Earth Planet. Sci. Lett. 626 (2024) 118529

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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

Fani Maoré, a new “young HIMU” volcano with extreme geochemistry

Catherine Chauvel [*], Edward C. Inglis [#], Pamela Gutierrez, Tu-Han Luu, Pierre Burckel, Pascale Besson

Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, UMR 7154, F-75005 Paris, France

ARTICLE INFO

Editor: Dr R. Hickey-Vargas

Keywords:
Trace elements
Radiogenic isotopes
OIB
Comoros
Mantle plumes

ABSTRACT

Intraplate volcanism provides remarkable insight into diverse sources in the mantle because its source can be quite shallow, or as deep as the core-mantle boundary, and its origin can be as diverse as recycled crustal material or undifferentiated mantle. While geophysical approaches can in some cases locate the source of magmas, a geochemical approach is necessary to characterize both the nature of the source and the way it melts to produce the erupted lavas.

Here we present geochemical and isotopic data obtained on a new submarine volcano (Fani Maoré) that was discovered in 2019 next to Mayotte Island in the Comoros. The radiogenic isotope data are remarkably uniform at subdued values intermediate between HIMU and EM1 compositions but trace element contents are unusual with a marked enrichment in Ba (Ba/Th ≈ 370 compared with the ocean island basalt (OIB) average of 100) and depletion in Pb (Ce/Pb ≈ 70 versus 25 for average OIB). This unique data set suggests that the basanites formed by melting of a carbonated mantle source that was highly enriched in Ba and volatiles. A similar source is also present under the East African Rift where contemporaneous basanite and carbonatite eruptions are known. This establishes a possible link between the volcanic activity of the Comoros and the East African Rift zone. More generally, it demonstrates that carbonated sources are more common in the mantle than previously thought and can be traced using trace element geochemistry. Other volcanoes in the world carry similar characteristics and we suggest that carbonated mantle sources explain the geochemical peculiarities of not only Fani Maoré in the Comoros but also those of Cape Verde volcanics and more generally those of many HIMU-like OIBs, in particular the so-called ‘young HIMU’ OIBs.

1. Introduction

In early 2019, a new active submarine volcano was identified ~55 km off the eastern coast of Mayotte island in the Comoros Archipelago (Feuillet et al., 2021). The start of volcanic activity was marked by deep seismic events associated with large seafloor displacements and the onset of lava eruption off the coast of Mayotte (Fig. 1). In less than one year, about 5 km^3 of lavas erupted to form the new volcanic edifice called Fani Maoré. This makes it the largest active submarine eruption ever documented (Feuillet et al., 2021).

Mayotte belongs to the Comoros Archipelago, which is located between Africa and Madagascar in a strait known as the Mozambique Channel (Fig. 1). While initial models for the formation of the archipelago invoked a simple linear mantle plume trace on the overlying plate (Esson et al., 1970), more recent work challenged this concept on the basis of the contemporaneous ages of volcanic edifices on different islands (Class et al., 1998; Michon, 2016; Quidelleur et al., 2022). Today the process that created this intermittent and dispersed magmatism across the archipelago remains unclear (Class et al., 1998; Famin et al., 2020).

In this contribution we present high-precision elemental and isotopic (Sr-Nd-Pb-Ba) data for a suite of basanite and phonolite samples collected during several cruises in the area (Rinnert et al., 2019). We use this unique dataset to discuss the tectonic context in which the Comoros archipelago forms but we also address broader scientific questions relative to the nature of the mantle source and its relationship to other OIB. We demonstrate that the basanites formed by melting of a quite unusual mantle source highly enriched in Ba, CO$_2$ and sulfur but with usual radiogenic isotopes compositions. We demonstrate that a carbonated mantle source best explains the geochemical characteristics

---

[*] Corresponding author.
E-mail address: chauvel@ipgp.fr (C. Chauvel).

[#] Now at School of Earth and Environmental Science, Cardiff University, Main Building, Park Place, Cardiff, United Kingdom, CF10 3AT.

https://doi.org/10.1016/j.epsl.2023.118529
Received 27 July 2023; Received in revised form 15 November 2023; Accepted 2 December 2023

of Fani Maoré. We finally suggest that similar sources occur under other island chains and produce lavas with the trace element characteristics of HIMU OIB and in particular the 'young HIMU' OIBs such as Cape Verde, Mururoa or some of the Canaries islands.

2. Geological context

Fani Maoré, the new submarine volcano, was discovered in May 2019 during MAYOBS1 cruise (Feuillet et al., 2019) on the seafloor at a depth of about 3300 m and a distance of about 55 km from Petite Terre, one of the two islands of Mayotte (see Fig. 1) in the Comoros Archipelago. The volcanic edifice is an 820 m high structure that is linked to Petite Terre by a volcanic ridge along which recent, probably late Quaternary eruptions also occurred (see Fig. 2) (Feuillet et al., 2021). The detailed petrology and chronology of eruptions is provided in several publications including Berthod et al. (2021a), Berthod et al. (2021b) and Berthod et al. (2022).

The Comoros Archipelago is located between Africa and Madagascar on ~150 Ma old oceanic lithosphere that formed during the opening of the Somali basin (Phethean et al., 2016) (see Fig. 1). The volcanic chain consists in four islands (Grande Comore, Moheli, Anjouan and Mayotte) with ages of subaerial volcanism ranging from 11 Ma to the present (see Fig. 1). Up to 2019, the oldest volcanism was reported for the islands of Mayotte and Anjouan, while the most recent eruption occurred on Grande Comore (Nougier et al., 1986; Pelleter et al., 2014). This time pattern has obviously changed since the birth of the new volcano offshore Mayotte. Finally, the four Comoros islands are aligned along an NNW-SSE direction on a transfer zone in the oceanic lithosphere (Feuillet et al., 2021).

The exact driver of volcanism in the Comoros Archipelago is still debated, with two main models. The first one suggests that a deep plume interacted with the oceanic lithosphere (Class et al., 1998; Claude-Ivanaj et al., 1998; Deniel, 1998; Class et al., 2005, 2009). The second model attributes melting and melt migration to a regional extensional tectonic regime linked to the East African Rift system, whereby extension-driven melting of the lithospheric mantle is accommodated along a series of transform faults, ultimately giving rise to the archipelago in its current arrangement (Michon, 2016; Famin et al., 2020; Michon et al., 2022).

3. Methods

During the first cruise in May 2019 and subsequent cruises, a large sample suite was collected by dredging at the eruption site, along the volcanic ridge and on the flank of Petite Terre, providing a unique set of juvenile oceanic lavas. The analyzed samples were dredged during the oceanographic cruises MAYOBS 1, MAYOBS 2, MAYOBS 4 and MAYOBS 15 (Feuillet et al., 2019; Fouquet and Feuillet, 2019; Jorry, 2019; Rinnert et al., 2019, 2020; Feuillet et al., 2021).

When glass was available at the surface of the samples, it was selected and picked under a binocular to be used for isotopic measurements. For major and trace elements, and for samples without glassy rims, the crystallized part of samples was crushed using an agate mortar. Major element concentrations were measured by XRF at University Paris

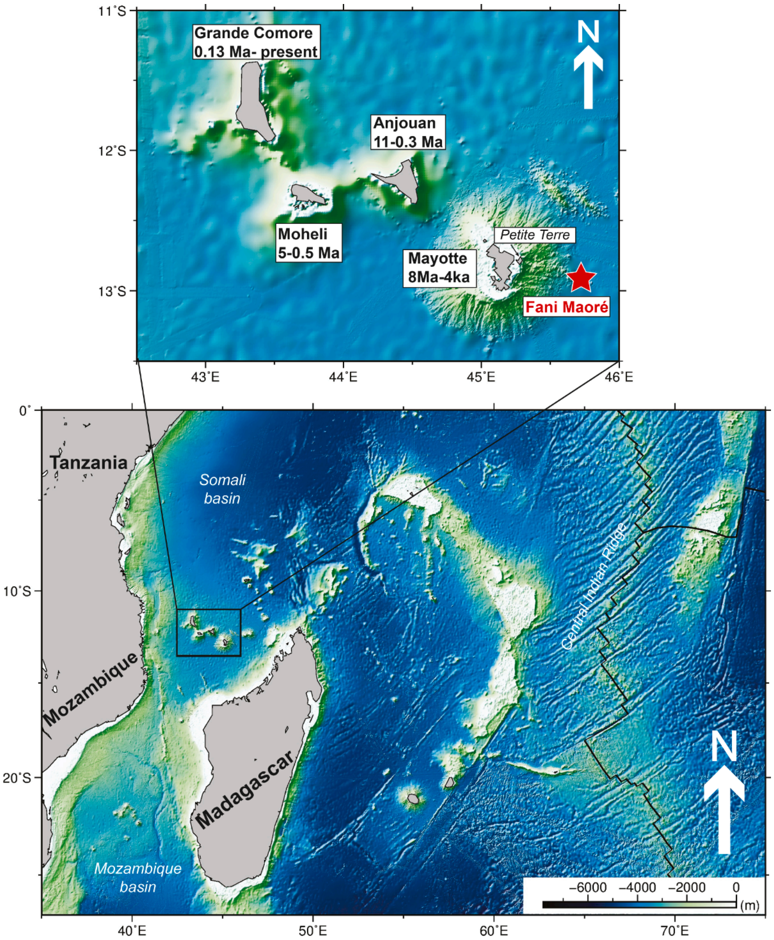

Fig. 1. Location of the new Fani Maoré volcano in the Comoros Archipelago and ages of volcanism on each island. The red star on the top inset map marks the site of the volcano that formed in 2018 and was discovered in 2019 on top of the oceanic crust. At these latitudes, one degree East corresponds to 106 km and one degree South to 111 km.

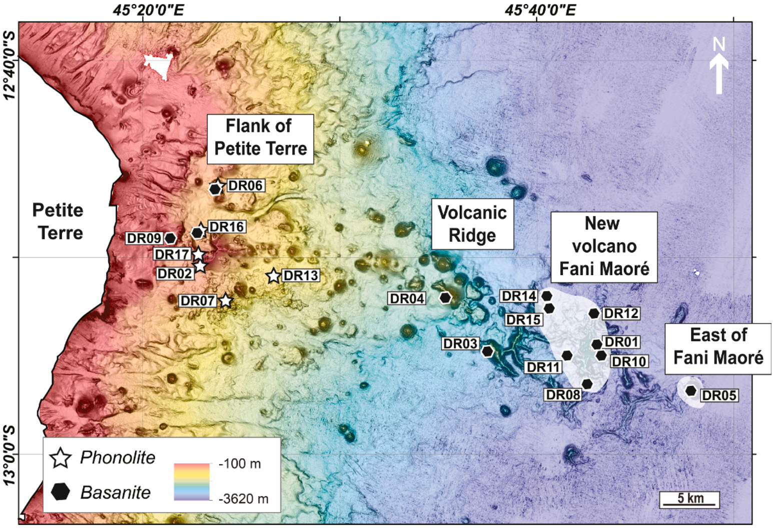

Fig. 2. A bathymetric map showing the site of the new eruptions and the dredge sites (DR) where samples presented here were collected. White stars mark the occurrence of phonolite and black hexagons denote basanites.

Cité while other data were acquired at the Institut de Physique du Globe de Paris. Trace elements were obtained using an Agilent 8900 ICP MS-MS, Sr and Nd isotopes were measured using a Nu TIMS and Pb, Hf and Ba isotopic compositions using either a Neptune or a Neptune Plus. Methods are primarily based on modified versions of the methods published by Chauvel et al. (2011) and by Charbonnier et al. (2020). The quality and accuracy of the data was evaluated by analyzing international standards (both rocks and solutions). Details are provided in the **Supplementary text file.**

4. Results

About 90 samples were analyzed for major and trace elements. In order to sample the various volcanic edifices, a subset of over 30 samples was analyzed for Sr, Nd, Hf and Pb isotopes and 19 of these samples were selected to measure Ba isotopic compositions. The full suite of elemental and isotopic data is given in **Supplementary Table 1.**

We distinguish two main types of lavas, basanites and phonolites (see Fig. 3) and four groups based on their location: the new volcano Fani Maoré, the volcanic ridge located between Fani Maoré and Petite Terre, the flank of Petite Terre and a small eruption site dredged east of Fani Maoré (see Fig. 2).

As shown in Fig. 3, basanites have low SiO_2 contents (< 47%) but moderately high NaO_2+K_2O contents (≈6%) associated with low MgO contents (≈ 4%). In contrast, the phonolites have higher silica contents (≈ 55%), much higher NaO_2+K_2O contents (≈14%) and extremely low MgO contents (<1%). Fig. 3 also shows how literature data published for lavas from Mayotte and the other islands in the Comoros Archipelago compare to the new results.

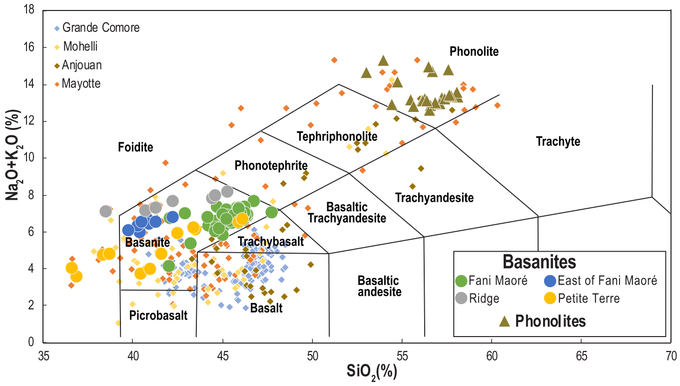

Fig. 3. Major element plot of the samples studied here (dots and triangles) plotted alongside literature data from the Comoros Archipelago (diamonds). Literature data from the Comoros islands is from GEOROC database.

Trace elements of basanites and phonolites from the various dredge sites are shown as extended trace element diagrams in Fig. 4. The general shape of the trace element patterns of basanites is rather constant among the four groups, with enriched and sloping trace element profiles and a significant negative K anomaly like those observed in HIMU-type basalts (Weaver, 1991). However, with few exceptions, the Fani Maoré basanites display several peculiar features: (a) strong enrichments in Ba (Ba/Th >300) whereas almost all basanites from other locations in the area have much lower ratios (<150); (b) strong depletion in Pb relative to Ce with Ce/Pb ratios generally between 57 and 72, while other analyzed basanites have variable but much lower Ce/Pb ratios (23 to 49); (c) large positive Sr and Eu anomalies (Sr/Sr*≈1.6 and Eu/Eu*≈1.25) while other samples have ratios at about 1; (d) persistently lower concentrations of Th, U, Nb, Ta, Zr and Hf than in other basanites translating into, for example, low Nb/La ratios of only ≈ 0.7–0.8 while samples from other locations in the Comoros archipelago have Nb/La ratios at about 1.2. When Ba/Th, Nb/La, Sr/Sr*, Eu/Eu* are plotted against Ce/Pb, it is clear that the composition of Fani Maoré differs from that of other volcanics in the Comoros Archipelago (Fig. 5**a-d**). In contrast, lavas erupted either on the flank of Petite Terre or along the volcanic ridge share common features with the other Comoros basalts from Mayotte or Grande Comore even if they tend to have intermediate values between Fani Maoré and the other Comoros islands.

The phonolites have very fractionated trace element patterns and display extreme deficiencies in Ba, Sr and Ti. Their Ba/Th and Eu/Eu* ratios are significantly lower than those of basanites (< 30 and between 0.3 and 0.7, respectively) but their Ce/Pb ratios do not differ from those measured on basanites from the same geographical area. Their Nb/La ratios are slightly higher than those of the basanites (see Figs. 5**a-d**).

The Sr, Nd, Hf and Pb isotopic compositions are given in **Supp Table 1** and plotted in **Supp** Figures 1**a-d**. In $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ space (**Supp Figure 1a)** the Fani Maoré data form a tight cluster that overlaps with literature data as compiled by GeoRoc for Mayotte. Basanites erupted on the flank of Petite Terre have more variable isotopic values but they also overlap with the field defined by published data on Mayotte. No significant difference exists between basanites and phonolites with the exception of one phonolite whose Sr isotopic

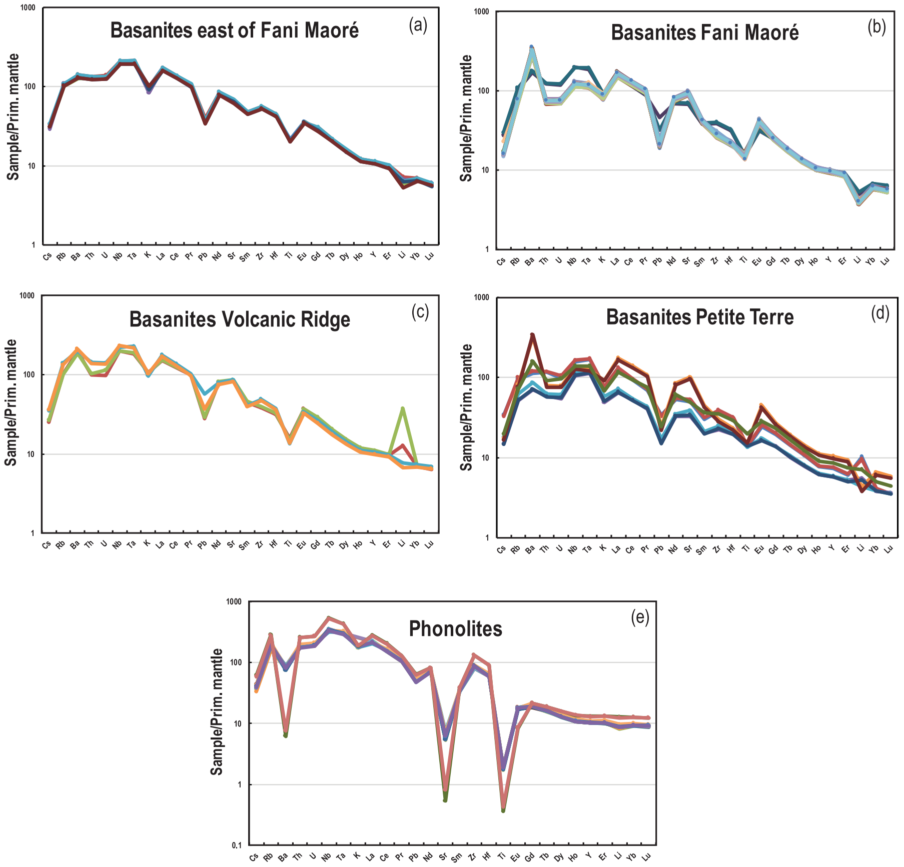

Fig. 4. Extended trace element diagrams for the lavas sorted by geographical location. Sample concentrations are normalized to the primitive mantle (PM) values of McDonough and S.S. Sun (1995).

composition is more radiogenic. This sample is highly vesicular and we suspect that the sample was contaminated with strontium from seawater. Various attempts to remove any seawater input by leaching produced variable Sr isotopic compositions suggesting that the procedure was not able to eliminate all the seawater strontium (see supplementary text for detailed explanations).

In Pb-Pb space (**Supp Figures 1b&c**), isotopic variations are larger than for Sr and Nd. Basanites from both Petite Terre and the volcanic ridge have lower Pb isotopic ratios than the Fani Maoré samples. Phonolites have $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ identical to the Fani Maoré samples but their $^{207}Pb/^{204}Pb$ are systematically lower, defining a vertical trend in **Supp Figure 1b.** In $^{176}Hf/^{177}Hf$ versus $^{144}Nd/^{143}Nd$ space, samples define a small vertical cluster (**Supp Figure 1d**). In **Suppl Figure 2**, the newly acquired isotopic data are plotted together with values reported in the literature for various ocean islands. In Sr-Nd, Sr-Pb and Pb-Pb isotopic spaces (**Supp Figure 2a, b and d**), the Fani Maoré samples overlap with data reported for the Australs, Canaries and Cape Verde Island chains. In Nd-Hf isotopic space (panel c), literature data are scarcer but the Fani Maoré lavas are located on the bottom side of the general OIB array, close to HIMU lavas from the Austral Islands (**Supp Figure 2**).

The Ba isotope data expressed as $\delta^{138/134}Ba_{NIST3104a}$ vary between 0.011 ± 0.052 ‰ (2SD) and 0.216 ± 0.027 ‰ (2SD) with an average composition of 0.102 ± 0.107 ‰ (2SD). There is no systematic difference between basanites and phonolites and the overall average is indistinguishable from average mantle value (Charbonnier et al., 2018) (**Sup Figure 3**). In addition, $\delta^{138/134}Ba$ values remain constant while $^{87}Sr/^{86}Sr$ or Ba/Th vary (**Sup Figure 3**). However, when looking in detail, the average Ba isotopic composition of Fani Maoré lavas (0.102 ± 0.107 ‰) falls on the high side of the range reported recently by Bai et al. (2022) for ocean island basalts (−0.07 to 0.14 ‰), at values similar to those reported for HIMU islands (St Helena and Cook-Australs).

5. Discussion

The complete set of geochemical data acquired on lavas sampled on Fani Maoré and other recent eruption sites next to Mayotte helps to solve several important scientific questions. Some of these relate to the tectonic setting in the area: how does Fani Maoré, the new volcano, relate to the Comoros Archipelago? And, what created the archipelago? Other questions have broader implications for mantle geochemistry: what process and what type of source can produce the very unusual geochemistry of Fani Maoré lavas? Are there similar volcanoes in other locations? These questions are addressed below.

5.1. Origin of the Ba and Pb anomalies in Fani Maoré lavas

Fani Maoré is exceptional in many respects. A remarkably large amount of basalt erupted to build an 800 m high volcanic edifice in less than a year (Feuillet et al., 2021). All these basalts are very alkaline and their strong enrichment in highly incompatible elements relative to less incompatible elements (see Fig. 4) suggests that they were produced by low degrees of melting in the presence of residual garnet. To explain the large volume of magma produced by low-degree melting in the presence of garnet, we propose that the source melted at great depth (≥ 100 km) and was continuously fed by ascending material from still deeper in the mantle. The resultant lavas have very homogeneous radiogenic isotopic compositions with, for example, $^{87}Sr/^{86}Sr=0.703350\pm0.000018$ (2SD, $n = 13$) demonstrating that the composition of the source did not change significantly during the entire emplacement period. Similarly, the trace element patterns of the erupted basanites are quite uniform. In Fig. 4**b**, all but three of the Fani Maoré samples have overlapping patterns

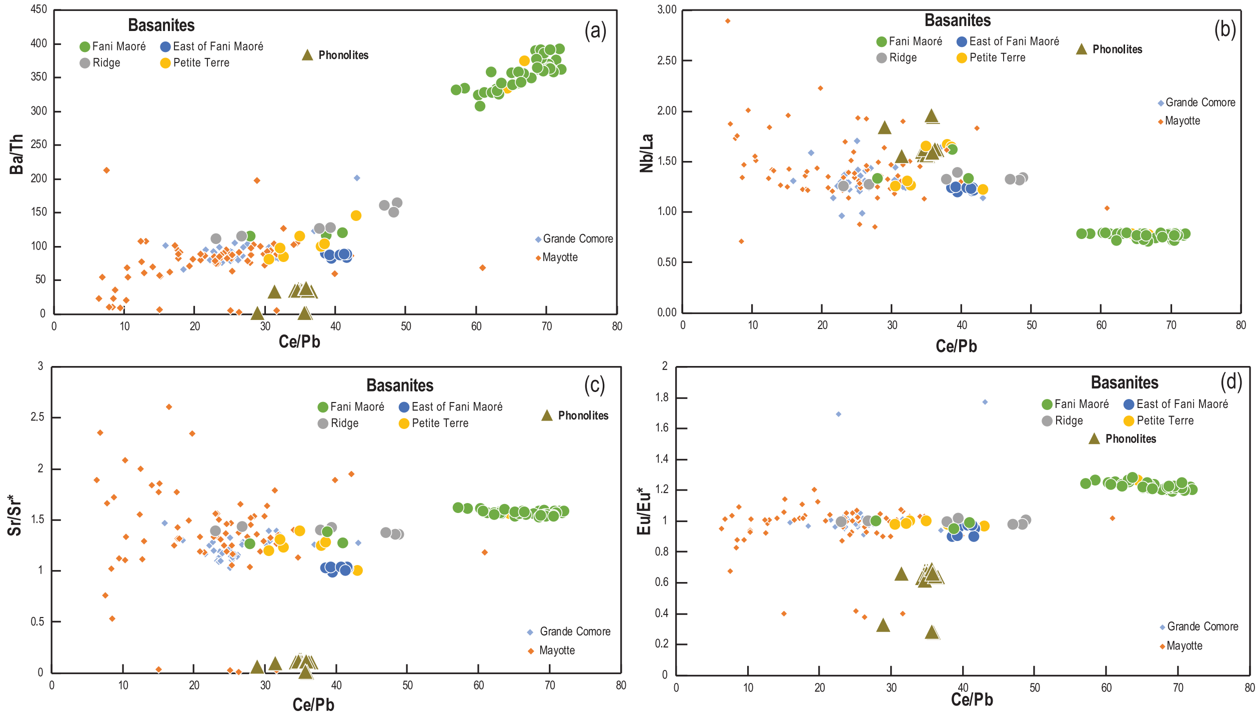

Fig. 5. Various trace element ratios plotted against Ce/Pb ratios. Panel (a) shows that Ba/Th and Ce/Pb are correlated and display extreme values not reported in any of the published data for Comoros lavas. In contrast to Fani Maoré basanites with their high Ba/Th and Ce/Pb, lavas erupted at other sites have much lower values that resemble those of Grande Comore and Mayotte basalts. Panels (b), (c) and (d) show how Fani Maoré lavas have low Nb/La and high Sr/Sr* and Eu/Eu* ratios compared to the other Comoros lavas. Due to fractionation of various mineral phases during differentiation, phonolites have low Ba/Th, Sr/Sr* and Eu/Eu* ratios and high Nb/La ratios compared to their basanitic counterparts at Petite Terre. New data are shown as dots and triangles while published data as downloaded from GeoRoc are shown as diamonds.

suggesting that the melting and fractionation processes that produced the lavas also remained unchanged for the duration of the volcano building. The three samples with slightly different trace element patterns were collected on the southern side of the volcano and we speculate that they could have been mixed with magmas similar to those produced along the volcanic ridge.

The most remarkable feature of the Fani Maoré lavas is their extreme Ba enrichment which is accompanied by smaller but still significant enrichments in Sr and Eu and large Pb depletion (Fig. 5), expressed by very high Ba/Th ratios at about 350 to 400 and Ce/Pb ratios between 60 and 70. These values can be compared with the usual OIB Ba/Th of about 100 and Ce/Pb of about 25 (Hofmann, 1986; Weaver, 1991). Producing these extreme values requires very unusual circumstances: they could be explained by secondary processes that affected the lavas after eruption, or by very unusual residual mineralogy during melting and/or fractional crystallization, or they could be due to melting of a peculiar source enriched in alkaline earth elements and depleted in Pb. Below we explore the various possibilities and we use constraints provided by trace elements and isotopic compositions to put forward the most likely interpretation.

5.1.1. *Could post-eruption processes explain the excess barium?*

Because lavas erupted at more than 3000 m water depth, they could have interacted with seawater and sediments at the eruption site. For example, if the lavas had digested sediments rich in baryte ($BaSO_4$), this could explain the excess Ba contents of the basanites. However, baryte forms a solid solution with celestine ($SrSO_4$) and given the origin of the baryte group, it is most likely that the Sr would originate from seawater and have its Sr isotopic composition. Digestion of sedimentary baryte $(Ba,Sr)SO_4$ by the erupting lavas would not only increase the Sr content of the lavas but would also shift the Sr isotopic compositions to more radiogenic values. Given the extremely constant Sr isotopic composition of Fani Maoré lavas and their unradiogenic value (0.703350±0.000018, 2SD) which is similar to those of Petite Terre basanites that lack Ba and Sr anomalies, and to other volcanic rocks in the Comoros Archipelago, such an interpretation is unlikely. This is confirmed by mixing calculations for Ba and Sr contents as well as Sr isotopes as shown in **Suppl Table 4**. In these calculations we constrain the Ba/Sr ratio of baryte by assuming that all the excess Ba and Sr seen in Fig. 4**b** for Fani Maoré basanites come from baryte ($(Ba,Sr)SO_4$). The mixing calculation demonstrates that about 0.5% of sedimentary baryte is necessary to account for the excess Ba and Sr present in the Fani Maoré lavas. We can then calculate its impact on the Sr isotopic composition of lavas. Using a seawater $^{87}Sr/^{86}Sr$ ratio of 0.70916 (Veizer et al., 1999) for baryte, we calculate that Fani Maoré lavas should have had an $^{87}Sr/^{86}Sr$ ratio of 0.7014 before contamination, an extremely low value that has never been reported in present-day volcanic rocks (**Suppl Table 4**). A supporting argument is the constancy at 0.102 ± 0.107‰ (2SD) of $\delta^{138/134}Ba$ values for lavas with or without Ba anomaly, a value within error of the mantle value. This value contrasts with the variable values, from −0.3‰ to +1.3‰, reported for seawater and baryte deposits (Charbonnier et al., 2018; Crockford et al., 2019; Middleton et al., 2023) (see **Sup Figure 3**). This suggests that interaction with seawater or digestion of sedimentary baryte cannot explain the barium excess in Fani Maoré lavas.

5.1.2. *Can unusual residual mineralogy explain the barium excess and the lead deficit?*

The presence of a residual phase during melting or crystallization can create negative anomalies in the resultant magma. This is the case for residual phlogopite or K-hollandite which create negative K and Ba anomalies in melts because of their high partition coefficients for these elements relative to those of Th, Nb or La (LaTourrette et al., 1995; Grassi et al., 2012; Suzuki et al., 2012). For example, Class and Goldstein (1997) suggested that the presence of residual phlogopite during melting could explain why lavas on La Grille, one of the Grande Comore volcanoes, have negative K and Ba anomalies while lavas erupted at another volcano, Karthala, do not. More recently, Zeng et al. (2021) argued that the large negative K, Ba and Pb anomalies of nephelinites from eastern China were due to residual K-hollandite during melting in the mantle transition zone. Fani Maoré basanites indeed have large negative K and Pb anomalies (**see** Fig. 4) but in contrast to La Grille volcanics and the eastern China nephelinites, they lack a negative Ba anomaly and instead have a large Ba positive anomaly. Residual phlogopite or K-hollandite are definitely not the best candidate to account for the large positive Ba anomaly.

Explaining a positive anomaly of a highly incompatible element is challenging. One possibility is that all neighboring elements in Fig. 4 are sequestered in one or more residual minerals, a situation that seems very unlikely considering the difference in geochemical behavior of elements such as Nb, Th, U, Rb and La. It would require an exceptional combination of residual phases, a situation that is extremely unlikely. We therefore need to explore other processes.

5.1.3. Can a CO_2-rich source explain the barium excess and the lead deficit?

One possibility is that the Ba excess (together with the excesses in Sr and Eu, see Figs. 4& 5) originate from the source. Assuming that part of the source consists in recycled oceanic crust, we can envision that alteration on the seafloor could have introduced baryte in the altered crust, as is the case at numerous hydrothermal sites (both black and white smokers) on the ocean floor (Griffith and Paytan, 2012). The presence of baryte in recycled altered oceanic crust would entrain an elevated Ba content into the mantle source; however, it would also have consequences on other chemical elements. For example, the sulfur and CO_2 contents in the source would be significantly increased and the Sr isotopic composition of the lavas would also be affected.

The CO_2 contents of Fani Maoré volcanic glasses have not yet been measured but other evidence exist to support high CO_2 contents in the lavas and their source. Sun and Dasgupta (2023) demonstrated recently that the primary melts of silica-poor alkaline OIBs are much richer in CO_2 than sub-alkaline lavas (3–11% versus 0–7%) and that their CO_2/Nb and CO_2/Ba ratios were much higher than in MORB (1850±196 and 226 ±22 (Sun and Dasgupta, 2023) versus 607±327 and 105±9 (Le Voyer et al., 2017)). We can estimate the amount of CO_2 present in Fani Maoré primary melts by using their Nb and Ba contents together with the ratios suggested by Sun and Dasgupta (2023). Berthod et al. (2021a) calculated that Fani Maoré erupted lavas resulted of 50% crystal fractionation of a mineral assemblage consisting in 20% olivine and 80% clinopyroxene. Using Adam and Green (2006) partition coefficients for Nb and Ba, we calculate a Nb primary melt content of about 65 ppm leading to a CO_2 content of about 12%, a value on the high side of the range suggested by Sun and Dasgupta (2023). Values calculated using Ba are similar for lavas without Ba anomaly and are of course higher for lavas with positive anomalies ($\geq$20%).

The presence of large quantities of CO_2 in Fani Maoré lavas is consistent with their extremely vesicular textures (Berthod et al., 2021a, 2022) and 'popping rocks' are very common (Feuillet et al., 2021). It also explains the large acoustic plume detected above the submarine volcano during the first scientific cruise (MAYOBS1) (see Figure 3 in Feuillet et al. (2021)) and the elevated concentrations of H_2, CH_4 and CO_2 measured in the plume above the flank of the volcano (Feuillet et al., 2021). Finally, indirect evidence of high CO_2 contents is the ubiquitous presence of large amounts of sulfur in the lavas, either as sulfides or as spherical droplets of iron sulfides in other minerals (Berthod et al., 2021a, 2022).

Chowdhury and Dasgupta (2020) demonstrated that melting of altered recycled oceanic crust produces carbonated silicate melts with much higher sulfur concentrations than normal silicate melts and that in these magmas, sulfide saturation occurs at much higher S concentration (SCSS>2500 ppm versus SCSS≈1500 ppm for MORB). They also show that assuming a 500 ppm S content in a recycled altered oceanic crust, low-degree melting of a carbonated source can only strip off a small proportion of the sulfur present in the recycled crust. Most sulfide remains in the residue. This has direct implications for the Pb content of the melts because Pb is highly compatible in sulfide ($K_D \approx 45$ according to Hart and Gaetani (2006)) and the melts should therefore be deprived in lead. This is indeed the case of Fani Maoré lavas which are marked by a large Pb deficit (3.2 ppm versus 5.9 ppm for other lavas and Ce/Pb ≈ 70 versus ≈ 35 for the other lavas, see Supp Fig 4a). The presence of residual sulfides in the source could not only explain the Pb deficit of Fani Maoré lavas (see Fig. 5) but it would also account for the copper contents of Fani Maoré basanites which are low relative to those of other basanites (**see Supp Table 1 and Supp Fig 4b**).

If baryte is present in the altered part of recycled oceanic crust in the mantle source, it will also impact the Sr isotopic composition of the lavas. Its impact on the Sr isotopic composition of the mantle source can be evaluated following the same line of reasoning as in Section 5.1.1 but here, we cannot assume that the baryte has a sedimentary origin. It could just as well have a hydrothermal origin and be formed by interaction between fluids and basaltic crust when the crust was present at the bottom of the ocean. Its Sr isotopic composition is therefore unknown but we can estimate its composition by doing a mass balance calculation similar to that presented in Section 5.1.1. Results are given in **supp Table 4**. Assuming an $^{87}Sr/^{86}Sr$ ratio of 0.70280 for the baryte-free recycled basalt and using the measured $^{87}Sr/^{86}Sr$ ratio of 0.70335 as the composition of the mixture, we calculate that the baryte has an $^{87}Sr/^{86}Sr$ ratio of 0.70497. Changing the $^{87}Sr/^{86}Sr$ ratio of the baryte-free recycled basalt at 0.70300 only modifies the baryte Sr isotopic ratio to 0.70438. Both values are much lower than what is presently reported for marine baryte (Paytan et al., 1993) suggesting that either it traces seawater at least as old as the Proterozoic (Prokoph et al., 2008) or it originates in hydrothermal vents where part of the strontium that precipitated came from a basaltic crust. In both cases, the proportion of baryte in the mantle source is about 0.005% (see supp Table 4) and it would add about 7.3 micrograms of sulfur in the source.

In summary, the presence of hydrothermally altered oceanic crust in the mantle source of Fani Maoré could explain its exceptional geochemical character. Melting of such source could produce carbonated silicate melts rich in CO_2 and S, and the presence of baryte in the source could explain the Ba and Sr excess of the lavas (see Supp Fig 5). In such source, sulfide might be residual during melting, leading to a lower-than-normal lead content in the liquid and higher-than-normal Ce/Pb ratios in erupted magmas.

5.2. Is the source of Fani Maoré exceptional or common among OIB?

Fig. 6 shows a compilation of Ba/Th and Ce/Pb ratios plotted as a function of SiO_2 for ocean island basalts. The figure clearly demonstrates that the elevated Ba/Th and Ce/Pb of Fani Maoré volcanics are exceptional. Given the large noise on the published data, it is difficult to quantify the difference between Fani Maoré lavas and lavas from other ocean islands but some general tendencies can be highlighted: while OIB have on average a Ba/Th ratio of 100 and a Ce/Pb ratio of 25 (Hofmann, 1986), Fani Maoré basanites average at 370 and 70. The only ocean island basalts with similarly elevated Ba/Th and Ce/Pb (≈160 and ≈48) come from Cape Verde and Fuerteventura in the Canaries islands, which are also the only ocean island chains where carbonatites have been found and it was also reported by Dixon et al. (2008) for Hawaiian rejuvenated lavas erupted at Niihau. Cape Verde carbonatites display extremely variable trace element patterns (Doucelance et al., 2010) but their average Ba/Th and Ce/Pb ratios are also high (≈ 400 and ≈ 70). Doucelance et al. (2003) did not discuss the elevated Ba/Th and Ce/Pb of the Cape Verde basalts and carbonatites but focused the discussion on the location and origin of the sources of magmas. Given the similarities between Cape Verde, Fuerteventura and Niihau rejuvenated basalts and Fani Maoré basanites, we suggest, as done by Dixon et al. (2008) for the Niihau rejuvenated basalts, that in all cases, a carbonated silicate melt

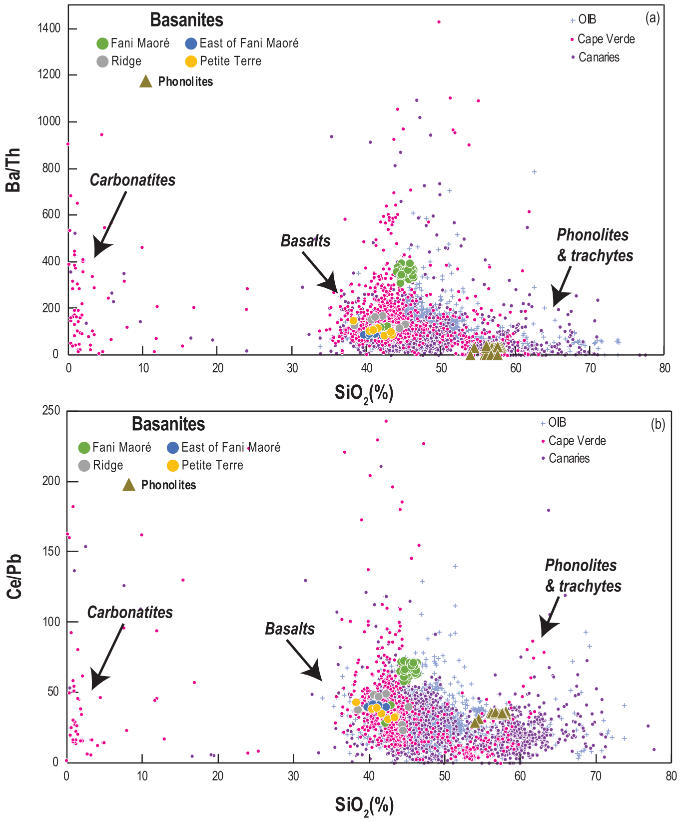

Fig. 6. Ba/Th and Ce/Pb ratios plotted as a function of SiO_2. The new data are compared to published data for ocean island basalts in general and Cape Verde in particular (the only known oceanic location where carbonatites have been reported) (database compiled from GEOROC and too large to be cited here). As is the case at Cape Verde, the Fani Maoré basanites have significantly higher Ba/Th and Ce/Pb ratios than other OIB.

produced basanites with exceptional geochemical characteristics. The presence of carbonatites on Cape Verde or Fuerteventura suggest that this type of lava might erupt on Fani Maoré or somewhere else along the Comoros archipelago.

Even if the Fani Maoré lavas are exceptional, similar carbonated sources could indeed be more common than previously thought. As discussed in Section 5.1.3, the CO_2 content of Fani Maoré primary melts is estimated at 12% using the CO_2/Nb ratio of Sun and Dasgupta (2023) and reaches values as high as 25% if calculated using their CO_2/Ba ratio. Here, we suggest that in such sources, sulfide might be residual during melting, leading to a deficit in lead in the liquid. This in turn, leads to higher-than-normal Ce/Pb ratios in erupted magmas. While Fani Maoré basanites have exceptionally high Ce/Pb ratios at ≈ 70, some other OIB also have high Ce/Pb. This is the case of typical HIMU OIB, which have Ce/Pb ratios higher than 30 (average of 35 for St Helena, 33 for Tubuai and Mangaia) and is also the case for islands such as the Canaries Islands (≈39), Mururoa and Fangataufa in the Gambier-Pitcairn chain (≈31) (Cordier et al., 2021) or Cape Verde Island (≈48) (Doucelance et al., 2010). Those islands are often referred to as 'young' HIMU islands because they share the same trace element characteristics as the HIMU islands (for example, high Ce/Pb) but they do not have the elevated Pb isotopic ratios of the HIMU islands ($^{206}Pb/^{204}Pb \geq 20$). As suggested originally by Vidal (1992), the source of 'young' HIMU islands is probably similar to that of HIMU islands but the age of the fractionation that created elevated U/Pb and Th/Pb ratios is not sufficiently old for enough radiogenic ^{206}Pb, ^{207}Pb and ^{208}Pb to be produced to translate into elevated Pb isotopic ratios.

In summary, based on combined petrological and geochemical constraints, a genetic link can be established between high carbon, high alkalinity and the distinctive trace element and isotopic characteristics of HIMU volcanics, suggesting that the source of such lavas contains recycled oceanic crust rich in volatiles. The presence of large quantities of carbon coupled to low degrees of melting facilitates the presence of residual sulfides and, as a consequence, high Ce/Pb ratios in the produced lavas .

5.3. Fani Maoré, Mayotte and the Comoros Archipelago

We demonstrated above that Fani Maoré basanites have very uniform geochemical and isotopic compositions. However, this composition is unique and not found at the other eruption sites in the Comoros Archipelago. Basanites sampled on the flank of Petite Terre, on the volcanic ridge located between Petite Terre and Fani Maoré, and east of Fani Maoré (see Fig. 2), generally have lower and more variable SiO_2 contents, more classical trace element patterns (see Figs. 3, 4& 5), similar but more variable radiogenic isotopes (see **Supp Table 1 and Supp Figure 1**), and importantly, they do not have Fani Maoré's large Ba excess and Pb deficit. With two exceptions, basanites other than those at Fani Maoré resemble basalts on the island of Mayotte, as described by Pelleter et al. (2014). This suggests that carbonated silicate melts occur in a sporadic manner and did not contribute significantly to liquids outside of the new volcano.

The restriction of phonolites to the flank of Petite Terre suggests that a pre-existing volcanic structure could have influenced the type of erupted products. Berthod et al. (2021b) discussed at length the processes involved in their genesis and concluded that the phonolites most probably formed by fractional crystallization of basanitic liquids. The new data presented in this study (**Supp Table 1**) fully support this interpretation. Indeed, phonolites have the same Sr and Nd isotopic composition as the basanites, suggesting that they share similar sources (see **Supp Figure 1**). Only small differences are seen in $^{176}Hf/^{177}Hf$ versus $^{143}Nd/^{144}Nd$ and $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ spaces (see **Supp Figures 1b&d**) where the phonolites have systematically higher $^{176}Hf/^{177}Hf$ and lower $^{207}Pb/^{204}Pb$ ratios than basanites. While the difference in Hf isotopes cannot be easily interpreted because of the lack of Hf isotopic data for Mayotte, the lower $^{207}Pb/^{204}Pb$ ratios resemble those of the Mayotte lavas reported by Späth et al. (1996) and Pelleter et al. (2014). We therefore suggest that during fractional crystallization at ≈17 km depth according to Berthod et al. (2021a), liquids interacted with the surrounding oceanic lithosphere. The assimilation-fractional crystallization process produced phonolites with lower $^{207}Pb/^{204}Pb$ and higher $^{176}Hf/^{177}Hf$ than the more primitive basanites.

When considering the Comoros Archipelago as a whole, it is now clear that no age progression exists between Mayotte at its eastern end and Grande Comore at its western end. The oldest lavas reported in the literature (Emerick and Duncan (1982); Emerick and Duncan (1983); Nougier et al. (1986)) were sampled at Mayotte at the eastern end of the archipelago adjacent to the youngest lavas on Fani Maoré (see also Fig. 1). The general concept of the archipelago being created on a moving plate above a fixed mantle plume clearly does not apply to the Comoros Archipelago and this requires another explanation. The first possible reason could be that a plume is absent below the archipelago but this is inconsistent with the seismic observations that clearly map a hot conduit under the Comoros (Dongmo Wamba et al., 2023). In addition, even if not a strong argument, lavas of the Comoros Archipelago have the same geochemical characteristics as ocean island basalts that are thought to be plume-derived, i.e., steeply sloping trace element patterns, the alkali nature of the magmas, and the same isotopic compositions. The origin of lavas in a hot rising plume that undergoes low-degree melting at depth is consistent with both geophysical and geochemical observations. A possible explanation for the lack of age progression along the chain is that the oceanic crust on which the archipelago rests did not move relative to the plume conduit. This is indeed quite possible given the general tectonic framework in the area (Phethean et al., 2016; Famin et al., 2020) and the location of the

Comoros Archipelago along a transfer zone between East Africa and Madagascar (Feuillet et al., 2021). In that area, the oceanic crust was most probably weakened and hot magmas were able to reach the surface at various places along the transfer zone.

5.4. *Where do magmas erupting in the Comoros archipelago come from?*

The geochemistry of the magmas erupted at Fani Maoré and at the various recent eruption sites located between Fani Maoré and Mayotte is very similar to that of intra-plate volcanic rocks such as ocean island basalts (see **Supp Figure 2** for their radiogenic isotopes). This suggests that the mantle source is located in the asthenosphere and that the process producing the lavas resembles that inferred for most ocean islands, i.e., hot mantle material partially melts as it approaches the overlying lithosphere. What is quite remarkable in the case of Fani Maoré is the rate of eruption (over 5 km^3 in less than a year, Feuillet et al. (2021)) of magmas that must have been produced by low degrees of melting, given their trace element enrichment and fractionated trace element patterns. This suggests that the rising material is continuously supplied under the eruption sites so that vast quantities of lavas could be produced within a short time. Such high magma productivity remains to be explained but the presence of vast amounts of CO_2 in the source and the rising magmas could potentially play a role.

A deep origin of the rising magmas is more difficult to establish and it could be connected either to the Réunion hotspot or to the East African plume. Several hints favor a common origin with magmas that erupted along the East African Rift. First, the Comoros archipelago has radiogenic isotope compositions clearly different from Réunion Island lavas (see Fig. 7) but overlapping with the East African Rift in Fig. 7. Similarly, the carbonatitic melts erupting along the East African Rift also have radiogenic isotopes similar to those reported for the Comoros lavas (this work and Späth et al. (1996), Class et al. (1998) and Pelleter et al. (2014) for example) (see Fig. 7). Finally, seismic tomographic maps of the mantle under the Archipelago show a hot zone linking the Comoros Archipelago and the East African Rift Zone (see **Supp Figure 4** and Dongmo Wamba et al. (2023)). These authors also point to a common source in a ponding zone located at about 1000 km depth (Dongmo Wamba et al., 2023). They not only argue that this deep ponding zone is large but they also suggest that it is separate from the zone that produces the magmas erupted in Réunion Island. Finally, they suggest that below the two ponding zones, two separate hot rising sources rose from the core mantle boundary. The ultimate source of the Comoros magmas might therefore be found at the core-mantle boundary, perhaps in the African Large Low Shear Velocity Province. Fig. 8 presents a sketch of the possible pathway of material producing the Comoros Archipelago within the mantle.

6. Conclusion

The geochemistry of Fani Maoré lavas in the Comoros Archipelago is exceptional and provides key elements to understand the nature of its source, its link with the East African Rift magmas and more generally a common origin with carbonatites and HIMU-type volcanoes.

Fani Maoré lavas are low degree melts with a strong alkaline flavor. There exceptional Ba excess and Pb deficit are features that have never been highlighted in any other ocean islands but that also occur in Cape Verde basanites and to a lesser extend at Fuerteventura in the Canaries and Niihau in the Hawaiian chain. We suggest that this peculiar geochemistry is due to the presence in the source of recycled hydrothermally-altered basaltic crust rich in baryte. Such material represents a carbonated mantle source that is enriched in Ba, CO_2 and S. Melting of such material provides the necessary excess barium and explains the lead deficit by having residual sulfides during low-degree partial melting in a high CO_2 environment.

More generally, similar types of recycled material can explain the occurrence of many types of volcanics: If the recycled oceanic crust is more heavily altered than in the Fani Maoré case, it produces carbonatites and if it contains less baryte than in the Fani Maoré case, it produces HIMU-like volcanics. A genetic link can therefore be established between carbonatites and HIMU ocean islands.

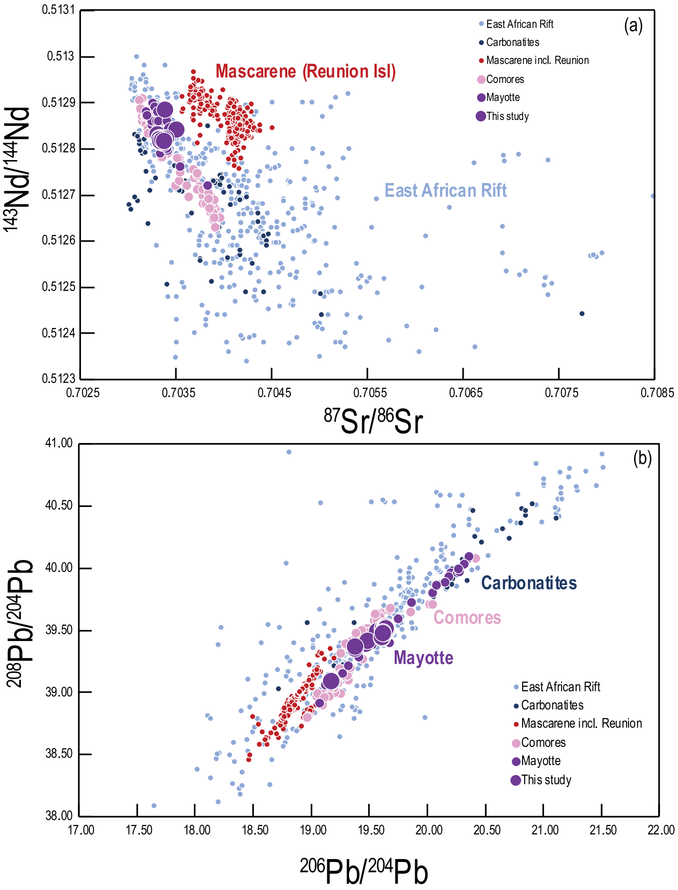

Fig. 7. $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ (panel a) and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ (panel b) plots. The new isotopic data obtained in this study resemble data published in literature for the various Comoros islands (Dupré and Allégre, 1983; Nougier et al., 1986; Späth et al., 1996; Class and Goldstein, 1997; Class et al., 1998; Deniel, 1998; Salters and White, 1998; Class et al., 2005; Pelleter et al., 2014). Data for East Africa and the Mascarene chain lavas are compiled from GeoRoc database. As a whole, both diagrams demonstrate that the radiogenic isotopes of Comoros lavas differ significantly from those reported for Réunion Island and other Mascarene lavas but overlap with those reported for basalts and carbonatites from the East African Rift zone.

CRediT authorship contribution statement

Catherine Chauvel: Writing – review & editing, Writing – original draft, Visualization, Supervision, Validation, Methodology, Investigation, Funding acquisition, Conceptualization, Data curation, Conceptualization. **Edward C. Inglis:** Writing – original draft, Writing – review & editing, Investigation, Methodology, Conceptualization. **Pamela Gutierrez:** Writing – original draft, Writing – review & editing, Methodology, Investigation, Validation, Formal analysis. **Tu-Han Luu:** Writing – original draft, Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Pierre Burckel:** Writing – original draft, Writing – review & editing, Methodology, Formal analysis, Data curation. **Pascale Besson:** Writing – original draft, Writing – review & editing, Validation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial

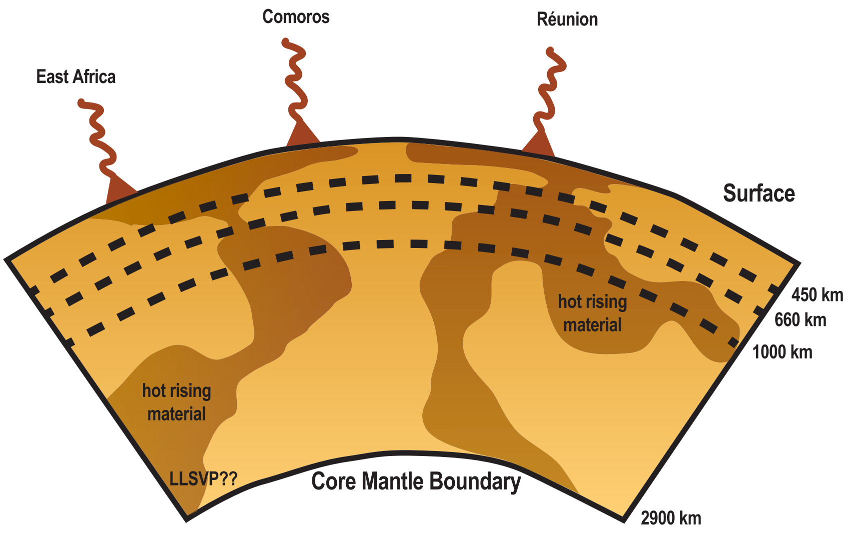

Fig. 8. Sketch of the pathway of hot rising material in the mantle, showing that Fani Maoré in the Comoros Archipelago shares the same source as the East African Rift while it is not the case for Réunion Island. The cartoon is inspired by the tomographic section of Dongmo Wamba et al. (2023) shown in Supp Fig. 4.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

data in the supplementary material

Acknowledgements

The MAYOBS campaigns were conducted by several French research institutions (IPGP/CNRS/BRGM/IFREMER/IPGS). We thank the captains and crews of the R/V Marion Dufresne and Pourquoi Pas?, and the mission chiefs of the MAYOBS campaigns (E. Rinnert, N. Feuillet, Y. Fouquet, S. Jorry, I. Thinon, E. Lebas, F. Paquet) for conducting marine operations that provided dredged samples. The authors thank the two reviewers (Nicole Williamson and Matt Jackson) whose comments contributed to clarify and improve the manuscript. The editor Rosemary Hickey-Vargas is thanked for her efficient handling of the submission. This work was financially supported by the ERC advanced grant SHRED awarded to CC (grant agreement n°833632) as well as by the Service National d'Observation en Volcanologie (SNOV, INSU) and the Réseau de Surveillance Volcanologique et Sismologique de Mayotte (REVOSIMA). Part of this work was supported by IPGP multidisciplinary program PARI, by the Region Ile-de-France SESAME Grants no. 12015908 and EX047016 and by the IdEx Université de Paris grant ANR-18-IDEX-0001.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.epsl.2023.118529.

References

Adam, J., Green, T., 2006. Trace element partitioning between mica- and amphibole-bearing garnet lherzolite and hydrous basanitic melt: 1. Experimental results and the investigation of controls on partitioning behaviour. Contrib. Mineral. Petrol. 152 (1), 1–17.

Bai, R., et al., 2022. Barium isotopes in ocean island basalts as tracers of mantle processes. Geochim. Cosmochim. Acta 336, 436–447.

Berthod, C., et al., 2022. Temporal magmatic evolution of the Fani Maoré submarine eruption 50 km east of Mayotte revealed by in situ sampling and petrological monitoring. Collect. C R Geosci. 354 (S2), 195–223.

Berthod, C., et al., 2021a. The 2018-ongoing Mayotte submarine eruption: Magma migration imaged by petrological monitoring. Earth Planet. Sci. Lett. 571, 117085.

Berthod, C., et al., 2021b. Mantle xenolith-bearing phonolites and basanites feed the active volcanic ridge of Mayotte (Comoros archipelago, SW Indian Ocean). Contributions to Mineralogy & Petrology 176 (10), 1-1-24.

Charbonnier, Q., Bouchez, J., Gaillardet, J., Gayer, É., 2020. Barium stable isotopes as a fingerprint of biological cycling in the Amazon River basin. Biogeosciences 17 (23), 5989–6015.

Charbonnier, Q., Moynier, F., Bouchez, J., 2018. Barium isotope cosmochemistry and geochemistry. Science Bulletin 63 (6), 385–394.

Chauvel, C., Bureau, S., Poggi, C., 2011. Comprehensive Chemical and Isotopic Analyses of Basalt and Sediment Reference Materials. Geostand. Geoanal. Res. 35 (1), 125–143.

Chowdhury, P., Dasgupta, R., 2020. Sulfur extraction via carbonated melts from sulfide-bearing mantle lithologies – Implications for deep sulfur cycle and mantle redox. Geochim. Cosmochim. Acta 269, 376–397.

Class, C., Goldstein, S.L., 1997. Plume-lithosphere interactions in the ocean basins: constraints from the source mineralogy. Earth Planet. Sci. Lett. 150, 245–260.

Class, C., Goldstein, S.L., Altherr, R., Bachèlery, P., 1998. The process of plume-lithosphere interactions in the ocean basins-the case of Grande Comore. J. Petrol. 39 (5), 881–903.

Class, C., Goldstein, S.L., Shirey, S.B., 2009. Osmium isotopes in Grande Comore lavas: A new extreme among a spectrum of EM-type mantle endmembers. Earth Planet. Sci. Lett. 284 (1), 219–227.

Class, C., Goldstein, S.L., Stute, M., Kurz, M.D., Schlosser, P., 2005. Grand Comore Island: A well-constrained "low 3He/4He" mantle plume. Earth Planet. Sci. Lett. 233 (3), 391–409.

Claude-Ivanaj, C., Bourdon, B., Allègre, C.J., 1998. Ra–Th–Sr isotope systematics in Grande Comore Island: a case study of plume–lithosphere interaction. Earth Planet. Sci. Lett. 164 (1), 99–117.

Cordier, C., Delavault, H., Chauvel, C., 2021. Geochemistry of the Society and Pitcairn-Gambier mantle plumes: What they share and do not share. Geochim. Cosmochim. Acta 306, 362–384.

Crockford, P.W., et al., 2019. Barium-isotopic constraints on the origin of post-Marinoan barites. Earth Planet. Sci. Lett. 519, 234–244.

Deniel, C., 1998. Geochemical and isotopic (Sr, Nd, Pb) evidence for plume–lithosphere interactions in the genesis of Grande Comore magmas (Indian Ocean). Chem. Geol. 144 (3), 281–303.

Dixon, J., Clague, D.A., Cousens, B., Monsalve, M.L., Uhl, J., 2008. Carbonatite and silicate melt metasomatism of the mantle surrounding the Hawaiian plume: Evidence from volatiles, trace elements, and radiogenic isotopes in rejuvenated-stage lavas from Niihau, Hawaii. Geochemistry, Geophysics, Geosystems 9 (9).

Dongmo Wamba, M., Montagner, J.P., Romanowicz, B., 2023. Imaging deep-mantle plumbing beneath La Réunion and Comores hot spots: Vertical plume conduits and horizontal ponding zones. Sci. Adv. 9 (4), eade3723.

Doucelance, R., Escrig, S., Moreira, M., Gariépy, C., Kurz, M.D., 2003. Pb-Sr-He isotope and trace element geochemistry of the Cape Verde Archipelago. Geochim. Cosmochim. Acta 67 (19), 3717–3733.

Doucelance, R., Hammouda, T., Moreira, M., Martins, J.C., 2010. Geochemical constraints on depth of origin of oceanic carbonatites: The Cape Verde case. Geochim. Cosmochim. Acta 74 (24), 7261–7282.

Dupré, B., Allégre, C.J., 1983. Pb-Sr isotope variation in Indian Ocean basalts and mixing phenomena. Nature 303, 142–146.

Emerick, C.M., Duncan, R.A., 1982. Age progressive volcanism in the Comores Archipelago, western Indian Ocean and implications for Somali plate tectonics. Earth Planet. Sci. Lett. 60 (3), 415–428.

Emerick, C.M., Duncan, R.A., 1983. Errata. Earth Planet. Sci. Lett. 62 (3), 439.

Esson, J., Flower, M.F.J., Strong, D.F., Upton, B.G.J., Wadsworth, W.J., 1970. Geology of the Comores Archipelago, Western Indian Ocean. Geological Magazine 107 (6), 549–557.

Famin, V., Michon, L., Bourhane, A., 2020. The Comoros archipelago: a right-lateral transform boundary between the Somalia and Lwandle plates. Tectonophysics 789, 228539.

Feuillet, N., et al., 2021. Birth of a large volcanic edifice offshore Mayotte via lithosphere-scale dyke intrusion. Nat. Geosci. (10), 787–795. https://doi.org/10.1038/s41561-021-00809-x.

Feuillet, N., Jorry, S., Rinnert, E., Thinon, I., Fouquet, Y., 2019. MAYOBS1 cruise, RV Marion Dufresne. https://doi.org/10.17600/18001217.

Fouquet, Y., Feuillet, N., 2019. MAYOBS4 cruise, RV Marion Dufresne. https://doi.org/10.17600/18001238.

Grassi, D., Schmidt, M.W., Günther, D., 2012. Element partitioning during carbonated pelite melting at 8, 13 and 22 GPa and the sediment signature in the EM mantle components. Earth Planet. Sci. Lett. 327-328, 84–96.

Griffith, E.M., Paytan, A., 2012. Barite in the ocean – occurrence, geochemistry and palaeoceanographic applications. Sedimentology 59 (6), 1817–1835.

Hart, S.R., Gaetani, G.A., 2006. mantle Pb paradoxes: the sulfide solution. Contrib. Mineral. Petrol. 152, 295–308.

Hofmann, A.W., 1986. Nb in Hawaiian magmas: constraints on source composition and evolution. Chem. Geol. 57, 17–30.

Jorry, S., 2019. MAYOBS2 cruise, RV Marion Dufresne. https://doi.org/10.17600/18001222.

LaTourrette, T., Hervig, R.L., Holloway, J.R., 1995. Trace element partitioning between amphibole, phlogopite, and basanite melt. Earth Planet. Sci. Lett. 135 (1), 13–30.

Le Voyer, M., Kelley, K.A., Cottrell, E., Hauri, E.H., 2017. Heterogeneity in mantle carbon content from CO2-undersaturated basalts. Nat. Commun. 8 (1), 14062.

McDonough, W.F., Sun, S.S., 1995. The composition of the Earth. Chem. Geol. 120, 223–253.

Michon, L., 2016. The Volcanism of the Comoros Archipelago Integrated at a Regional Scale. In: Bachelery, P., Lenat, J.F., Di Muro, A., Michon, L. (Eds.), Active Volcanoes of the Southwest Indian Ocean: Piton de La Fournaise and Karthala. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 333–344.

Michon, L., Famin, V., Quidelleur, X., 2022. Evolution of the East African Rift System from trap-scale to plate-scale rifting. Earth Sci. Rev. 231, 104089.

Middleton, J.T., Paytan, A., Auro, M., Saito, M.A., Horner, T.J., 2023. Barium isotope signatures of barite–fluid ion exchange in Equatorial Pacific sediments. Earth Planet. Sci. Lett. 612, 118150.

Nougier, J., Cantagrel, J.M., Karche, J.P., 1986. The Comores archipelago in the western Indian Ocean: volcanology, geochronology and geodynamic setting. J. Afr. Earth Sci. 5 (2), 135–145 (1983).

Paytan, A., Kastner, M., Martin, E.E., Macdougall, J.D., Herbert, T., 1993. Marine barite as a monitor of seawater strontium isotope composition. Nature 366 (6454), 445–449.

Pelleter, A.A., et al., 2014. Melilite-bearing lavas in Mayotte (France): An insight into the mantle source below the Comores. Lithos 208-209, 281–297.

Phethean, J.J.J., et al., 2016. Madagascar's escape from Africa: A high-resolution plate reconstruction for the Western Somali Basin and implications for supercontinent dispersal. Geochem. Geophys. Geosyst. 17 (12), 5036–5055.

Prokoph, A., Shields, G.A., Veizer, J., 2008. Compilation and time-series analysis of a marine carbonate δ18O, δ13C, 87Sr/86Sr and δ34S database through Earth history. Earth Sci. Rev. 87 (3), 113–133.

Quidelleur, X., et al., 2022. Holocene volcanic activity in Anjouan Island (Comoros archipelago) revealed by new Cassignol-Gillot groundmass K–Ar and 14C ages. Quat. Geochronol. 67, 101236.

Rinnert, E. et al., 2019. MAYOBS. https://doi.org/10.18142/291.

Rinnert, E., Thinon, I., Feuillet, N., 2020. MD 228/MAYOBS15 cruise. RV Marion Dufresne. https://doi.org/10.17600/18001745.

Salters, V.J.M., White, W.M., 1998. Hf isotope constraints on mantle evolution. Chem. Geol. 145, 447–460.

Späth, A., Roex, A.P.L., Duncan, R.A., 1996. The geochemistry of lavas from the Comores archipelago, western Indian ocean: petrogenesis and mantle source region characteristics. J. Petrol. 37 (4), 961–991.

Sun, C., Dasgupta, R., 2023. Carbon budget of Earth's deep mantle constrained by petrogenesis of silica-poor ocean island basalts. Earth Planet. Sci. Lett. 611, 118135.

Suzuki, T., Hirata, T., Yokoyama, T.D., Imai, T., Takahashi, E., 2012. Pressure effect on element partitioning between minerals and silicate melt: Melting experiments on basalt up to 20 GPa. Phys. Earth Planet. Inter. 208-209, 59–73.

Veizer, J., et al., 1999. 87Sr/86Sr, δ13C and δ18O evolution of Phanerozoic seawater. Chem. Geol. 161 (1), 59–88.

Vidal, P., 1992. Mantle: more HIMU in the future? Geochim. Cosmochim. Acta 56, 4295–4299.

Weaver, B.L., 1991. Trace element evidence for the origin of ocean-island basalts. Geology 19, 123–126.

Zeng, G., et al., 2021. Nephelinites in eastern China originating from the mantle transition zone. Chem. Geol. 576, 120276.