Pre-Cordilleran mantle metasomatism preserved in alkali basalts of Isla Isabel, México

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Abstract

The presence of HIMU (high-$^{238}U/^{204}Pb$) signatures in ocean island basalts has long been used to argue that ancient oceanic crust has been tectonically recycled into the mantle sources of plume-derived volcanic hotspots such as St. Helena or Mangaia. However, alternative hypotheses regarding the origins of HIMU signatures have also been put forward. This paper addresses the origins of HIMU-like Pb isotopic signatures in Isla Isabel, a small (~1 km^2) intraplate volcanic island located off the western coast of México, southeast of the southern tip of Baja California. The Nd-Hf isotopic signatures of Isla Isabel are nearly identical to St. Helena and Mangaia, however since there is no mantle plume underlying Isla Isabel it is unlikely that these signatures derive from recycled oceanic crust. We argue that Isla Isabel lavas were instead produced by mixing of depleted mantle-like material and continental lithospheric mantle that was metasomatized ≥600 Ma ago, an age that overlaps with the regional breakup of Rodinia. Such preservation of ancient tectonic events is remarkable, since the exposed geological record in continental México preserves a very limited record of geological events older than the Mexican Cordillera (<165 Ma). Isla Isabel therefore illustrates that the origins of HIMU-type intraplate lavas are not limited to ancient recycled oceanic crust. Rather, they can also preserve information about the evolution of the upper mantle through large-scale tectonic cycles, even when these events have been otherwise erased from the surficial rock record.

Introduction

Isla Isabel is an intraplate volcanic island overlying the western México continental shelf (**Fig. 1**) that hosts HIMU-like isotopic signatures with undetermined provenance (Housh et al., 2010). The geological history of the region surrounding Isla Isabel is complex. Subduction of the Farallon Plate generated volcanism in northwestern México until 12 Ma ago, when seafloor spreading along the Pacific-Guadalupe Ridge ended and subduction in this region ceased (Lonsdale, 1991). Subsequently, the volcanic arc migrated southward to the presently active Trans-Mexican Volcanic Belt (TMVB; e.g., Ferrari et al., 2012) and northwestern México transitioned to an extensional tectonic regime, marked most notably by the opening of the Gulf of California (Lonsdale, 1991). Isla Isabel lies on the extended strike of the TMVB onto the continental shelf, toward the Gulf of California, and is located ca. 100 km north of the northernmost extent of the subduction zone. Thus, it is considered unlikely the ca. 5 Ma volcanic history of Isla Isabel is related to regional subduction; rather, it is thought to be related to local extension from the prior regional tectonic reorganization (Housh et al., 2010).

Intraplate basalts with broadly similar geochemical compositions to Isla Isabel occur in northwestern mainland México (Aranda-Gómez et al., 2007) and within the TMVB (Díaz-Bravo et al., 2014). The radiogenic Pb isotopic and olivine major element compositions of these rocks have been attributed to metasomatism of the mantle wedge underlying the active and paleo-volcanic arcs and to crustal assimilation. Isla Isabel presents a complementary perspective on the sub-Mexican mantle in that its geochemistry is largely unaffected by either subduction or crustal assimilation processes (Housh et al., 2010). Alkali basalts are also found on islands several hundred km southwest of Isla Isabel that overlie oceanic, rather than continental lithosphere. Two of these islands, Socorro and Guadalupe, are generated by mantle plumes imaged by seismic tomography that extend through 30-40% of the total mantle depth (e.g., Koppers et al., 2021); by contrast, no mantle plume is known to underlie Isla Isabel.

A previous study of Isla Isabel basalts identified their distinct geochemical and isotopic compositions compared to the arc-related volcanic rocks of the TMVB (Housh et al., 2010). Notably, like intraplate-type basalts from the TVMB (Díaz-Bravo et al., 2014), their Pb isotope signatures trend toward those of HIMU (high $\mu = {}^{238}U/{}^{204}Pb$) ocean island basalts (OIB; Housh et al., 2010). HIMU is one of several theoretical mantle components, which among OIB is most commonly associated with recycling of ancient (>2 Ga old) subducted oceanic crust (e.g., Chauvel et al., 1995; Stracke et al., 2005; Nebel et al., 2013). The HIMU component is classically found in OIB from Mangaia and St. Helena (Zindler and Hart, 1986; Stracke et al., 2005), although the Pb isotopic signature of Isla Isabel lavas is not as radiogenic as in these localities (Housh et al., 2010). HIMU-like isotope compositions have also been identified in continental intraplate rocks unrelated to recycled subducted crust, and ancient mantle metasomatism has been proposed for an alternative mechanism to generate highly radiogenic Pb signatures (Ballentine et al., 1997; Rooney et al., 2014; cf., Díaz-Bravo et al., 2014). This paper uses combined Sr-Nd-Hf-Pb isotopic and trace element compositions to clarify the origins of the HIMU-like isotope signatures of Isla Isabel lavas and to determine whether intraplate magmas can provide constraints on the geochemical evolution of the mantle during tectonic reorganization processes.

Methods and Results

Nine Isla Isabel samples, originally studied by Housh et al. (2010) were analyzed for their ^{87}Sr-^{143}Nd-^{176}Hf-^{206,207,208}Pb isotopic compositions. Full details of analytical methods are given in the Supplementary Information. Isla Isabel samples have homogeneous Sr-Nd-Hf-Pb isotopic compositions (**Table 1**). The combined Sr-Nd-Pb isotopic signatures of Isla Isabel lavas plot at the edge of the TMVB arrays or extend these arrays and overlap the compositional fields of global non-hotspot intraplate basalts (**Fig. 2**). Their Sr and Nd isotopic compositions are intermediate between depleted mid-ocean ridge basalt (MORB) mantle (DMM, e.g., East Pacific Rise MORB) and highly enriched isotopic compositions (EM) and are dissimilar to HIMU-type OIB (**Fig. 2a**). The average ^{206}Pb/^{204}Pb ratio of Isla Isabel basalts is 19.330 ±0.027 (2 s.d.), significantly less radiogenic than classical HIMU-type OIB but more radiogenic than DMM or TMVB lavas (**Fig. 2b**). The ^{208}Pb*/^{206}Pb* compositions of Isla Isabel lavas also differ from both DMM and classical HIMU lavas (**Fig. 2c**). By contrast, their Nd and Hf isotopic signatures fall below the mantle array and are almost identical to the Nd-Hf isotopic signatures of classical HIMU hotspots (**Fig. 2d**), making them clearly distinct from nearly all other global non-hotspot intraplate lavas.

Discussion

Comparison of HIMU-like signatures in Isla Isabel

The Nd-Hf isotopic compositions of Isla Isabel lavas (**Fig. 2d**) imply that they may share a common history with classical HIMU OIB. The location of the samples below the mantle array indicates their sources tap a mantle component that has experienced a past enrichment event that produced lower Sm/Nd and Lu/Hf ratios compared to the sources of lavas that lie on the mantle array. The less radiogenic ^{176}Hf/^{177}Hf for a given ^{143}Nd/^{144}Nd ratio exhibited by HIMU lavas relative to other OIB has been previously attributed to fractionation events that were more extreme with respect to Lu-Hf than Sm-Nd, resulting in long-term decoupling of the two isotope ratios (cf., Nebel et al., 2013). The amount of decoupling depends on both the timing and the degree of fractionation between the corresponding parent and daughter elements (Chauvel et al., 2008). Classical HIMU are generally associated with geologically old (>2 Ga) sources, because this allows simultaneous generation of very radiogenic Pb and relatively unradiogenic Sr, Nd, and Hf isotopic signatures. However, an alternative hypothesis holds that HIMU-like isotopic signatures can be generated by mantle metasomatism in little as 200 Ma (e.g., McCoy-West et al., 2016).

Isla Isabel lavas possess less radiogenic Pb isotopic signatures (**Fig. 2c**) compared to HIMU OIB localities. Additionally, their combined $^{208}Pb^{*}/^{206}Pb^{*}$ compositions, which record the long-term Th/U ratio of its mantle source, are incompatible with mixing between DMM and an OIB HIMU component (**Figs. 1c, S1**). Instead, the Pb isotopic compositions of Isla Isabel lavas lie along an array of global non-hotspot intraplate lavas with $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ compositions that link depleted isotopic signatures (e.g., MORB) with an ancient enriched Pb isotopic signature (**Fig. S2**). For example, the Isla Isabel Pb isotopic signature can be modeled as a mixture of EPR-like depleted material and an enriched Pb isotopic component that was introduced 600 Ma ago and raised both the Pb isotopic ratios and the U/Pb ratio of the Isla Isabel mantle source (**Fig. S2**). Introduction of this component at ages like those expected for HIMU OIB would instead require that the Isla Isabel source has a low U/Pb ratio, less than that of the depleted mantle. Further, Isla Isabel lavas lack the strongly positive Nb anomalies associated with recycled crust (e.g., Cordier et al., 2021); instead, they have Ce/Pb and Nb_N/Nb^{*} ratios that resemble DMM (e.g., Arevalo & McDonough, 2010; **Fig. S3**). Finally, Isla Isabel olivine have high CaO and low NiO compositions (Housh et al., 2010; **Fig. S4**) that require their derivation from peridotite rather than mantle pyroxenite associated with subducted oceanic crust (e.g., Herzberg et al., 2014). A similar observation was previously reported for intraplate-type basalts from the TMVB (Díaz-Bravo et al., 2014), implying that pyroxenite signatures are generally absent from the regional mantle.

Modern HIMU-type OIB associated with geochemical signatures of recycled oceanic crust are spatially associated with deep mantle plumes (Jackson et al., 2018). By contrast, there is no known mantle plume beneath Isla Isabel or in the region of northwestern México (Smith, 1999; Mora-Klepeis, 2021; Koppers et al., 2021) that would be capable of delivering deeply recycled oceanic crust to the melting region of Isla Isabel. Recycling of subducted crust at shallower mantle depths is also unlikely due to the higher density of subducted crust, which transforms to eclogite in subduction zones, compared to upper mantle peridotites (Brandenburg et al., 2008). Alternatively, ancient mantle plumes and fluids released during subduction can metasomatize the upper mantle and change local isotopic evolution pathways (e.g., Homrighausen et al., 2018). For example, a CO_2-rich metasomatic origin for the classical HIMU island Mangaia was also evaluated (Weiss et al., 2016), and a single analysis of CO_2 in a basaltic glass from Isla Isabel (Housh et al., 2010) yielded a CO_2 abundance similar to those of melt inclusions from Mangaia (Cabral et al., 2014). Therefore, an ancient metasomatic origin is most likely for Isla Isabel. This interpretation has also been invoked for other non-hotspot intraplate basalts, for example HIMU-like intraplate lavas from Africa are argued to be related to melting of amphibole-rich metasomes that were generated 700 Ma ago (Rooney et al., 2014).

A pre-Cordilleran metasomatic origin of Isla Isabel HIMU signatures

To determine the origin of Isla Isabel's distinct isotope composition, a solid-state mixing model between convecting, depleted upper mantle (DMM; compositions from Salters & Stracke, 2004 and Workman

& Hart, 2005) and metasomatized continental lithospheric mantle (CLM; compositions based on Wittig et al., 2010, see Supplementary Information) is applied to the collected data. The calculated $\Delta\varepsilon^{176}$Hf and $^{207}Pb/^{206}Pb$ compositions of the metasomatized component depend in part on the time this metasomatism occurred, with earlier metasomatism producing lower $\Delta\varepsilon^{176}$Hf and $^{207}Pb/^{206}Pb$ if the effect of metasomatism on parent-daughter ratios is held constant. One constraint on this age is provided by the Hf model ages of the Isla Isabel samples (τ_{176} = 616 ±35 Ma, 2 s.d.). Although this likely provides only a minimum age for the time of metasomatism (Supplementary Information), it is the only contextualized age information available for the mantle source of Isla Isabel.

This model produces a mixing curve between modern DMM and metasomatized CLM that passes through both the Isla Isabel data and, at higher proportions of metasomatized mantle, also passes through literature data for Mangaia (**Fig. 3**). A relatively high proportion of a fusible, metasomatized CLM component beneath Isla Isabel may have promoted mantle melting when the mantle lithosphere was reactivated by recent tectonic reorganization (cf., Hoernle et al., 2011), thus providing an explanation for localized volcanism. By contrast, a model representing 3 Ga old recycled oceanic crust (cf., Nebel et al., 2013) can also reproduce the isotopic composition of Mangaia and St. Helena rocks (cf., Nebel et al. (2013), but not Isla Isabel signatures. In both cases, the model uses a global average DMM value as the depleted mixing component, although MORB from a geographically close location to Isla Isabel, e.g., the northern East Pacific Rise (NEPR), have slightly negative $\Delta\varepsilon^{176}$Hf values. These compositions can be explained analogously to those of Isla Isabel, however in this case the metasomatic CLM component must be either older or possess more enriched Lu/Hf-Sm/Nd ratios (cf., **Fig. 3**, "alternative" model). In this context, the $\Delta\varepsilon^{176}$Hf compositions of Isla Isabel and NEPR samples may reflect pervasive dispersion of variably metasomatized Mexican CLM throughout the continental and oceanic lithosphere along the Mexican margin.

The origin of the Isla Isabel mantle metasomatic component cannot be related to the modern subduction zone, since the Hf isotopic compositions of the Isla Isabel rocks likely require that their mantle source differentiated from the depleted mantle at least 600 Ma ago, whereas the Farallon Plate is likely less than 165 Ma old (e.g., Engebretson et al., 1985). By contrast, surficial volcanic rocks in México provide only a limited record of tectonic events prior to the generation of the Mexican Cordillera. For example, collisional-extensional regimes related to the assembly and breakup of the Precambrian supercontinent Rodinia are preserved only by the Oaxaquia microplate of southern México, ca. 1200 km SE of Isla Isabel (e.g., Keppie and Ortega-Gutiérrez, 2010). The last of these preserved extensional events occurred between 750 and 545 Ma ago, an age that overlaps the Hf model ages of the studied Isla Isabel samples and thus provides a potential explanation for their negative $\Delta\varepsilon^{176}$Hf compositions (**Fig. 3**). The lithospheric mantle beneath Isla Isabel may therefore preserve a geochemical memory of events related to ancient supercontinent cycles that have been largely overprinted on the Mexican mainland. Dispersed metasomatized CLM in other localities may similarly preserve geochemical information about ancient tectonic events but this is only exceptionally unlocked by non-hotspot intraplate volcanoes such as Isla Isabel.

Conclusion

Combined Sr-Nd-Hf-Pb isotopic compositions for the intraplate volcanic island Isla Isabel reflect a HIMU-type mantle source that was likely generated by ancient metasomatic event affecting Mexican CLM. Dispersal of this component to a relatively high degree under Isla Isabel, and possibly to a lesser extent throughout the regional oceanic mantle, generated the HIMU-like isotopic characteristics Isla Isabel basalts. Hafnium isotopic compositions constrain the age of the metasomatic event to be older than Mesozoic-to-recent subduction of the Farallon Plate that produced the Mexican Cordillera. This demonstrates that the utility of HIMU-type intraplate lavas is not limited to understanding ancient subduction of oceanic crust; rather, they can provide critical access to other ancient tectonic processes for which few remnants remain in the accessible geological record.

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Table and Figures

Table 1. Sr, Nd, Hf and Pb isotope data of Isla Isabel samples.

Sample	$^{87}Sr/^{86}Sr$	2SD	n (n_d) [a]	εNd [b]	2SD	n (n_d) [a]	εHf [b]	2SD	n (n_d) [a]	$^{206}Pb/^{204}Pb$	2SD	$^{207}Pb/^{204}Pb$	2SD	$^{208}Pb/^{204}Pb$	2SD	n (n_d) [a]
NAY-2	0.703267	0.000009	1 (1)	5.14	0.05	4 (1)	4.66	0.54	2 (1)	19.3049	0.0012	15.6430	0.0013	38.9373	0.0042	7 (1)
NAY-3	0.703285	0.000009	3 (2)	5.03	0.05	4 (2)	5.55	0.09	7 (2)	19.3559	0.0010	15.6488	0.0009	39.0148	0.0030	12 (2)
NAY-4	0.703260	0.000009	1 (1)	4.97	0.07	2 (1)	5.38	0.27	2 (1)	19.3269	0.0012	15.6465	0.0015	38.9600	0.0054	7 (1)
NAY-13	0.703251	0.000009	1 (1)	4.92	0.07	2 (1)	4.96	0.25	2 (1)	19.3317	0.0006	15.6507	0.0006	38.9762	0.0022	7 (1)
NAY-14	0.703245	0.000009	1 (1)	4.92	0.07	2 (1)	5.59	0.27	2 (1)	19.3364	0.0026	15.6566	0.0031	38.9952	0.0101	8 (1)
NAY-15	0.703253	0.000009	1 (1)	5.00	0.08	2 (1)	5.49	0.24	2 (1)	19.3324	0.0011	15.6483	0.0012	38.9688	0.0041	6 (1)
NAY-31	0.703256	0.000009	1 (1)	4.96	0.07	2 (1)	5.62	0.17	2 (1)	19.3275	0.0009	15.6450	0.0009	38.9567	0.0029	7 (1)
NAY-32	0.703224	0.000009	1 (1)	5.13	0.07	2 (1)	5.75	0.17	2 (1)	19.3234	0.0009	15.6392	0.0011	38.9282	0.0036	7 (1)
NAY-35	0.703250	0.000009	1 (1)	4.95	0.07	2 (1)	5.46	0.17	2 (1)	19.3287	0.0010	15.6468	0.0010	38.9637	0.0034	11 (1)
BHVO-2 [c]	0.703470	0.000009	1 (1)	6.99	0.04	8 (1)	10.81	0.10	6 (1)	18.5980	0.0003	15.5368	0.0004	38.1930	0.0010	7 (1)

Notes:

[a] n refers to number of individual analyses, n_d refers to number of separate digestions of a given sample.

[b] Epsilon notation normalised to CHUR values $^{176}Hf/^{177}Hf$ = 0.282785 and $^{143}Nd/^{144}Nd$ = 0.512630 (Bouvier et al., 2008).

[c] Measured BHVO-2 values are within reference values reported by Weis et al. (2005): $^{176}Hf/^{177}Hf$= 0.283096 ±20, $^{143}Nd/^{144}Nd$ = 0.512983 ±10, $^{206}Pb/^{204}Pb$ = 18.6173 ±465, $^{207}Pb/^{204}Pb$ = 15.5355 ±54, $^{208}Pb/^{204}Pb$ = 38.2108 ±384.

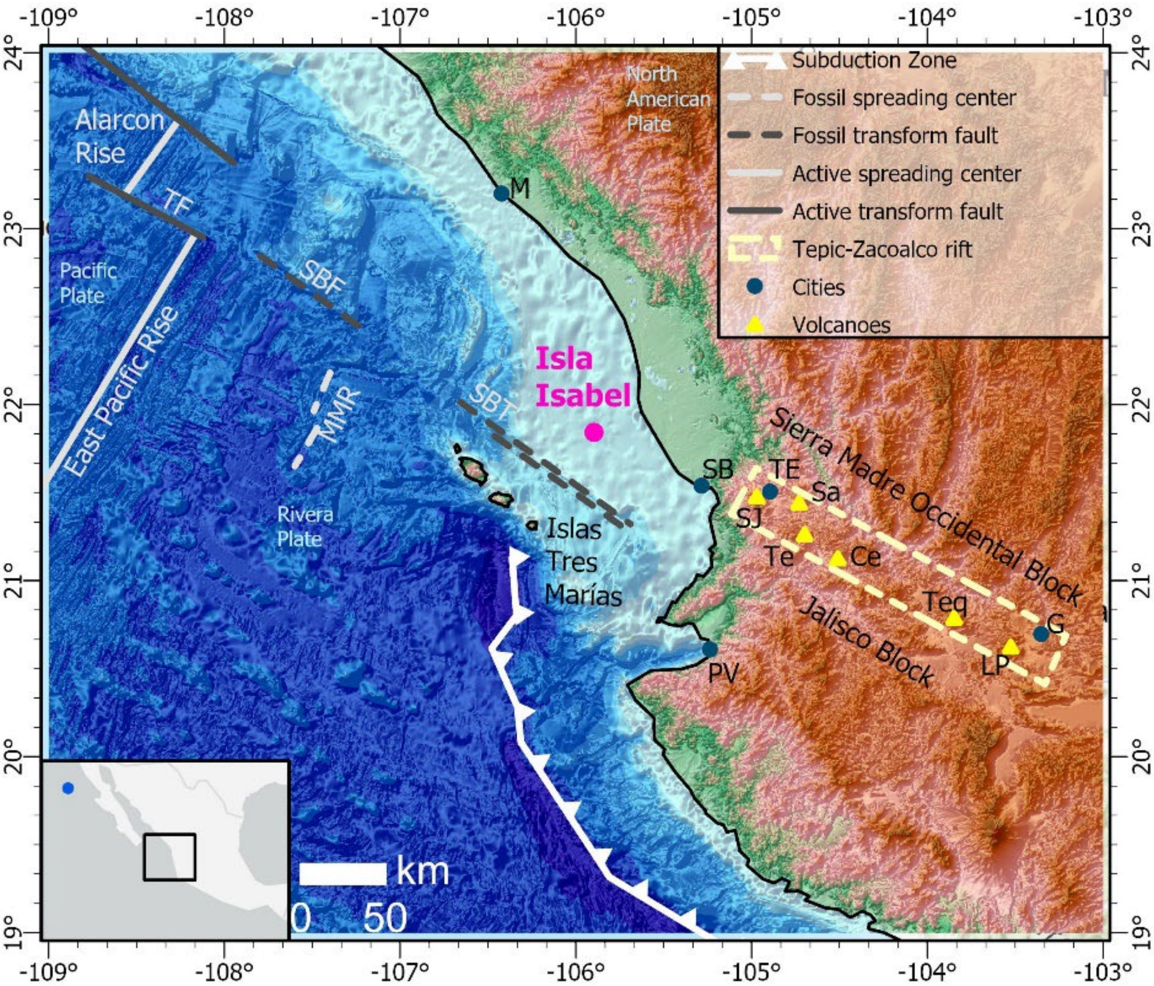

Figure 1. Map of the location of Isla Isabel, showing also relevant tectonic features (TF = Tamayo fault; SBF = San Blás fault; SBT = San Blás Trough; MMR = María Magdalena Rise). Cities (M = Mazatlán; SB = San Blás; TE = Tepic; G = Guadalajara; PV = Puerto Vallarta) and volcanoes of the western TMVB (SJ = San Juan; Sa = Sangangüey; Te = Tepetiltic; Ce = Ceboruco; Teq = Tequila; LP = Sierra La Primavera) are shown. The blue point on the inset map is the island Guadalupe. Features shown have been adapted from Housh et al. (2010), bathymetry grid data obtained from GEBCO (https://www.gebco.net/) (GEBCO Compilation Group, 2021).

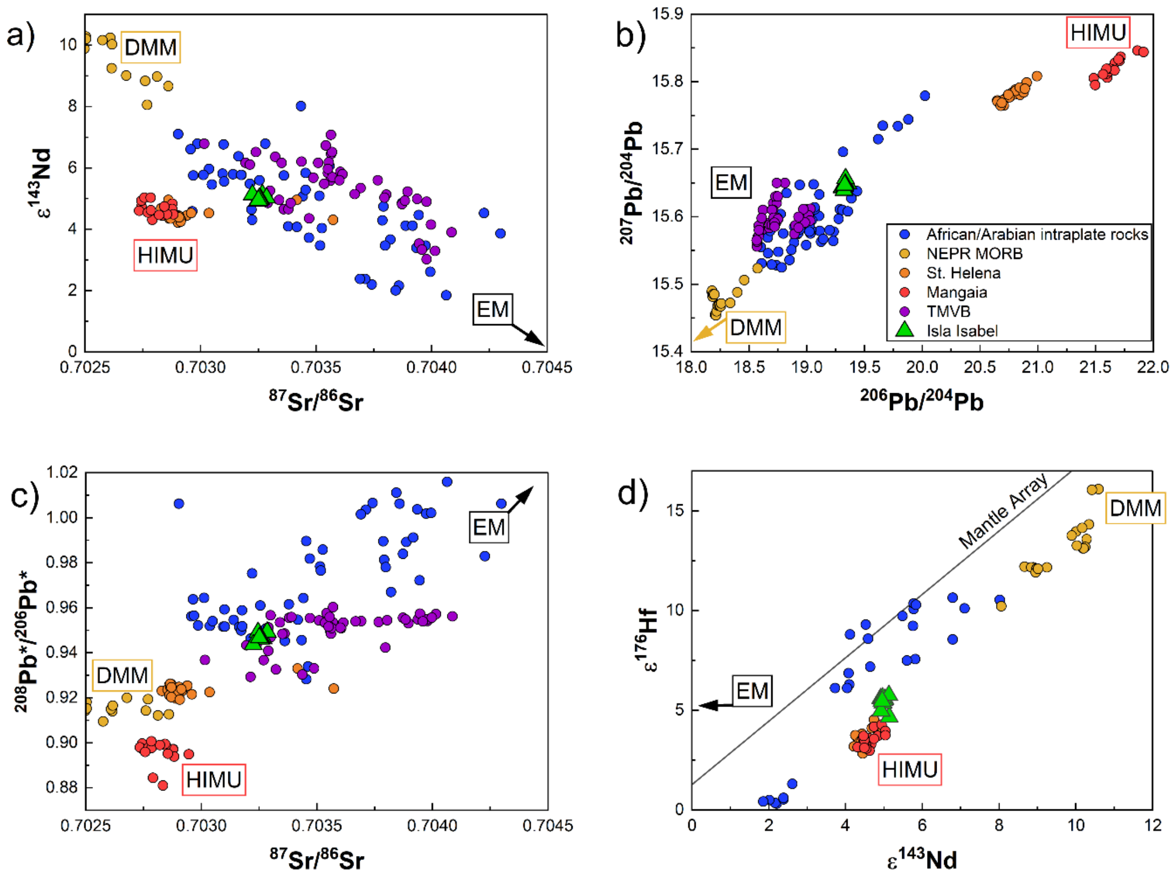

Figure 1. Isotope composition of Isla Isabel lavas. a) $^{87}Sr/^{86}Sr$ vs $\varepsilon^{143}Nd$, b) $^{206}Pb/^{204}Pb$ vs $^{207}Pb/^{204}Pb$, c) $^{208}Pb^{*}/^{206}Pb^{*}$ vs $^{87}Sr/^{86}Sr$, the $^{208}Pb^{*}/^{206}Pb^{*}$ ratio is calculated as described in Stracke et al., 2005, d) $\varepsilon^{143}Nd$ vs $\varepsilon^{176}Hf$ with mantle array according to Chauvel et al. (2008). For comparison, isotopic data from MORB, HIMU OIB, TMVB (intraplate lavas, where available), and African-Arabian intraplate rocks are plotted. Approximate compositions of OIB mantle components (DMM, HIMU, EM) are shown. The references for literature data are given in the Supplementary Information.

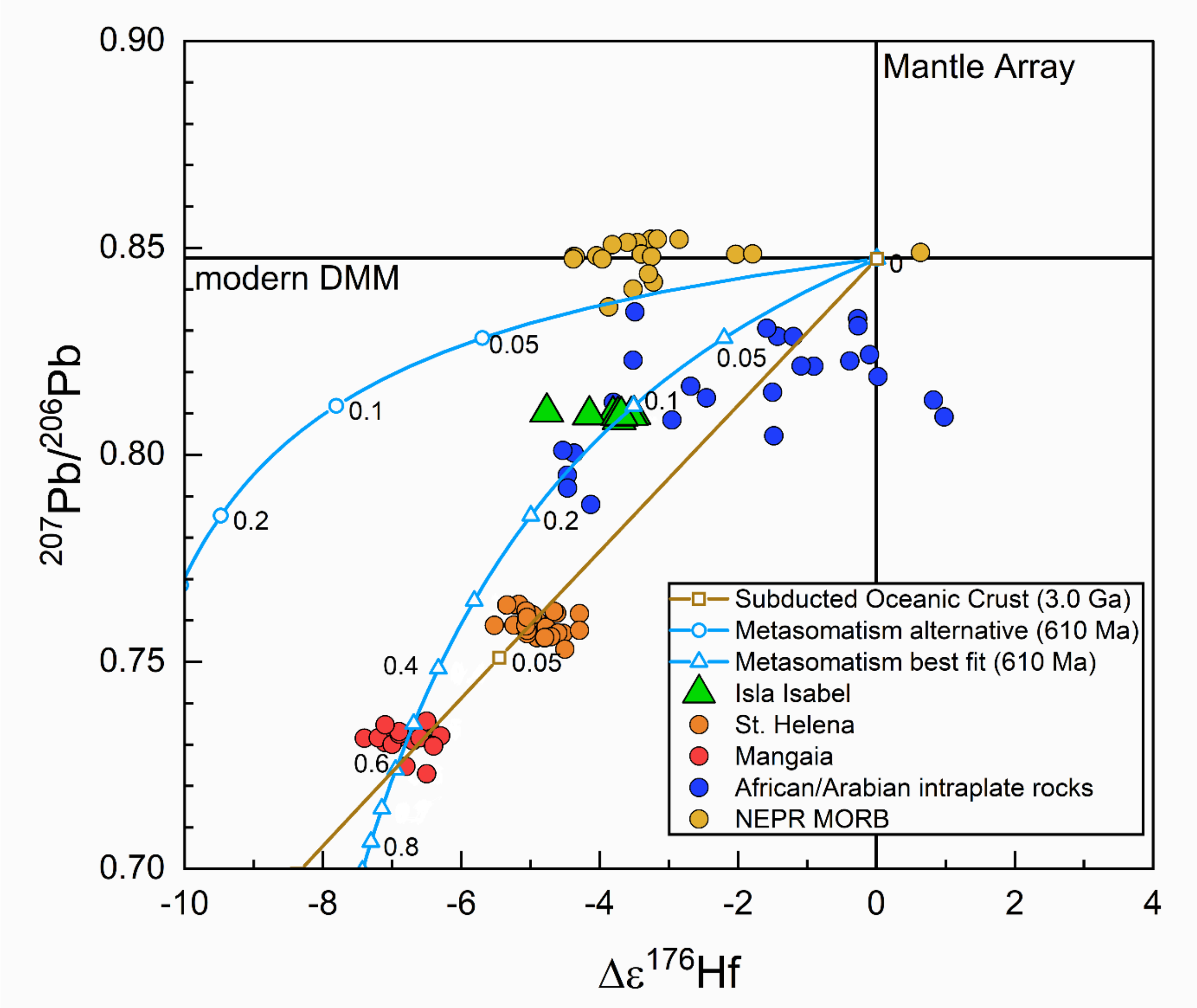

Figure 2. Mixing model for the $\Delta\varepsilon^{176}$Hf (deviation of the ε^{176}Hf compositions of a sample from the mantle array given the sample ε^{143}Hf) versus ^{207}Pb/^{206}Pb compositions of DMM and metasomatized CLM compared to Isla Isabel and literature data. The blue lines represent the model mixing lines, for both best fit and alternative metasomatism models, as well as for a model for 3 Ga old recycled subducted oceanic crust (after Nebel et al. 2013). Symbols on the mixing lines represent the fraction metasomatized CLM component added. Comparison data are the same as in **Fig. 2**.

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Supplementary information and figures for:

Pre-Cordilleran mantle metasomatism preserved in alkali basalts of Isla Isabel, México

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1. Methods

The nine analyzed Isla Isabel samples are the same as in Housh et al. (2010) and were provided by the Smithsonian Museum of Natural History. The GPS coordinates for sample collection locations are provided in Table 1 of Housh et al. (2010) and replicated in **Table S1**. Housh et al. (2010) only reported isotopic data for four samples and no Hf isotopic data. All sample powders, except for that for BHVO-2, were repetitively leached with 2M HCl in an ultrasonic bath in 20-minute intervals. After each leaching interval, the acid and all suspended fine particles were removed with a pipette. The leaching was repeated until the acid solution remained transparent after the 20-minute ultrasonication. At this point, the leachate was again removed, and the leach was stopped by adding mQ H_2O to the sample and ultrasonicating the sample for a further 20 minutes. Subsequently, the H_2O was decanted from the sample with a pipette and the sample residues were gently dried. They were subsequently digested in a 4:1 mixture of concentrated, distilled HF and concentrated, double-distilled HNO_3 for >3 days.

The separation method for Hf was adapted from Münker et al. (2001) and completed on a separate aliquot from the same sample digestion used for Sr-Nd-Pb separations. First, high field strength elements (HFSE), including Hf, were separated from matrix elements in 1M HCl-0.1M HF on BioRad AG50-X8, 200-400 mesh cation exchange resin. The sample aliquots were then dried and repetitively dissolved in drops of concentrated, high-purity $HClO_4$ to oxidize Ti. Following this, Hf was separated from other HFSE on 50-100 µm Eichrom Ln resin. The Hf collection procedure was calibrated, which was accomplished using the basaltic reference material BCR-2. This second column step encompasses separation of Ti (in 0.09M HCit-0.45M HNO_3-1 wt% H_2O_2) and Zr (in 2M HCl-0.1M HF) and finally the collection of Hf isotopes using 6M HCl-0.04M HF. Lead was separated from matrix elements using BioRad AG1-X8 anion exchange resin using 0.5N HBr (matrix) and 0.5M HNO_3 (Pb). Following this, Nd was separated from the Pb matrix fraction in two steps using BioRad AG50-X8, 200-400 mesh cation exchange resin and 50-100 µm Eichrom Ln resin. Strontium was separated from the sample matrix on Eichrom Sr resin using the matrix fraction collected in the first step of Nd separation.

The Nd, Hf, and Pb isotopic compositions of the Isla Isabel samples were measured using the Thermo Scientific Neptune multi-collector inductively coupled plasma source mass spectrometry (MC-ICP-MS) in the Isotope Geochemistry and Cosmochemistry group at ETH Zürich. Neodymium isotopic compositions were normalized to $^{146}Nd/^{144}Nd = 0.7219$ and $^{142}Nd/^{144}Nd = 1.141876$ using a $^{142}Ce/^{140}Ce$ ratio that was empirically calculated from the offset in fractionation-corrected $^{143}Nd/^{144}Nd$ ratios between the JNdi-1 standard with and without an added Ce dopant. The corrected $^{143}Nd/^{144}Nd$ ratios were then normalized to a reference JNdi-1 $^{143}Nd/^{144}Nd$ value of 0.512115 (Tanaka et al., 2004) on a per-session basis. Hafnium isotopic compositions were normalized to $^{179}Hf/^{177}Hf = 0.7325$ and corrected $^{177}Hf/^{176}Hf$ ratios were normalized to a reference value of 0.282160 for the JMC475 standard (Blichert-Toft et al., 1997). Lead isotopic compositions were corrected for mass bias using Tl doping and a $^{203}Tl/^{205}Tl$ ratio calculated to produce a total offset of zero between measured $^{206,207,208}Pb/^{204}Pb$ and $^{207,208}Pb/^{206}Pb$ ratios and the reference values of Baker et al. (2004). External precisions (estimated as the 2σ s.d. of all measured standards in one measurement session) were 0.06-0.09 for $\varepsilon^{143}Nd$ (two measurement sessions), 0.24 for $\varepsilon^{176}Hf$ (one measurement session), 0.0009-0.0010 for $^{206}Pb/^{204}Pb$, 0.0008-0.0012 for $^{207}Pb/^{204}Pb$, and 0.0020-0.0032 for $^{208}Pb/^{204}Pb$ (three measurement sessions). The obtained isotopic compositions for BHVO-2 digested and processed with the Isla Isabel samples agree with literature reference values (**Table 1**).

Strontium isotopic compositions were measured using the Thermo Scientific Triton thermal ionization mass spectrometer (TIMS) in the Isotope Geochemistry and Cosmochemistry group at ETH Zürich. The data were normalized to $^{88}Sr/^{86}Sr = 8.375209$ and the corrected $^{87}Sr/^{86}Sr$ values were normalized to a reference $^{87}Sr/^{86}Sr$ ratio of 0.710245 for the NBS987 standard (mean of published values on the GeoREM database). The external precision for $^{87}Sr/^{86}Sr$ ratios, estimated as the s.d. of all measured standards, was 0.000009. Measured isotopic compositions for BHVO-2 digested and chemically separated with the Isla Isabel samples agree with literature reference values (**Table 1**).

For all samples and isotopic systems, uncertainties of single measurements are expressed as the larger of (i) the 2σ standard error of the measurement and (ii) the 2σ standard deviation of all measured standards as reported in the sections above. The reported values and uncertainties of replicated standard and sample measurements are the weighted average and 2σ standard deviation of individual runs, weighted by the uncertainty of individual measurements as previously defined.

2. Model age calculations

The timing of the metasomatic event that generated the Nd-Hf-Pb isotopic signatures associated with HIMU OIB can be constrained with the help of the Lu-Hf and Sm-Nd isotopic systems, and through this potentially linked to tectonic or magmatic events. To determine the age constraints for the model calculations, the closing time of the systems τ was calculated based on the collected isotope data. Since the Lu-Hf isotope system experiences very small amounts of fractionation between parent and daughter elements during partial melting of intraplate basalts from metasomatized mantle, measured Lu/Hf ratios of the rocks are assumed to be the same as in the magma source (cf., Pilet et al., 2008; Rooney et al., 2014):

$$\tau_{176} = \frac{1}{\lambda} * ln\left(\frac{\frac{^{176}Hf}{^{177}Hf}_{sample} - \frac{^{176}Hf}{^{177}Hf}_{DMM}}{\frac{^{176}Lu}{^{177}Hf}_{sample} - \frac{^{176}Lu}{^{177}Hf}_{DMM}} + 1\right)$$

The average τ_{176} value based on the Isla Isabel isotope data is $\tau_{176} = 616 \pm 35$ Ma. The same calculations for the Sm-Nd system result in a younger age of $\tau_{143} = 376 \pm 27$ Ma, both of which reflect pre-Cordilleran ages. The average τ_{143} age is somewhat older than the age of mantle metasomatism inferred from the Nd isotopic compositions of mantle xenoliths in northwest México, approximately 700 km NNE of Isla Isabel (<227 Ma; Nimz et al., 1995). The difference in the ages implied by the two isotope systems is likely related to differences in the closed system behavior of Hf isotopes compared to Nd isotopes. It has been observed that although the two isotope systems have similar compatibility behaviors, among mantle lithologies the Sm-Nd system seems to be more sensitive to later-stage disturbances, like melt-rock interactions, than the Lu-Hf system (Stracke et al., 2011). Thus, the Lu-Hf system is considered the more robust indicator of the timing of the metasomatic or other enrichment event affecting the Isla Isabel mantle source. A geologically parsimonious explanation for the differing model ages is that they reflect distinct events that affected the Sm-Nd and Lu-Hf systems differently. For example, the >735 Ma mantle depletion age inferred from the least metasomatized mantle xenoliths of Nimz et al. (1995, from northwest México ca. 700 km NNE of Isla Isabel), along with the average Hf depletion age of Isla Isabel samples (616 Ma) may reflect collision-rifting cycles associated with the supercontinent Rodinia (e.g., Keppie and Ortega-Gutiérrez, 2010). The Paleozoic Nd model ages of the northwest México mantle xenoliths (Nimz et al., 1995) and the Isla Isabel samples may reflect distinct episodes of smaller-scale magmatism that are recorded for example in the Coahuila terrane of northwestern México and the southern United States (e.g., Denison et al., 1969).

It is important to note that these model ages do not necessarily directly reflect the time at which the regional continental lithospheric mantle (CLM) was metasomatized, since they reflect the measured ε^{176}Hf and Lu/Hf ratios of the samples, which represent the composition mixed mantle source (DMM + CLM) and not the composition of the metasomatic CLM component itself. Since the $\Delta\varepsilon^{176}$Hf composition of Isla Isabel basalts is a mixture of depleted mantle ($\Delta\varepsilon^{176}$Hf near 0) and the metasomatized component, the latter must have a $\Delta\varepsilon^{176}$Hf composition that is more negative than Isla Isabel. More negative $\Delta\varepsilon^{176}$Hf signatures would require more time to evolve from a pre-metasomatic peridotite that is DMM-like compared to less negative $\Delta\varepsilon^{176}$Hf signatures, unless the Lu/Hf ratio of the more negative $\Delta\varepsilon^{176}$Hf domain is low enough to allow the negative $\Delta\varepsilon^{176}$Hf signatures to develop in a shorter time. For example, Woodhead et al. (2017) reported Hf isotopic data for a global assemblage of mantle-derived zircon, which, due to their very low Lu/Hf ratios and relatively young ages (<120 Ma), preserve their initial Hf compositions. Within their "group A," in which Hf isotopic compositions are correlated with age, a kernel density estimate reveals a peak ε^{176}Hf composition of ca. -3. Assuming the most extreme case of Lu/Hf = 0, which will produce the youngest possible τ_{176} age, if the metasomatized CLM contributing to the Isla Isabel source possessed a ε^{176}Hf of -3, its τ_{176} would be ca. 750 Ma. In the most extreme possible example for Isla Isabel, a metasomatized CLM source with Lu/Hf = 0 and ε^{176}Hf ≈ +0.4 would produce a τ_{176} virtually identical to the average τ_{176} of the samples. However, this would require that the metasomatized CLM contributes ca. 55% of the Hf budget of Isla Isabel basalts. Such a high proportion would more likely produce a more volatile-rich mafic lithology, approaching a lamproite or a carbonatite, than the alkali basalts that characterize Isla Isabel. The Isla Isabel samples would also likely possess trace element characteristics that are common in these rock types, such as enrichments in Th and Ba (e.g., Hoernle et al., 2002), which are absent in the Isla Isabel basalts. Thus, utilizing the Lu/Hf ratios of the Isla Isabel samples to calculate the age of CLM metasomatism likely underestimates the age of regional CLM metasomatism. There are no regional constraints on the Lu/Hf and ratio of the CLM that would permit the model to be constructed otherwise, however mantle xenoliths from northwestern México (ca. 700 km NNE of Isla Isabel; Nimz et al., 1995) similarly preserve a pre-Cordilleran model age of >735 Ma in their Nd model ages. Further, there are no direct constraints on the U,Pb/Th ratios or Pb isotopic compositions of the regional lithospheric mantle that could be used to complete the model into its form in **Fig. 3**.

3. Model fitting of the metasomatized component

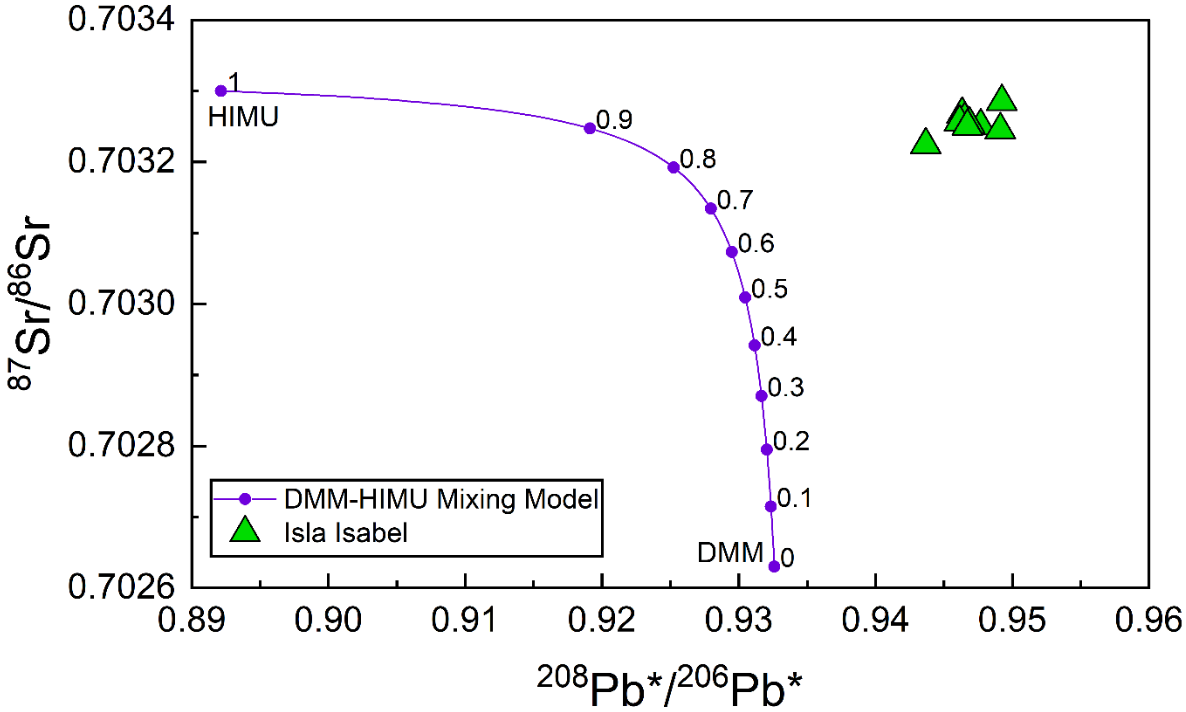
Determining the starting composition of the enriched component of the Isla Isabel magma source is difficult as combined data for the Sm-Nd, Lu-Hf, and U,Th-Pb isotopic systems is relatively scarce for lithospheric mantle xenoliths. Compositions able to generate the required isotope compositions can be found by model fitting and using literature data for global xenoliths of CLM. For the Pb isotope compositions, a ^{238}U/^{204}Pb of 56.3 (Wittig et al., 2010) observed in metasomatized continental mantle xenoliths reproduce the isotopic compositions of Isla Isabel lavas assuming a starting age of 616 Ma (i.e. the average Lu-Hf model age of the samples). However, the Lu/Hf and Sm/Nd ratios of the same rocks are not able to reproduce the observed Nd and Hf isotopic compositions of Isla Isabel lavas; instead, the component requires a more enriched Lu/Hf ratio compared to the depleted mantle than the enrichment of Sm/Nd ratios compared to the depleted mantle. This incongruous enrichment can be observed in the same metasomatized mantle samples from Wittig et al. (2010), but the enrichment is not extreme enough (e.g., ^{176}Lu/^{177}Hf = 0.02 and ^{147}Sm/^{144}Nd = 0.21; Wittig et al., 2010) to produce Nd-Hf isotopic compositions as far below the mantle array as what is observed for Isla Isabel lavas. In order to produce a fit to the Isla Isabel data, the Lu/Hf ratio of their most extreme sample was thus adjusted downwards, and its Sm/Nd ratio was proportionally adjusted upwards. This represents an artificial arithmetic adjustment; however, it mimics the same metasomatic enrichment process observed in the samples of Wittig et al. (2010), but to a higher degree.

The best fit mixing line for the Isla Isabel samples also passes through samples from Gerba Guracha, which have been suggested to originate from melting of amphibole-rich lithospheric metasomes, resulting in their HIMU-like compositions (Rooney et al., 2014). Isla Isabel samples have similar ^{207}Pb/^{206}Pb and $\Delta\varepsilon^{176}$Hf values to the lavas from Gerba Guracha (Fig. 2), which speaks for the possibility of a similar metasomatic component being involved in the island's magma source.

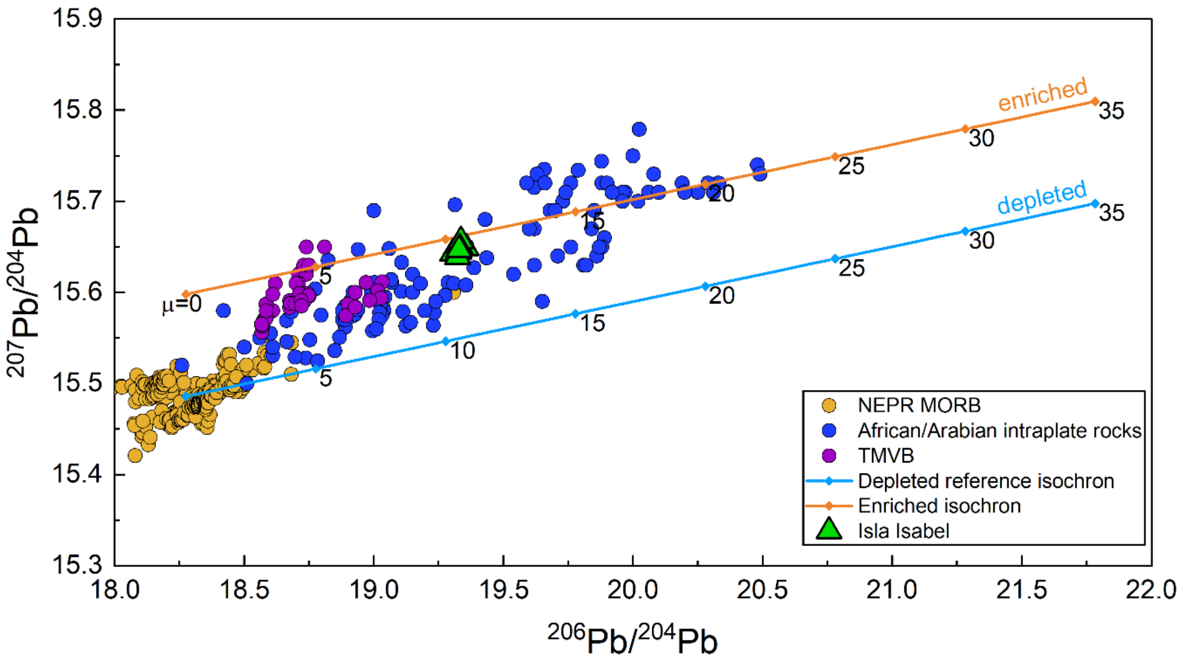
Supplementary table and figures

Supplementary Table S1. GPS collection coordinates for samples used in this study.

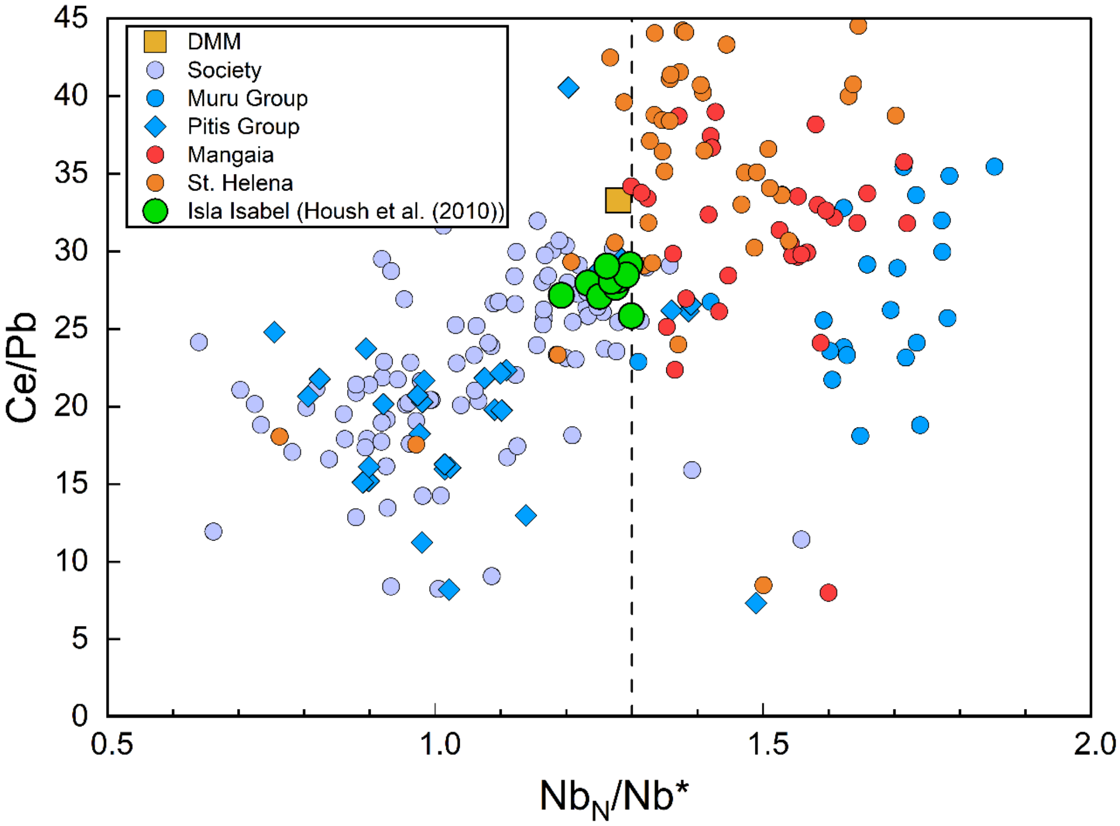
Sample	Latitude	Longitude
NAY-2	21.8436	-105.8794
NAY-3	21.8436	-105.8794
NAY-4	21.8500	-105.8878
NAY-13	21.8463	-105.8844
NAY-14	21.8491	-105.8851
NAY-15	21.8492	-105.8888
NAY-31	21.8480	-105.8879
NAY-32	21.8433	-105.8864
NAY-35	21.8445	-105.8861



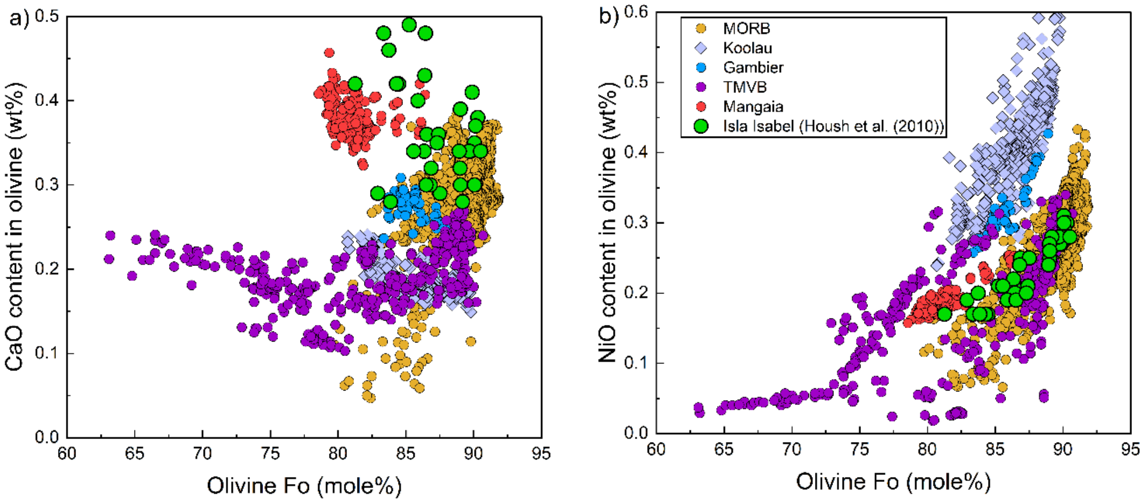
Supplementary Figure S1. $^{87}Sr/^{86}Sr$ versus $^{208}Pb^*/^{206}Pb^*$ non-linear isotope mixing model. Points and numbers indicate the fraction of HIMU component in the mixture. This simple model indicates that mixing between enriched (e.g., HIMU component originating from recycled subducted oceanic crust) and a depleted (e.g., DMM) endmembers is unable to produce Isla Isabel isotope compositions. Endmember isotopic compositions are derived from the literature (DMM: $^{87}Sr/^{86}Sr = 0.7026$, $^{206}Pb/^{204}Pb = 18.23$, $^{208}Pb/^{204}Pb = 37.84$, Workman and Hart, 2005; HIMU: $^{87}Sr/^{86}Sr = 0.7033$, $^{206}Pb/^{204}Pb = 22$, $^{208}Pb/^{204}Pb = 40.8$, Stracke et al., 2005). The choice of Pb and Sr elemental abundances in the mixing model is arbitrary, since there is no possible mixing line that would pass through the Isla Isabel data; the displayed mixing line is thus only illustrative.



Supplementary Figure S2. Isotope model of $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ isochrons adapted from Rooney et al. (2014). The model compares the evolution of Pb-Pb isochrons with varying μ values at a fixed time (ca. 600 Ma) based on the Isla Isabel Hf isotope data (τ_{176}). The reference depleted isochron starts with an initial composition representing DMM Pb isotope signatures (Workman and Hart, 2005) using μ ranges from 0-35. This isochron lies below the Isla Isabel data. The adjusted, enriched isochron is fitted to the most extreme Isla Isabel value by increasing the initial value of $^{207}Pb/^{204}Pb$ from 15.486 to 15.598. This increase could represent a geochemical enrichment event affecting DMM material, generated for example by incorporation of subducted oceanic crust or metasomatized CLM. Along with the Isla Isabel samples, intraplate rocks that have metasomatized mantle sources are plotted for reference. Together, they illustrate a broad mixing line between the two isochrons.



Supplementary Figure S3. Ce/Pb versus Nb_N/Nb^* (Nb_{PM} / $(La_{PM} * Th_{PM})^{1/2}$, where PM indicates normalization to the primitive mantle composition of McDonough & Sun, 1995) for Isla Isabel and comparison data from literature. These trace element ratios can be used to infer information about the sources of intraplate magmas because they are relatively unaffected by partial melting and fractional crystallization and have distinct values in continental curst and mantle material. Trace element compositions of Isla Isabel (Housh et al., 2010) overall overlap with depleted mantle values (22 ±10; Arevalo and McDonough, 2010), while classical HIMU rocks such as Mangaia and St. Helena, which are thought to derive from recycled, subducted oceanic crust and tend to have high Nb_N/Nb^* and Ce/Pb values (Cordier et al., 2021). The vertical dashed line represents the boundary between the Pitis (depleted) and Muru (recycled) group lavas within the Pitcairn-Gambier hotspot chain, as proposed by Cordier et al. (2021). The lack of strongly elevated Ce/Pb and Nb_N/Nb^* ratios, producing a dissimilarity with the Muru group, indicates that a classical HIMU origin is unlikely for the Isla Isabel isotope composition.



Supplementary Figure S4. Olivine compositions of Isla Isabel (Housh et al., 2010) compared to literature data: a) CaO versus forsterite (Fo) content; b) NiO versus forsterite content. Isla Isabel olivines have low NiO and high CaO contents, overlapping with both olivines from MORB (Sobolev et al., 2007) and the TMVB (Díaz-Bravo et al., 2014). These data are consistent with derivation of Isla Isabel lavas from partial melting of peridotite source (e.g., high CaO, low NiO; Díaz-Bravo et al., 2014). The recycling of oceanic crust tends to generate hybrid pyroxenite mantle lithologies, which produce low CaO, high NiO olivines when melted, as observed in the Ko‘olau (Hawai‘i) and Gambier (French Polynesia) olivines. The lack of evidence for a pyroxenite component in the Isla Isabel olivine compositions argues against derivation of Isla Isabel lavas from recycled oceanic crust, and rather implies the involvement of metasomatized mantle lithologies, for example with carbonatitic melts (McCoy-West et al., 2016; Weiss et al., 2016).

Literature data

For comparison with the Isla Isabel data, literature values from lavas of different locations and origin were plotted.

Figures 2, 3, and S2: MORB (Castillo et al., 2000; Niu et al., 2002; Debaille et al., 2006; Waters et al., 2011; Mougel et al., 2014; Mallick et al., 2019), TMVB (Pier et al., 1992; Petrone et al., 2003; Valdez-Moreno et al., 2006; Díaz-Bravo et al., 2014), African and Arabian intraplate rocks (Bertrand et al., 2003; Lucassen et al., 2008; Rooney et al., 2014), St. Helena (Hanyu et al., 2014) and Mangaia (Woodhead, 1996; Nebel et al., 2013)

Supplementary Figure S3: DMM (Salters and Stracke, 2004), Pacific islands (Cordier et al., 2021), St. Helena (DIGIS Team, 2021), Mangaia (DIGIS Team, 2021), Isla Isabel (Housh et al., 2010)

Supplementary Figure S4: MORB (Sobolev et al., 2007), Koolau (Sobolev et al., 2007), Gambier (Delavault et al., 2015), TMVB (Díaz-Bravo et al., 2014), Mangaia (Herzberg et al., 2014), Isla Isabel (Housh et al., 2010)

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