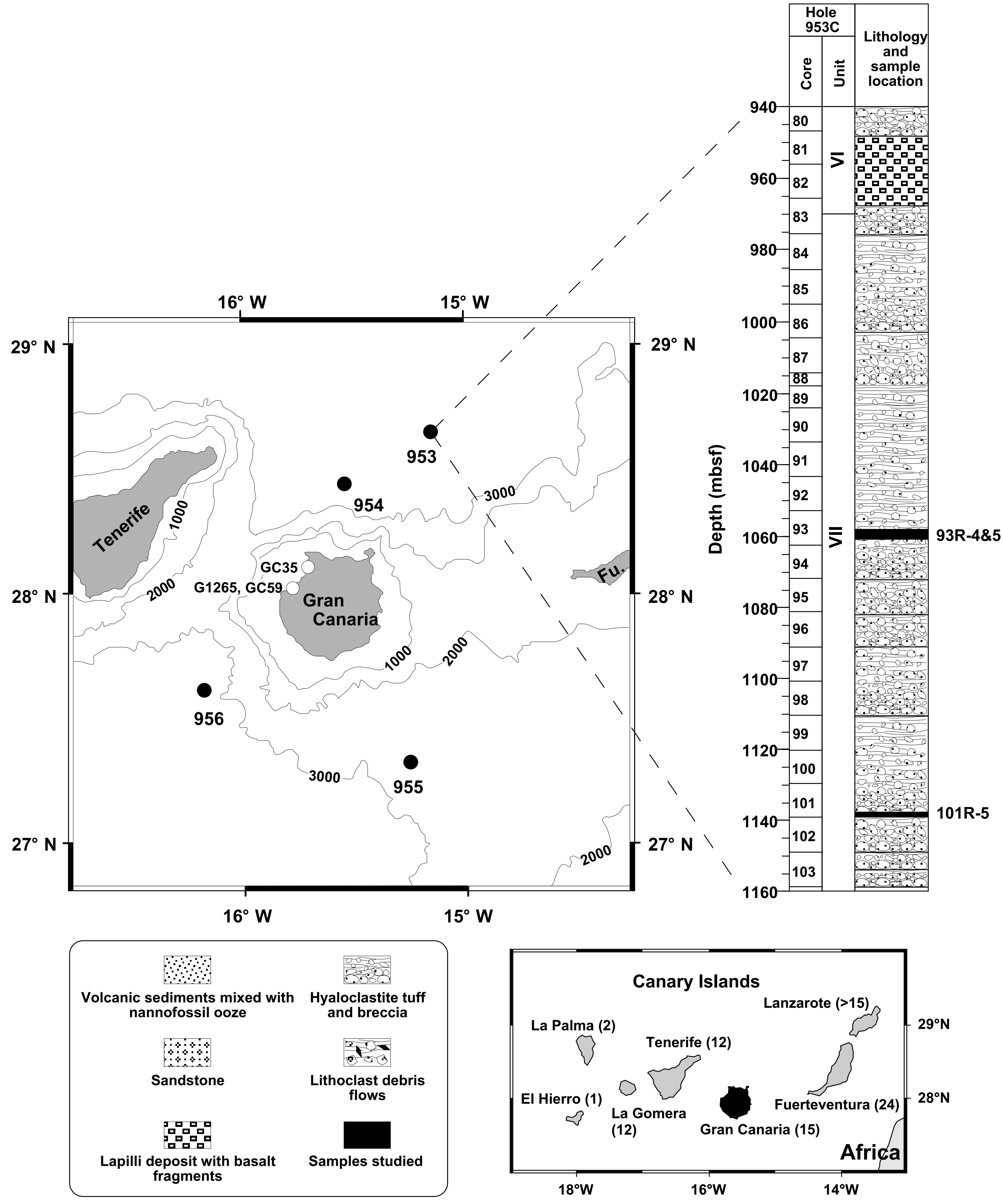

Fig. 1. Gurenko et al.

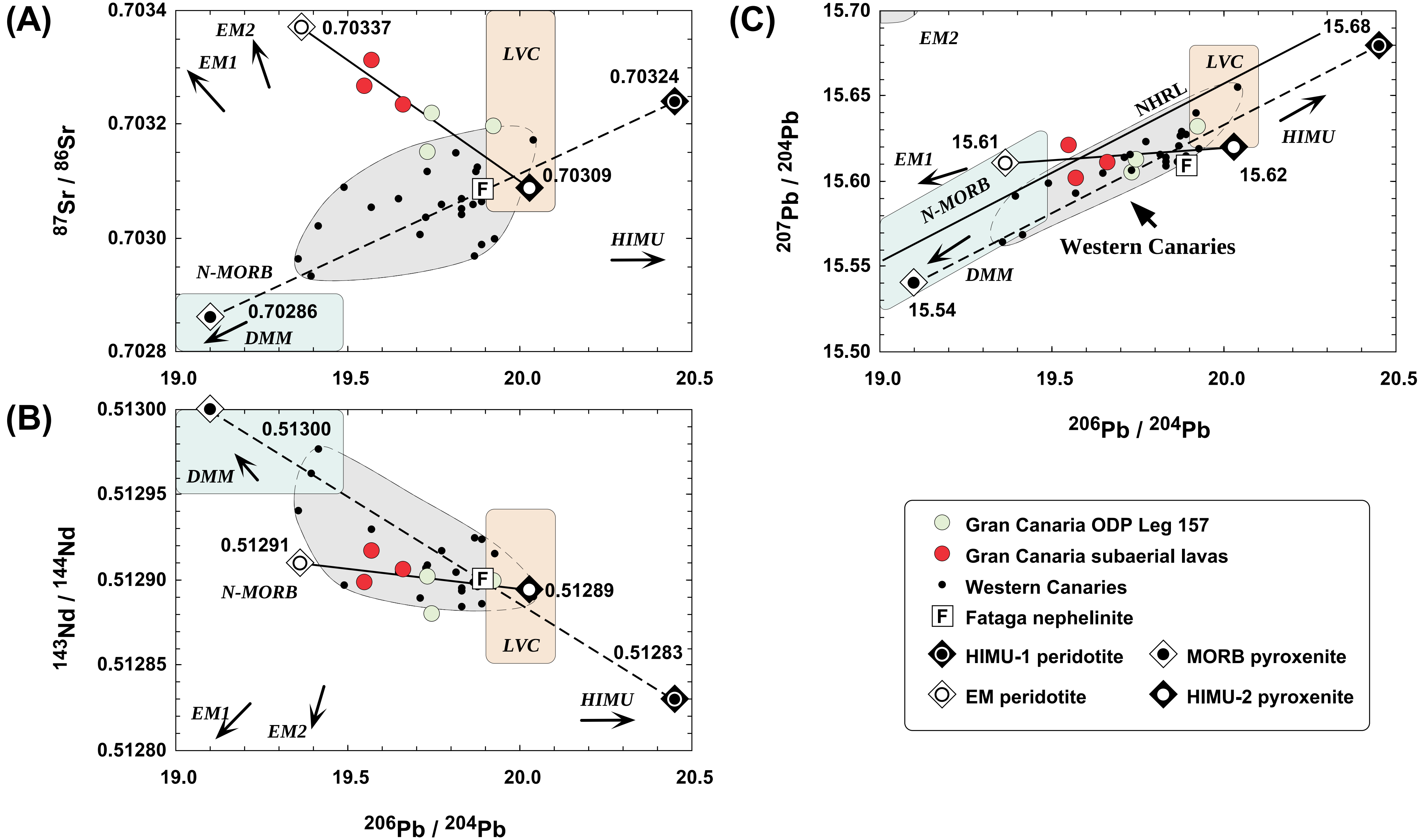

Fig. 2. Gurenko et al.

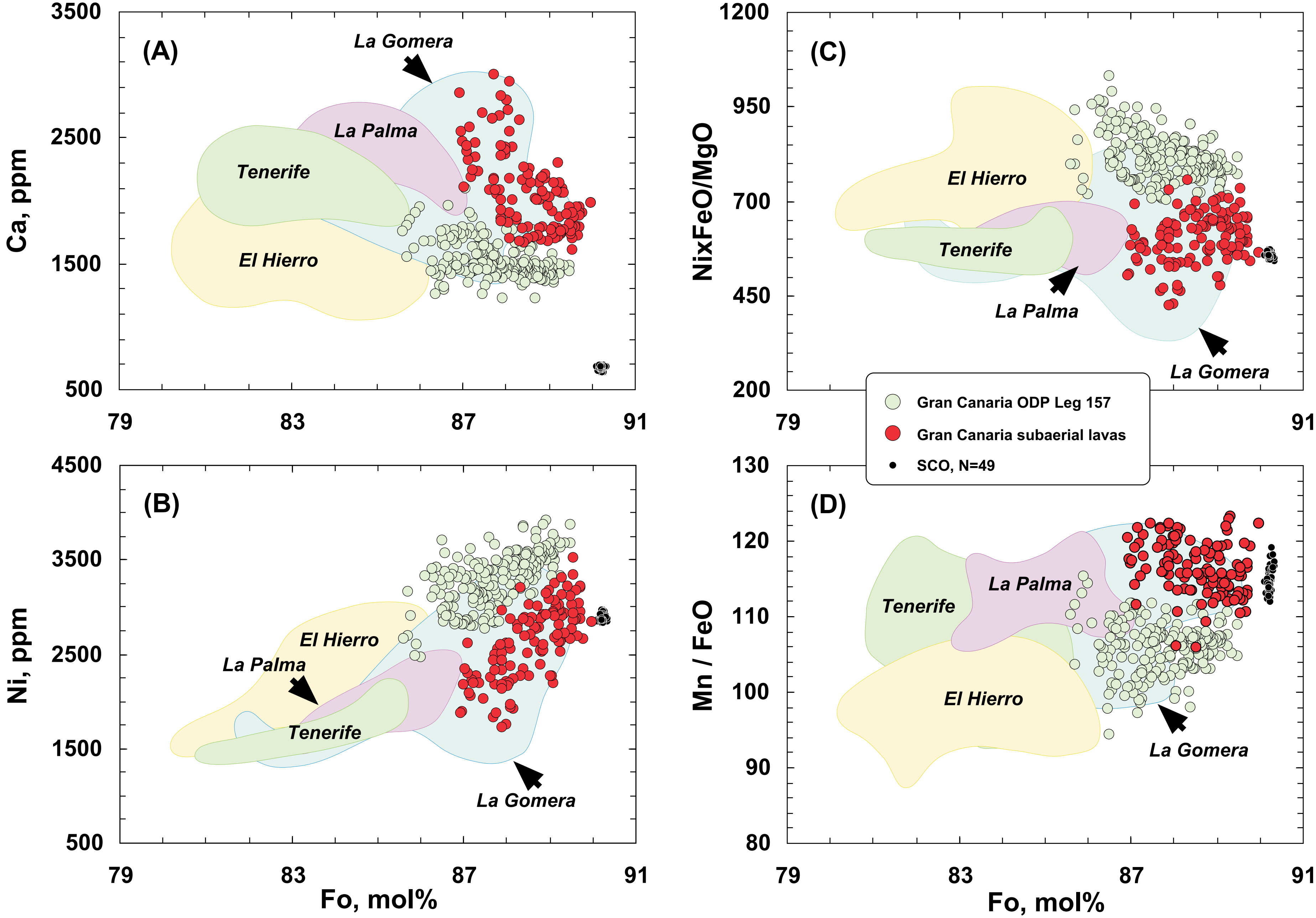

Fig. 3: Gurenko et al.

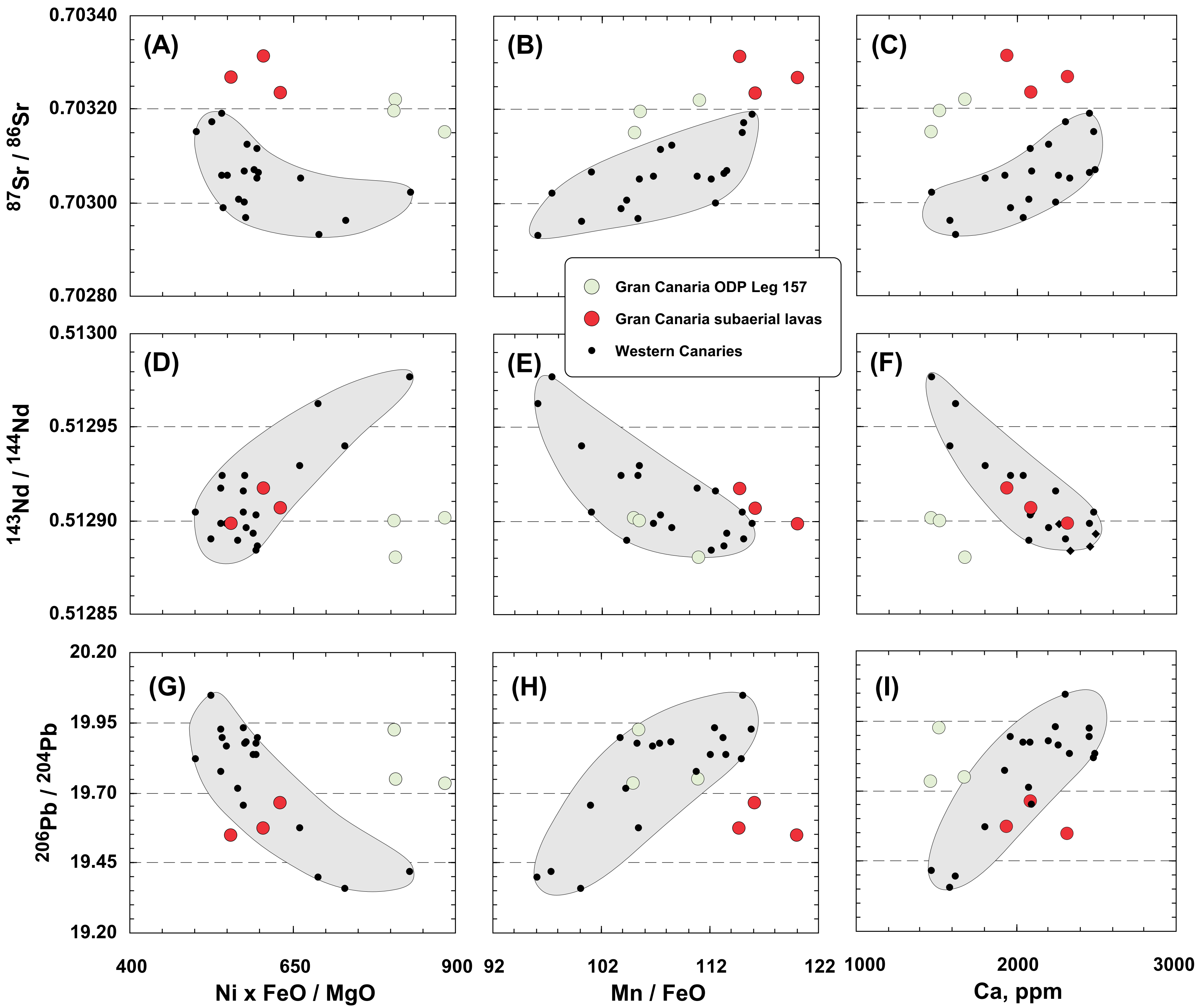

Fig. 4. Gurenko et al.

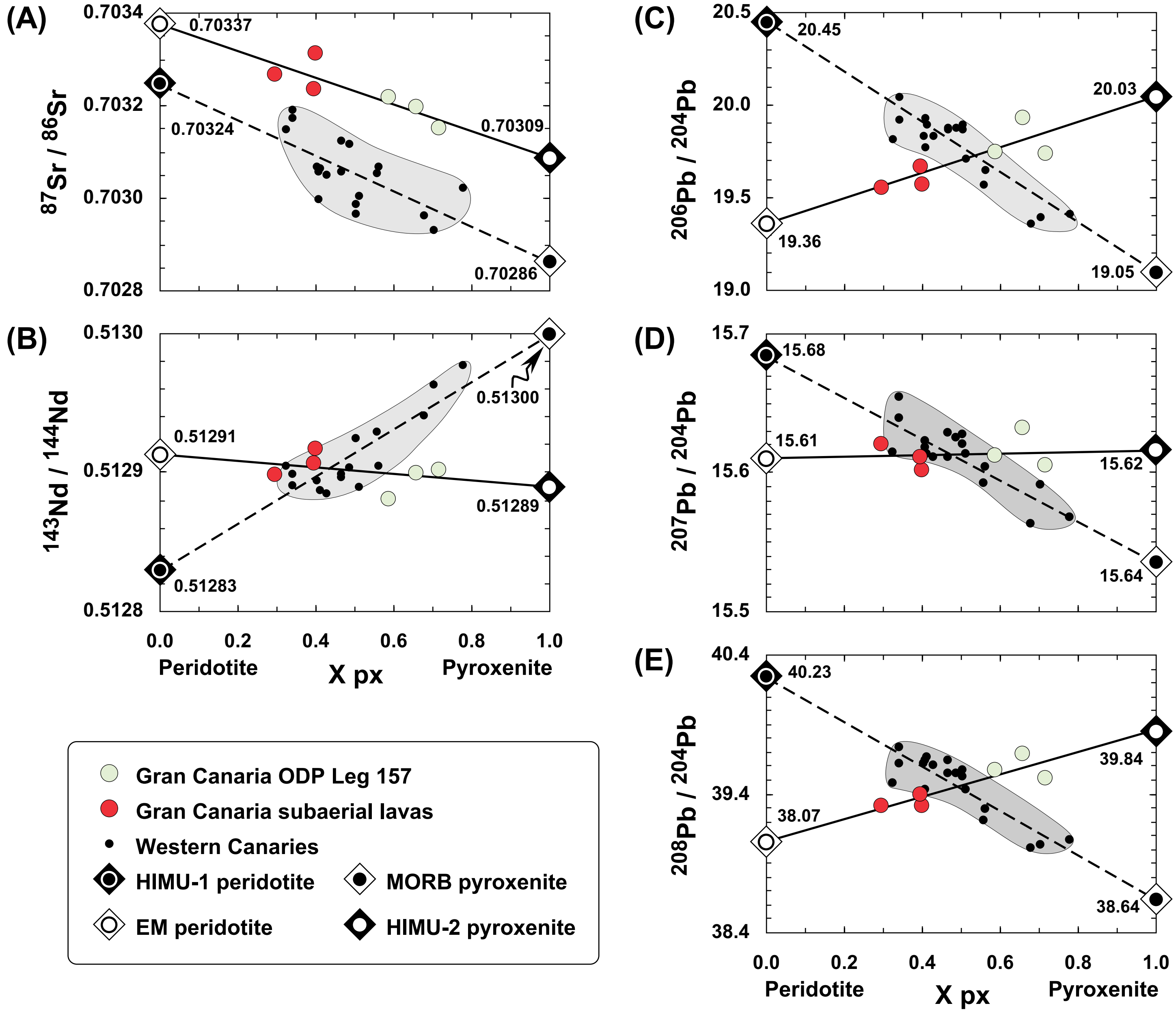

Fig. 5: Gurenko et al.

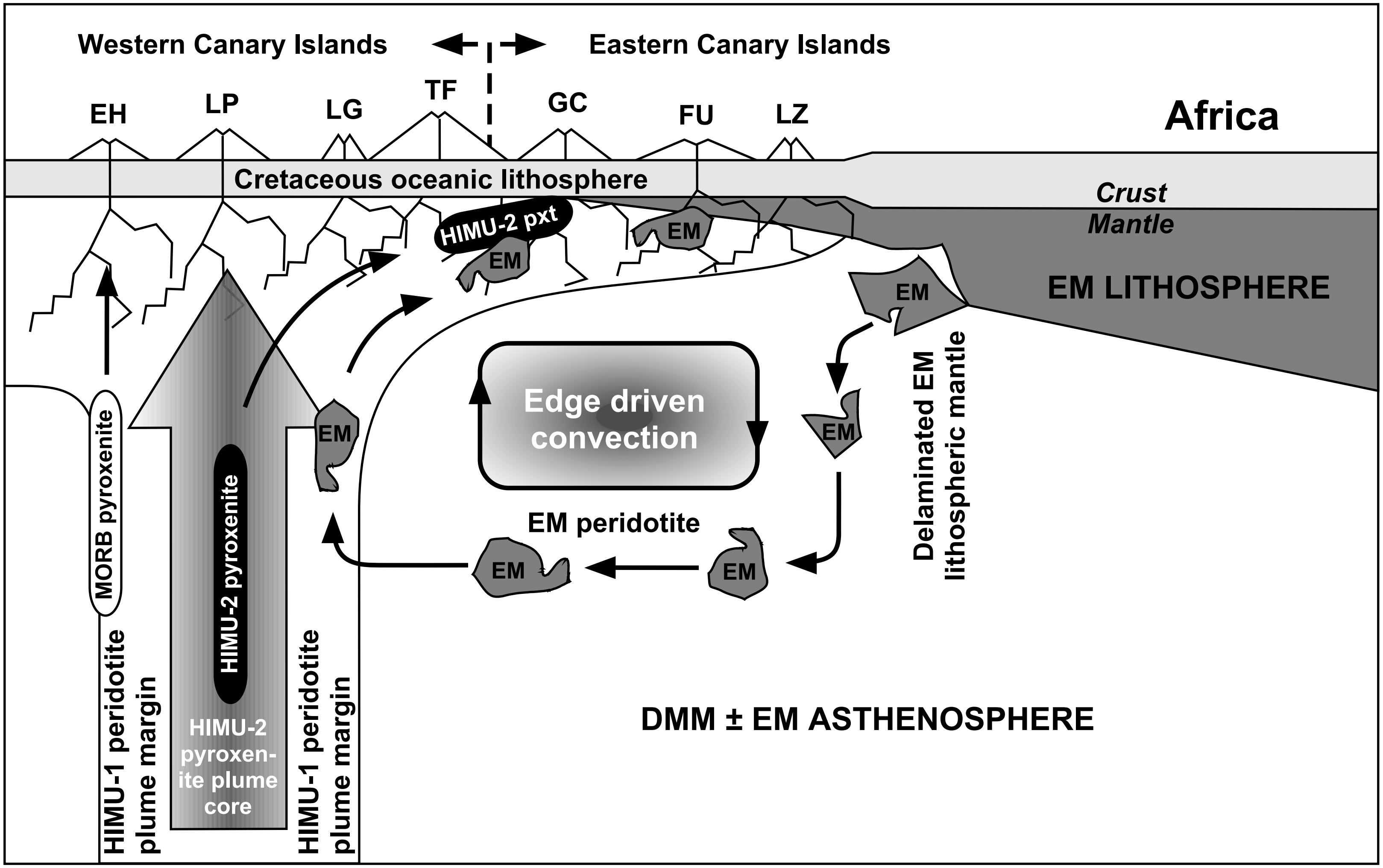

Fig. 6: Gurenko et al.

Table 1 Summary of olivine phenocryst and bulk rock Sr, Nd and Pb isotopic composition of Canary lavas

Sample	N	Fo mol%	2σ	Ni ppm	2σ	Ni*	2σ	Mn ppm	2σ	Mn*	2σ	Ca ppm	2σ
Gran Canaria Volcaniclastic Apron, ODP Leg 157, Hole 953													
93R-4	13	86.7	1.9	2978	851	809	171	1414	225	110.9	4.4	1678	331
93R-5	166	87.9	1.6	3301	551	806	107	1229	162	105.5	6.4	1522	265
101R-5	22	87.0	1.7	3331	371	885	107	1314	173	105.0	4.4	1465	363
Gran Canaria													
G1265	29	88.2	1.7	2342	651	556	116	1370	169	120.0	3.7	2318	489
GC35	25	88.6	1.5	2766	741	631	123	1284	186	116.1	5.0	2093	480
GC59	68	88.7	1.5	2697	742	607	126	1252	191	114.8	6.5	1945	637
Reference San Carlos olivine													
SCO	49	90.2	0.1	2883	90	556	17	1096	21	114.8	3.0	651	127

Table 1 (continued)

Sample	X_{px}	2σ	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Gran Canaria Volcaniclastic Apron, ODP Leg 157, Hole 953							
93R-4**	0.59	0.17	0.703219(3)	0.512880(3)	19.748(1)	15.613(1)	39.573(4)
93R-5*	0.66	0.16	0.703195(3)	0.512900(3)	19.926(4)	15.632(4)	39.685(9)
101R-5**	0.72	0.13	0.703150(3)	0.512901(3)	19.733(1)	15.605(1)	39.510(5)
Lavas subaerially erupted on Gran Canaria							
G1265***	0.30	0.13	0.703267(17)	0.512898(14)	19.549	15.621	39.307
GC35	0.40	0.15	0.703234(7)	0.512906(7)	19.663(2)	15.611(2)	39.399(4)
GC59	0.40	0.17	0.703312(7)	0.512917(6)	19.571(1)	15.602(0)	39.309(1)
Reference San Carlos olivine							
SCO	–		ND	ND	ND	ND	ND

Olivine analyses are average compositions calculated for each individual sample taking the fist three, highest Fo numbers, the analyses are given at $\pm 2\sigma$ – 2 sigma standard deviation that represents the entire compositional range; individual analyses are listed in Table S1; On-line Supplementary information; N = number of olivine crystals analyzed, Fo = forsterite, Ni* = Ni×FeO/MgO, Mn* = Mn/FeO; SCO = international San-Carlos olivine standard USNM 111312/444 (Jarosewich et al. 1980), continuously analyzed as an unknown sample after each 30-50 olivine crystals studied here; X_{px} = fraction of anticipated pyroxenite melt contributed to the chemical composition of the individual lava and calculated from Ni* and Mn* values (see text). The Sr-Nd-Pb isotopic ratios are original data in the case of the Gran Canaria Volcaniclastic Apron samples and taken from Gurenko et al. (2006) for the lavas subaerially erupted on Gran Canaria. The ODP Leg 157 drilled samples are strongly altered basaltic fragments; the isotopic data for sample 93R-5 (ODP sample label 157-953C-93R-5, 13-27 cm) labeled with (*) were obtained for clinopyroxene separates, and for samples 93R-4 (ODP sample label 157-953C-93R-4, 18-24 cm) and 101R-5 (ODP sample label 157-953C-101R-5, 116-123 cm) labeled with (**) were obtained for fresh groundmass. Sr-Nd-Pb isotopic data for sample G1265 labeled with (***) are taken from Hoernle et al. (1991).

Table 2 Linear regression constants [a]

Isotopic Ratio	Eq. 1 (WCI) A	B	R^2	Eq. 2 (GC-ODP) A	B	R^2
$^{87}Sr/^{86}Sr$	–3.89e–4	0.703244	0.455	–2.83e–4	0.703373	0.715
$^{143}Nd/^{144}Nd$	1.7e–4	0.512829	0.681	–2.4e–5	0.512913	0.115
$^{206}Pb/^{204}Pb$	–0.983	20.448	0.909	0.669	19.378	0.664
$^{207}Pb/^{204}Pb$	–0.103	15.684	0.898	0.005	15.611	0.006
$^{208}Pb/^{204}Pb$	–0.979	40.231	0.948	0.769	39.073	0.720

[a] Linear regression constants (*A* and *B*) used for calculation of Sr-Nd-Pb isotopic compositions of peridotite and pyroxenite components in the Canary plume. The linear regressions ($y = A \times X_{px} + B$) relate the fraction of pyroxenite component (X_{px}) calculated using the parameterization of Sobolev et al. (2008; see text) and the corresponding isotopic ratios; R^2 = squared coefficient of linear correlation. Three linear regressions were calculated: Eq. 1 – the line fitting the fraction of pyroxenite component (X_{px}) and whole rock Sr-Nd-Pb isotopic compositions of the lavas from the western Canary Islands (WCI including Teno Massif on Tenerife, La Gomera, La Palma and El Hierro; Gurenko et al., 2009); Eq. 2 – the line accounting for the compositions of the Gran Canaria subaerially erupted and drilled during the ODP Leg 157 shield stage lavas. The $^{143}Nd/^{144}Nd$ and $^{207}Pb/^{204}Pb$ ratios show no correlation with X_{px} values suggesting that peridotite and pyroxenite components have rather similar Nd and ^{207}Pb isotopic compositions.

Table 3 Estimated Sr-Nd-Pb isotopic compositions of peridotite and pyroxenite components of the Canary plume [a]

Component	Peridotite (WCI) [b]		Peridotite (GC-ODP) [c]		Pyroxenite (WCI) [b]		Pyroxenite (GC-ODP) [c]		LVC [d]
	Iso Ratio	Uncert	Iso Ratio	Uncert	Iso Ratio	Uncert	Iso Ratio	Uncert	
$^{87}Sr/^{86}Sr$	0.70324	0.00005	0.70337	0.00003	0.70286	0.00005	0.70309	0.00003	0.7030–0.7034
$^{143}Nd/^{144}Nd$	0.51283	0.00001	0.51291	0.00001	0.51300	0.00002	0.51289	0.00001	0.5128–0.5129
$^{206}Pb/^{204}Pb$	20.45	0.09	19.36	0.07	19.05	0.09	20.03	0.07	19.9–20.1
$^{207}Pb/^{204}Pb$	15.68	0.01	15.61	0.01	15.54	0.01	15.62	0.01	15.62–15.68
$^{208}Pb/^{204}Pb$	40.23	0.10	38.07	0.07	38.64	0.10	39.84	0.07	39.6–39.9

[a] Sr-Nd-Pb isotopic compositions of peridotite and pyroxenite components of the Canary plume were obtained using parameterization modified after Sobolev et al. (2008) to convert the olivine Ni×FeO/MgO and Mn/FeO ratios to weight fraction of pyroxenite derived melt (X_{px}) and given in Table 2 linear regression equations (see text). Uncert = uncertainty in the inferred isotopic ratios of peridotite and pyroxenite components includes two sources of independent random errors: (1) average 2-sigma analytical errors of the analyzed isotopic ratios and (2) uncertainty due to deviations of measured isotopic ratios from the ratios calculated using the regression equations and calculated as:

$$\sigma_y^2 = \frac{1}{N-2}\sum_{i=1}^{N}(y_i - Ax_i - B)^2 ,$$

where A and B are constants in linear relation, N = number of measured points (Taylor 1982).

[b] Compositions of peridotite and pyroxenite components defined for the western Canary Islands (WCI) by Gurenko et al. (2009).

[c] Compositions of peridotite and pyroxenite components defined during the present study for the Gran Canaria subaerially erupted and drilled during the ODP Leg 157 shield stage lavas (GC-ODP; the respective linear regression equations are given in Table 2)

[d] Isotopic composition of the low-velocity component of the upwelling mantle proposed by Hoernle et al. (1995) as a potential source of intraplate volcanism in the eastern North Atlantic, the western Mediterranean and Europe. Note very close isotope compositions of LVC and the peridotite component inferred during this study.