

Discovery of young submarine volcanism in the Cook Islands: New constraints on the location of the Rarotonga hotspot

Yifan Du^{a,*}, Matthew G. Jackson^a, Brian Jicha^b, Andrew Kylander-Clark^a, Benjamin L. Byerly^a, Michael Bizimis^c, Sæmundur Ari Halldórsson^d, Gareth G.E. Seward^a, Olivia E. Anderson^a, Matthew Rioux^a, Kevin Konrad^e, Sunna Harðardóttir^a, Ruixia Bai^a, Andrea Giuliani^f, Douglas A. Wiens^g, S. Shawn Wei^h, Gerald McCormackⁱ, John Michael Parianos^j

^a Department of Earth Science, University of California Santa Barbara, Santa Barbara, CA 93106, USA

^b Department of Geoscience, University of Wisconsin–Madison, 1215 West Dayton Street, Madison, WI 53706, USA

^c School of the Earth, Ocean, and Environment, University of South Carolina, 701 Sumter Street, EWS 617, Columbia, SC 29208, USA

^d Nordic Volcanological Centre, Institute of Earth Sciences, University of Iceland, 102 Reykjavík, Iceland

^e College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, USA

^f Earth and Planets Laboratory, Carnegie Institution for Science, Washington, DC 20015, USA

^g Department of Earth, Environmental, and Planetary Sciences, Washington University in St. Louis, Saint Louis, MO 63130, USA

^h Department of Earth and Environmental Sciences, Michigan State University, East Lansing, MI 48824, USA

ⁱ Cook Islands Natural Heritage Trust, Rarotonga, Cook Islands

^j Cook Islands Seabed Minerals Authority, Rarotonga, Cook Islands

ARTICLE INFO

Associate editor: James M.D. Day

Keywords:

OIB
Hotspots
Cook–Austral
Rarotonga
Geochemistry
Geochronology

ABSTRACT

A multiple-hotspot origin has been proposed for the Cook–Austral volcanic lineament in the southwest (SW) Pacific. One candidate, the Rarotonga hotspot, is associated with volcanism on only two islands: Rarotonga (1.157 ± 0.003 to 1.697 ± 0.055 Ma) and Aitutaki (youngest stage: 1.382 ± 0.058 to 1.941 ± 0.035 Ma), located ~ 250 km apart in a north–south (N–S) direction. Their overlapping eruption ages and lack of clear age progression preclude a robust evaluation of a hotspot origin. This study identifies and investigates a new volcanic feature, Tama Seamount—located ~ 80 km east–southeast (ESE) of Rarotonga Island along a Pacific plate flowline—potentially associated with the Rarotonga hotspot. New ages from two lavas ($^{40}\text{Ar}/^{39}\text{Ar}$ groundmass ages: 0.664 ± 0.027 and 0.816 ± 0.020 Ma) and from a nepheline syenite xenolith—including zircon U–Pb dating (weighted mean age: 0.74 ± 0.02 Ma) and a biotite $^{40}\text{Ar}/^{39}\text{Ar}$ age (0.730 ± 0.007 Ma)—constrain Tama’s age. These ages align with a Rarotonga hotspot age progression based on Pacific plate motion, and support a Rarotonga hotspot origin for Tama. We also report on the first lava samples dredged from the submarine flanks of Rarotonga Island, which exhibit geochemical fingerprints and an age (1.493 ± 0.007 Ma) consistent with those of previous Rarotonga samples. Furthermore, radiogenic isotopes of Tama samples in this study overlap with existing Rarotonga Island data, supporting a genetic relationship between Tama Seamount and Rarotonga Island. Together, these new results suggest Tama Seamount represents the youngest known expression of the Rarotonga hotspot.

1. Introduction

Volcanic hotspot tracks, such as those observed in Hawaii (Fig. 1), occur when oceanic plates move over upwelling mantle plumes (Morgan, 1971). The mantle plume model for volcanic hotspots predicts

that the age of hotspot volcanism progressively increases in the direction of plate motion (i.e., presently west–northwest [WNW] on the Pacific plate). Additionally, an active hotspot volcano is expected to be located above the mantle plume. The relationship between the age of the hotspot-derived volcanoes and their distance from the youngest or

* Corresponding author.

E-mail address: ydu823@ucsb.edu (Y. Du).

<https://doi.org/10.1016/j.gca.2025.12.058>

Received 17 July 2025; Accepted 28 December 2025

Available online 29 December 2025

0016-7037/© 2025 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

currently active volcano is known as the age progression of the hotspot (Fig. 2).

The Cook–Austral volcanic lineament in the southwest Pacific is a linear volcanic chain with ages ranging from zero to 20 Ma (Chauvel et al., 1997; Lassiter et al., 2003; Figs. 1 and 2). However, no single, clear age progression is observed for hotspot volcanism along this lineament. Instead, several loci of active or young (<2 Ma) volcanism occur along the volcanic lineament, spaced roughly 1,000 km apart (Figs. 1 and 3), including Macdonald Seamount (Diraison, 1991; Johnson and Malahoff, 1971), Arago Seamount (Bonneville et al., 2006), and Rarotonga and Aitutaki Islands (Turner and Jarrard, 1982; Rose and Koppers, 2019).

Building on earlier work by Diraison (1991), Chauvel et al. (1997) proposed a “three-hotspot” model to explain the absence of a single age

progression along the Cook–Austral volcanic lineament, identifying three distinct volcanic age progressions (Macdonald, Rurutu–Arago, and Rarotonga) which align with models for regional plate motion velocity (Rose and Koppers, 2019; Figs. 1 and 3). Critically, all three hotspots are associated with mantle potential temperatures exceeding ambient mantle (Bao et al., 2022), supporting a model in which all three hotspots are fed by thermally buoyant plumes.

Further supporting the three-hotspot model, seamounts in the Cretaceous Western Pacific Seamount Province (WPSP) (Figs. 1 and 2)—which approximately coincide geographically with the reconstructed hotspot tracks using absolute plate motion models—exhibit ages and geochemical signatures associated with the three proposed hotspots in the Cook–Austral Islands (Konter et al., 2008; Konrad et al., 2018;

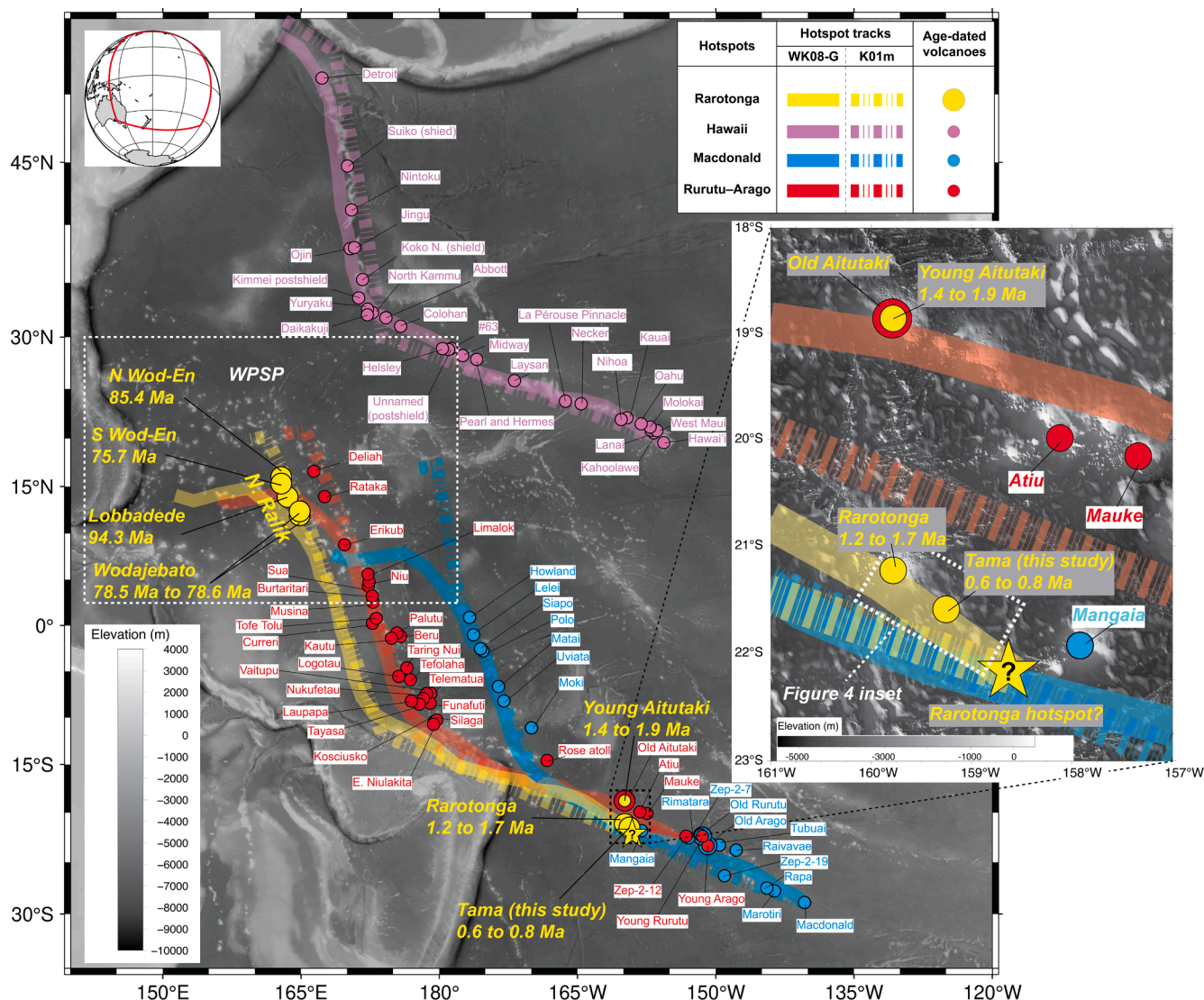


Fig. 1. Bathymetric map (GEBCO Compilation Group, 2024; GMRT compilation, Ryan et al., 2009) illustrating the Hawaii hotspot (purple) and three proposed hotspot tracks in the Cook–Austral region: Macdonald (blue), Rurutu–Arago (red), and Rarotonga (yellow). Modified from Konrad et al. (2018), Jackson et al. (2020), Konter et al. (2025), and references therein. Age-dated volcano data for the Hawaii, Macdonald, Rurutu–Arago, and Rarotonga hotspots are compiled from Jackson et al. (2024) and references therein. The outline for WPSP is after Rose and Koppers (2019). Colored bands represent reconstructed hotspot tracks based on two absolute plate motion models: WK08-G (solid lines; Wessel and Kroenke, 2008) and K01m (dashed lines; Konter et al., 2025). Circles mark age-dated volcanoes along each hotspot track, colored to match their respective hotspot. When multiple eruptive stages are present at a single volcano, the symbol for the older stage is larger and the younger stage is smaller. The Macdonald hotspot track is anchored to Macdonald Seamount. The current Rurutu–Arago hotspot location follows Konter et al. (2025). The present-day Rarotonga hotspot location is estimated to lie on a Pacific plate flowline ~140–200 km ESE of Rarotonga Island, based on the age of Rarotonga lavas (1.16–1.70 Ma; Rose and Koppers, 2019) and Pacific plate motion in the region (~120 km/Ma; Wessel and Kroenke, 2008). A yellow star labeled with a “?” marks the estimated hotspot location at ~170 km ESE of Rarotonga Island on the map. Ages and volcano names for the North Raliks are also shown (Koppers et al., 2007).

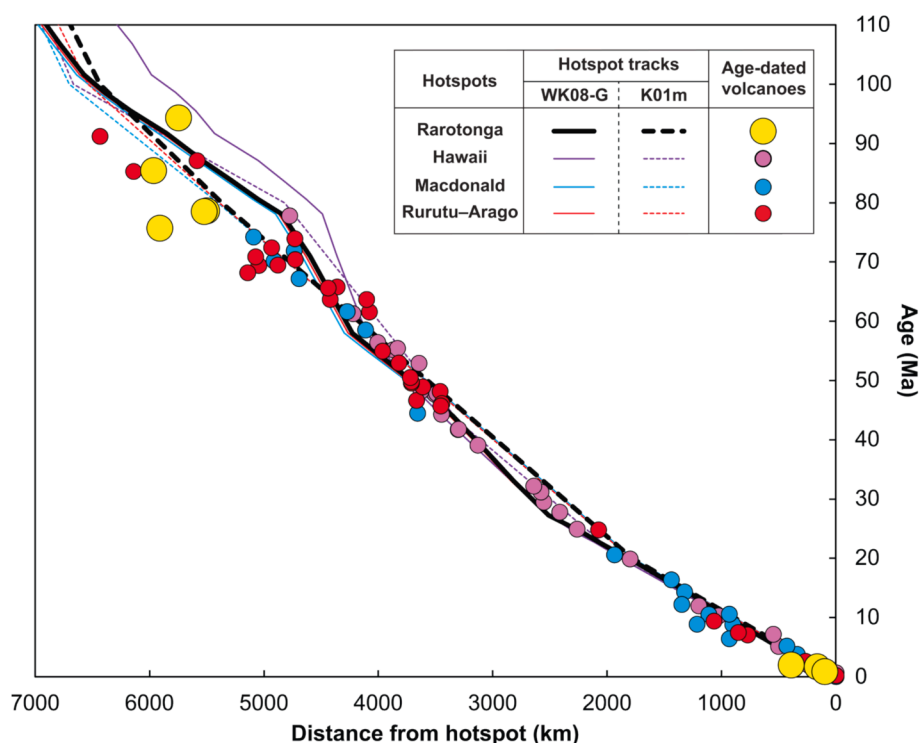


Fig. 2. Age versus distance relationships (age progressions) for volcanoes in the Hawaii hotspot and the three hotspots in the Cook–Austral volcanic lineament. Modified after Jackson et al. (2024) and references therein. Age data are compiled from Konrad et al. (2018), Jackson et al. (2024), and Konter et al. (2025). Two absolute plate motion models—WK08-G (solid lines; Wessel and Kroenke, 2008) and K01m (dashed lines; Konter et al., 2025)—are shown for comparison. Details on hotspot locations are provided in Fig. 1 caption.

Finlayson et al., 2018; Jackson et al., 2024; Konter et al., 2025). The links between the Cretaceous seamounts from the WPSP and the 0–20 Ma volcanic lineament suggest that all three hotspots in the Cook–Austral Islands are long-lived (Figs. 1 and 2).

There are still aspects of the three-hotspot model for the Cook–Austral volcanic lineament that are not well understood (Figs. 2 and 3). Critically, large geographic regions remain unsampled and uncharacterized along all three hotspot tracks. Recently, Buff et al. (2021) reported that Rose Atoll (24.8 ± 1.0 Ma) and possibly Moki Seamount (44.5 ± 10.1 Ma) fill significant geographic gaps between the younger portions (the Cook–Austral volcanic lineament) and the older Cretaceous segments of the Rurutu–Arago and Macdonald hotspots, respectively (Fig. 2). However, the age of Moki Seamount is imprecise and therefore does not conclusively link it to the Macdonald hotspot. Nonetheless, even with this potentially unfilled gap in the Macdonald hotspot track, there is growing evidence that at least two long-lived hotspots—Rurutu–Arago and Macdonald—have been active since at least ~70 Ma and ~100 Ma, respectively (Koppers et al., 2007; Konter et al., 2008; Finlayson et al., 2018; Konrad et al., 2018; Konter et al., 2025).

The third hotspot track in the Cook–Austral volcanic lineament—the Rarotonga hotspot (Chauvel et al., 1997)—consists of only two closely spaced (~250 km) volcanic islands that exhibit recent, overlapping periods of volcanism based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating: Rarotonga Island (1.157 ± 0.003 to 1.697 ± 0.055 Ma) and the young stage of volcanism on Aitutaki Island (1.382 ± 0.058 to 1.941 ± 0.035 Ma) (Rose and Koppers, 2019). Thus, no hotspot age progression is observed in the currently available data for this proposed hotspot, precluding a critical evaluation of a hotspot origin (Figs. 2 and 3). While the 76–94 Ma seamounts (Koppers et al., 2007; Konter et al., 2008) in the North Ralik group of the WPSP have ages, locations, and geochemistry that tentatively link them to the Rarotonga hotspot (Jackson et al., 2024), one would have to accept a ~75 Myr gap in this hotspot track between Rarotonga Island and the youngest Ralik Seamount, which remains

unsampled and uncharacterized. Another critical data gap in the putative Rarotonga hotspot track is the absence of an identified active volcano or of any volcanism younger than Rarotonga Island. Using the absolute plate motion model of Wessel and Kroenke (2008), the Rarotonga hotspot is predicted to be located 140–200 km ESE of Rarotonga Island along a Pacific plate flowline that accounts for the 1.16–1.70 Myr of Pacific plate motion since lavas at Rarotonga Island erupted (the star with “?” in Fig. 1 provides the estimated location of the Rarotonga hotspot).

To search for evidence of volcanic activity younger than that on Rarotonga Island along the Rarotonga hotspot track, we conducted dredge operations in the Cook Islands region aboard the R/V *Thomas G. Thompson* (cruise TN426) in December 2023 (Fig. 4). We targeted a small seamount—named *Tama* (which translates to “child” in Cook Islands Māori)—for dredging because it is the largest volcanic structure located on a Pacific plate flowline ~80 km ESE of Rarotonga Island (see location of Dredge 12 of the expedition in Fig. 4). In a subsequent dredge, we obtained the first samples of the submarine flanks of Rarotonga Island.

We present new Sr–Nd–Pb isotopic data, major and trace element concentrations, as well as geochronological data ($^{40}\text{Ar}/^{39}\text{Ar}$ on groundmass and biotite, and U–Pb on zircon) on samples obtained by dredging of these two volcanoes to test the existence of younger volcanism associated with the putative Rarotonga hotspot. The deep-sea dredge at *Tama* Seamount recovered both lava and diverse xenoliths representing different parts of the lithosphere, including peridotite (mantle), gabbro (mid-ocean ridge basalt [MORB] crust), ocean island basalt (OIB) lavas, and OIB-related xenoliths (sampling the surface and volcanic interior of *Tama* Seamount). Recovered syenite xenoliths (OIB-related) are notable for containing zircon and biotite, which, together with the host lava groundmass, provide robust age constraints on the *Tama* Seamount. This study also reports, for the first time, oceanic crust xenoliths from this region—an important finding for understanding SW Pacific geodynamics, as the oceanic crust here was formed during the

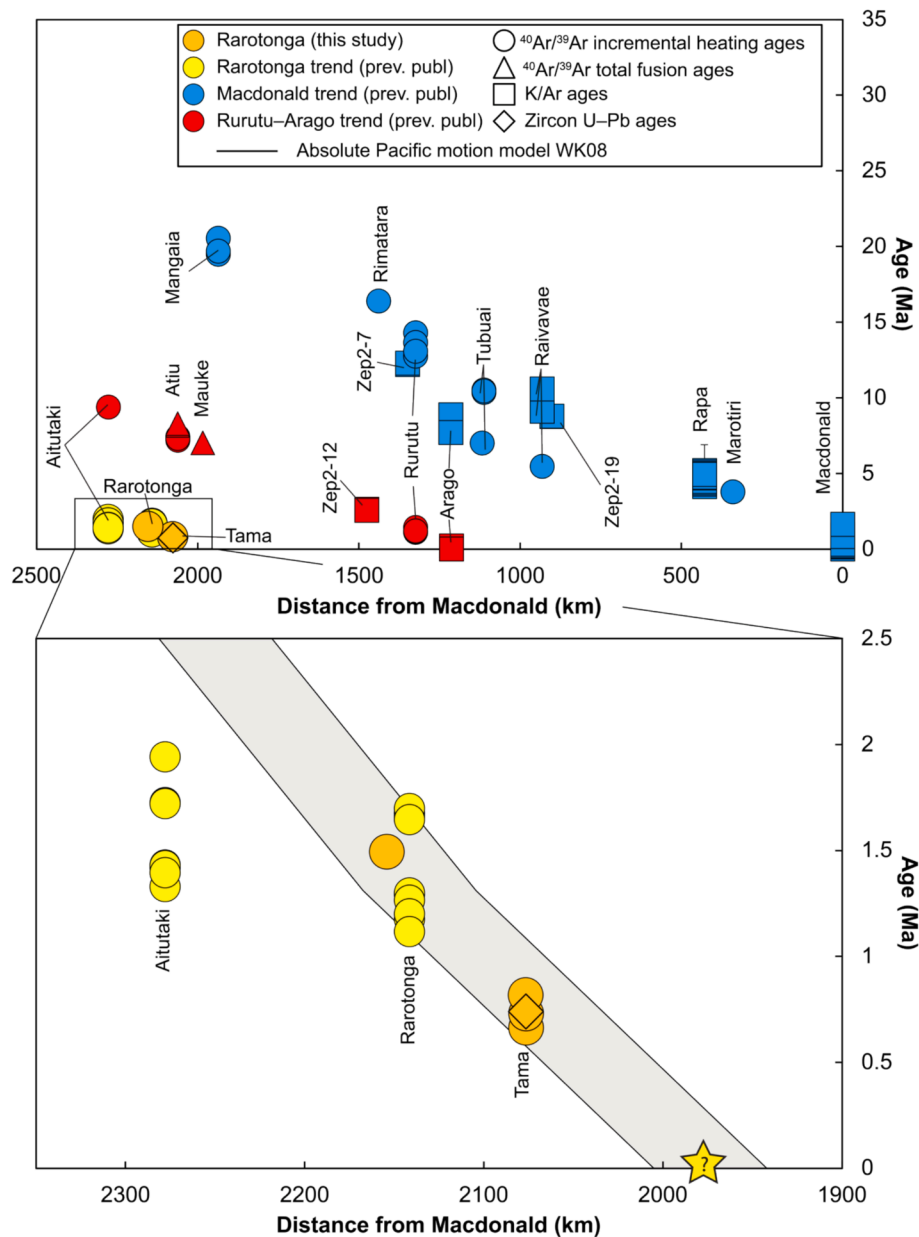


Fig. 3. Age progressions in the Cook–Austral volcanic lineament, showing islands and seamounts associated with the Macdonald (blue symbols), Rurutu–Arago (red symbols), and Rarotonga (yellow [previously published] and orange [this study] symbols) hotspots. Distances (x-axis) are calculated from Macdonald Seamount. Modified after Jackson et al. (2020) and Rose and Koppers (2019), and references therein. Previously published ages shown in the figure are compiled from Rose and Koppers (2019) and references therein. Two published ages from Rarotonga—DT77-R-9 (1.521 ± 0.007 Ma) and DT77-R-1 (1.533 ± 0.009 Ma)—were excluded due to their relatively short plateaus compared to other Rarotonga samples. The grey band in the lower panel shows the WK08-G hotspot track reconstruction; the width of the grey band coincides with the uncertainty of the Rarotonga hotspot track (i.e., as defined by the oldest and youngest $^{40}\text{Ar}/^{39}\text{Ar}$ plateau ages from Rarotonga Island lavas, which bracket the upper and lower bounds of the grey band, respectively). The yellow star marks the estimated location of the Rarotonga hotspot, and is located ~ 170 km ESE (i.e., the average of 140 km and 200 km) of Rarotonga Island (see Fig. 1 caption for calculation of current Rarotonga hotspot location). The oldest Tubuai sample (sample ID: 6 K989-R03, 16.7 ± 0.6 Ma, plateau age, 1σ ; Hanyu et al., 2013) and a Mitiaaro sample (sample ID: MIT-60C, 12.3 ± 0.4 Ma, 1σ ; Turner and Jarrard, 1982) were excluded by Rose and Koppers (2019) due to poor quality and are therefore excluded from this figure and our discussion.

Cretaceous Normal Superchron. The new geochemical data from both Tama lavas and xenoliths show that Tama Seamount has isotopic compositions consistent with derivation from the Rarotonga hotspot. The geochronological data reveal that the Tama Seamount is significantly younger than Rarotonga Island and lies on an age progression consistent with Pacific plate velocity, extending the Rarotonga age progression approximately 80 km ESE of Rarotonga Island. The geochemical and temporal relationships provide strong evidence for a Rarotonga hotspot origin and support the hypothesis that Rarotonga may represent an age-progressive hotspot, supporting the “three-hotspot” model in the

Cook–Austral Islands.

2. Geological background and new samples

Previous studies have identified multiple hotspots—Macdonald, Rurutu–Arago, and Rarotonga—that produced overlapping volcanic tracks in the region of the Cook–Austral volcanic lineament in the SW Pacific, and these hotspots generated three distinct age versus distance trends (Figs. 2 and 3). Notably, some islands exhibit multiple episodes of volcanism attributed to different hotspots. For example, the older

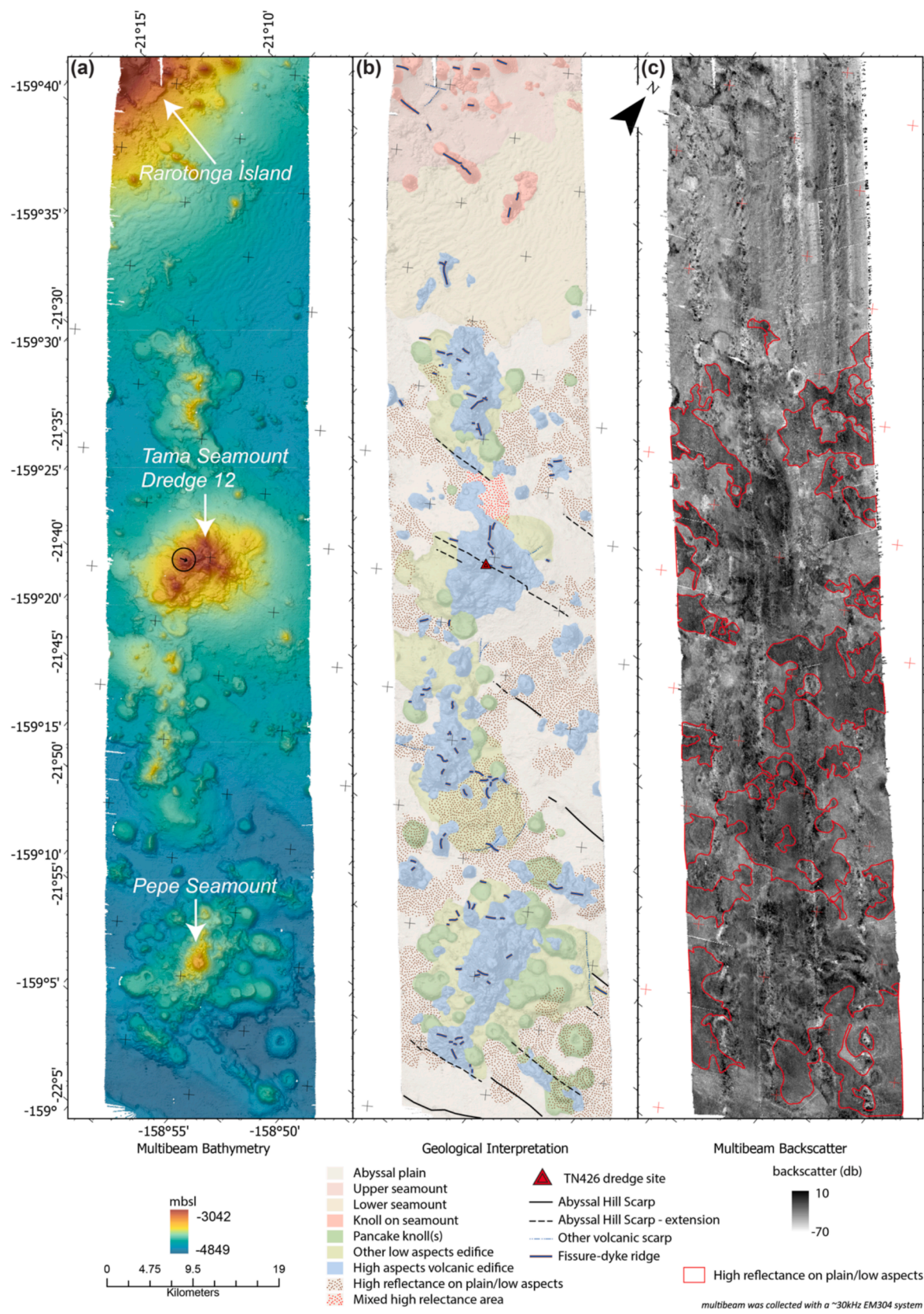


Fig. 4. Seafloor maps of the study area. (a) Seafloor bathymetric map of the studied area, showing locations of Rarotonga Island (sampled in this study), Tama Seamount (sampled in this study), and Pepe Seamount (not yet sampled). The map shown here was generated aboard the MV Anuanua Moana, and this seafloor mapping expedition took place after our dredging expedition. Thus, Pepe was not yet mapped at the time of our expedition and was therefore not targeted for dredging. The black arrow shows the Tama dredge track (DR12) and is encompassed by a black circle. (b) Geological interpretation of the studied area. (c) Seafloor backscatter map, where darker tones indicate higher reflectivity. Red outlines show the interpreted limits of the higher reflectivity zones.

volcanic stage on Aitutaki Island (9.39 ± 0.07 Ma) is attributed to the Rurutu–Arago hotspot, while a younger stage (1.382 ± 0.058 to 1.941 ± 0.035 Ma) of volcanism on Aitutaki Island is linked to the putative Rarotonga hotspot (Figs. 1 and 3; ages compiled from Rose and Koppers, 2019). Arago Seamount (Bonneville et al., 2006) and Rurutu Island (Chauvel et al., 1997) are two additional examples of volcanoes that have contributions from two different Cook–Austral hotspots. The geochronology and geochemistry of hotspot volcanoes in this region have been comprehensively reviewed by previous studies (Rose and Koppers, 2019; Jackson et al., 2020).

The geological setting of Rarotonga Island was thoroughly reviewed by Turner and Jarrard (1982) and is briefly summarized here. As the youngest island in the Cook Islands, Rarotonga is characterized by a steeply dissected volcanic shield with a large caldera. Unlike other islands in the region, it is surrounded by limited coral reefs. The sub-aerial portion of Rarotonga Island was recently dated by Rose and Koppers (2019) using the $^{40}\text{Ar}/^{39}\text{Ar}$ method, yielding ages ranging from 1.157 ± 0.003 to 1.697 ± 0.055 Ma. Here we present the first sampling of volcanic rocks collected from the submarine flanks of Rarotonga Island. Unlike Rarotonga Island, Tama Seamount has never been sampled prior to this study, and here we also report the first samples obtained from this seamount.

The submarine samples in this study include both lavas ($n = 2$ from Tama and $n = 2$ from Rarotonga) and xenoliths ($n = 6$ from Tama) that were collected by dredging during the TN426 seagoing expedition. Supplementary Table S1 provides dredge locations, modal mineralogy, and sample descriptions for the samples with new $^{40}\text{Ar}/^{39}\text{Ar}$ ages and zircon U–Pb ages, radiogenic isotope data, and major and trace element concentrations presented in this study. Supplementary Fig. S1 shows plane-polarized light (PPL) and crossed-polarized light (XPL) images of thin sections for all samples reported here.

The Rarotonga and Tama dredge samples include silica-undersaturated lavas from Tama Seamount (two foidites; Fig. 5) and Rarotonga Island (two tephrites; Fig. 5), as well as a suite of xenoliths

from Tama Seamount. The xenoliths from Tama Seamount comprise OIB-type igneous rocks (two nepheline syenites and a hornblende), two MORB-like tholeiites (a gabbro and a fine-grained basalt), and a peridotite.

3. Methods

The complete methods used in this study are provided in the Supplementary Materials and are briefly summarized here. Geochronological characterization of the dredged samples in this study was conducted on three lavas—two lavas from Tama Seamount (TN426-D12-4-lava and TN426-D12-44-X16-lava) and one from Rarotonga Island (TN426-D14-13-lava)—and one nepheline syenite xenolith from Tama Seamount (TN426-D12-4-xenolith) that is hosted within the TN426-D12-4-lava. Lava groundmass ages were determined using $^{40}\text{Ar}/^{39}\text{Ar}$ incremental heating methods at the WiscAr Lab, University of Wisconsin–Madison. Additionally, biotite grains from the nepheline syenite xenolith (TN426-D12-4-xenolith) were selected for a $^{40}\text{Ar}/^{39}\text{Ar}$ age determination at WiscAr Lab after preliminary Rb–Sr isotopic data collected at ETH Zurich showed insufficient ingrowth of radiogenic Sr for successful dating. Zircon U–Pb ages from the same xenolith (TN426-D12-4-xenolith) were obtained at the Petrochronology Lab at the University of California, Santa Barbara (UCSB).

Radiogenic isotopic compositions for Nd and Pb (using a double-spike method; Baker et al., 2004) were measured using Thermal Ionization Mass Spectrometry (TIMS) at UCSB, and Sr isotope analyses were conducted at the University of South Carolina using Multi-Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS).

Major and trace element analyses were conducted at the University of Iceland using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), respectively. The analyses of geologic reference materials (BCR-2, BHVO-1, BHVO-2, AGV-2, BIR-1, W-2), which were treated as unknowns and analyzed alongside the samples presented here, are

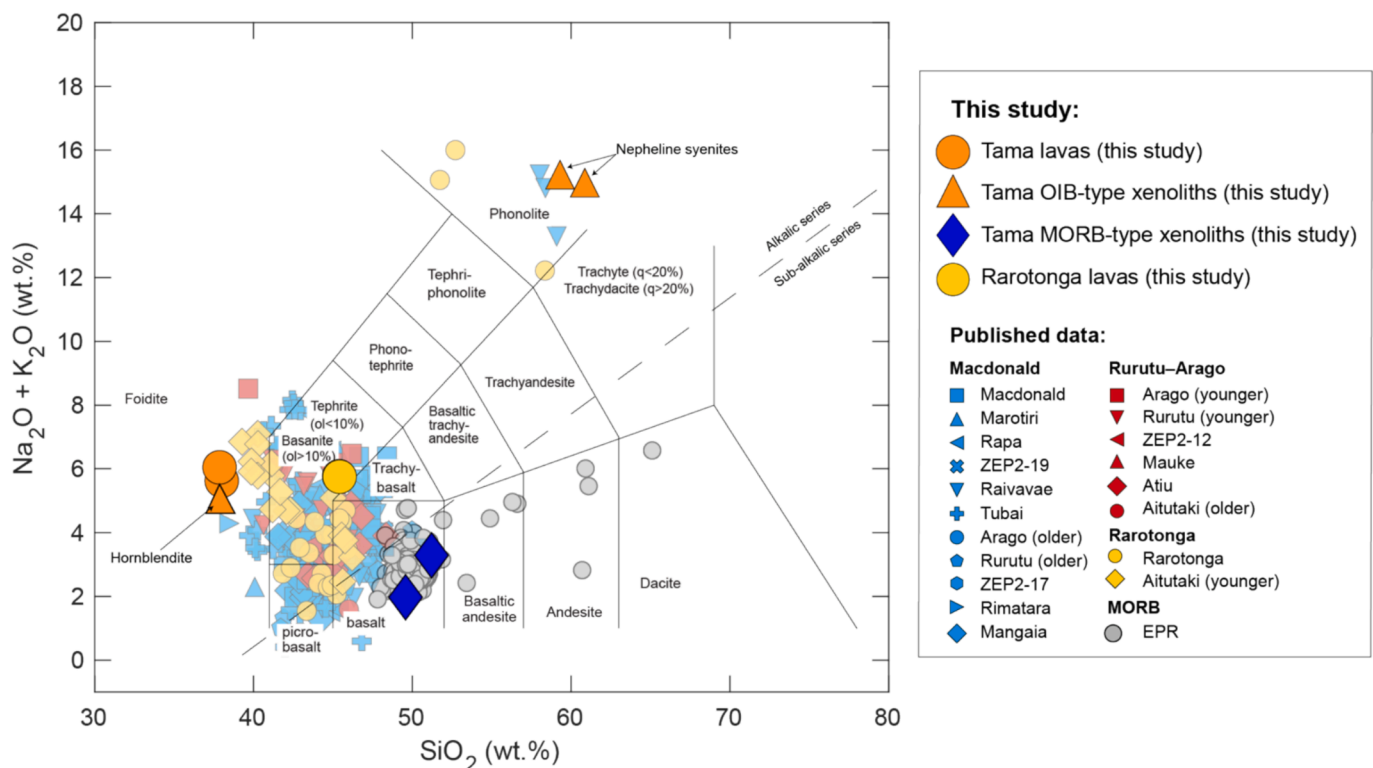


Fig. 5. Total alkali–silica (TAS) diagram of igneous samples in this study. Reference groups compiled by Harðardóttir and Jackson (2025; no filter applied). East Pacific Rise (EPR) MORB compiled from Gale et al. (2013; no filter applied).

provided in [Supplementary Table S2](#).

4. Results

4.1. Major and trace element data

4.1.1. Tama and Rarotonga lavas

The four dredged lavas reported here—two from Tama Seamount (TN426-D12-4-lava and TN426-D12-4-X16-lava) and two from Rarotonga Island (TN426-D14-11-lava and TN426-D14-13-lava)—are silica-undersaturated: the Tama lavas are foidites, and the Rarotonga lavas are tephrites (see [Fig. 5](#) for TAS plot and [Supplementary Table S2](#) for the complete dataset). The Tama lavas have MgO ranging from 7.6 to 7.7 wt%, and the two Rarotonga lavas have MgO ranging from 7.8 to 8.0 wt% ([Supplementary Fig. S2a](#)).

The Tama lavas exhibit K, Pb, and Ti depletion and slight depletion in Zr and Hf. These patterns closely resemble some of the previously published lavas from Rarotonga and Aitutaki (see [Fig. 6a](#) for spider diagram), which display a broadly similar spidergram shape to the Tama lavas reported here (Rarotonga data compiled from [Harðardóttir and Jackson, 2025](#)). The new Rarotonga lavas reported here do not exhibit the same strong K, Pb, and Ti depletions, nor do they exhibit comparable levels of Zr and Hf depletion. The shape of the spidergrams of the new Rarotonga lavas is similar to some of the previously observed lavas at Rarotonga and Aitutaki (see [Fig. 6a](#) for spider diagram).

4.1.2. Tama xenoliths

The three types of xenoliths dredged from Tama Seamount—OIB-type igneous rocks, MORB-type igneous rocks, and peridotitic rocks—exhibit variable mineralogy and trace element characteristics. Two of the OIB-type xenoliths from Tama Seamount are nepheline syenites, with SiO₂ contents ranging from 59.3 to 60.9 wt%, and MgO contents ranging from 0.6 to 1.0 wt% ([Supplementary Fig. S2a](#)).

One of the analyzed nepheline syenite xenoliths (i.e., TN426-D12-4-xenolith) displays large positive Zr and Hf anomalies (relative to similarly compatible trace elements)—consistent with the observed presence of zircon in this xenolith (see Section 6.1 of the [Supplementary Materials](#))—as well as positive Ba, K, and Sr anomalies ([Fig. 6b](#)). In contrast, the other nepheline syenite xenolith (i.e., TN426-D12-44-X5-xenolith) is also enriched in Ba, K, and Sr but shows negative anomalies for Zr and Hf, consistent with the absence of zircon (see Section 6.1 of the [Supplementary Materials](#)). Both samples exhibit conspicuous negative Ti anomalies.

The third OIB-type xenolith, sample TN426-D12-38-xenolith, is a hornblende (37.9 wt% SiO₂ and 9.6 wt% MgO; [Supplementary Fig. S2a](#)), and is enriched in incompatible elements and exhibiting mild negative anomalies for U, K, Pb, Sr, and Ti ([Fig. 6c](#); see Section 6.2 of the [Supplementary Materials](#)).

The two MORB-type xenoliths—which have radiogenic isotopes that place them within the field for East Pacific Rise (EPR) lavas (see [Section 4.3](#))—are the only tholeiites in this study. They plot squarely within the field for basaltic tholeiites from the EPR from the [Gale et al. \(2013\)](#) database ([Fig. 5](#)). These two MORB-like samples have MgO contents ranging from 7.1 to 8.5 wt% ([Supplementary Fig. S2a](#)). Significantly, these MORB-like xenoliths have trace element patterns with shapes that are similar to EPR lavas ([Fig. 6d](#)). The MORB-like gabbro (TN426-D12-43-xenolith) has a slight positive Sr anomaly, typical for MORB gabbros that have accumulated plagioclase, whereas the MORB-like basalt (TN426-D12-21-xenolith) has a slight negative Sr anomaly, not unlike EPR MORB. Similar to many EPR lavas, the two MORB xenoliths both show Ba, K, and Pb depletion relative to elements of similar mantle compatibility ([Fig. 6d](#)).

The peridotite xenolith (sample TN426-D12-28-xenolith) from Tama Seamount has a (La/Sm)_N of 4.5 (where “N” indicates normalization to primitive mantle from [McDonough and Sun, 1995](#)) and La concentrations ~6.5 times the primitive mantle (PM) value. It also displays a

spoon-shaped rare earth element pattern on the spider diagram ([Supplementary Fig. S3](#)).

4.2. Geochronology

4.2.1. Zircon U–Pb age

Complete U–Pb age data on zircon grains separated from the nepheline syenite xenolith (TN426-D12-4-xenolith) can be found in [Supplementary Table S3](#). Spot analyses were ²⁰⁷Pb-corrected using the Isoplot Add-in for Microsoft Excel ([Ludwig, 2012](#)) and corrected for initial ²³⁰Th disequilibrium ([Mattinson, 1973](#); [Schärer, 1984](#)), following the equation of [McLean et al. \(2011\)](#). We used an estimated melt Th/U ratio of 5.36, based on the average of the observed range of Th/U in volcanic rocks from the Rarotonga hotspot (Th/U ranges from 4.33 to 7.05; [Supplementary Materials](#)). The ²⁰⁷Pb-corrected and ²³⁰Th-corrected spot analyses yield a weighted mean age of 0.74 ± 0.02 Ma (2σ, n = 30), where the reported uncertainty includes the analytical uncertainty, uncertainty associated with the ²³⁰Th-correction, and the long-term reproducibility of the UCSB lab added in quadrature. See [Fig. 7](#) and [Section 2](#) of the [Supplementary Materials](#) for additional details.

4.2.2. ⁴⁰Ar/³⁹Ar Age Data

The ⁴⁰Ar/³⁹Ar age determinations in this study are summarized in [Table 1](#), with complete datasets provided in [Supplementary Table S4](#) and associated plots shown in [Fig. 8](#) and [Supplementary Fig. S4](#). Groundmass was separated from TN426-D12-4-lava and TN426-D12-44-X16-lava from dredge 12 of Tama Seamount, as well as dredge 14 lava sample TN426-D14-11-lava (Rarotonga Island). Biotite was separated from the zircon-bearing nepheline syenite xenolith (TN426-D12-4-xenolith) hosted in lava sample TN426-D12-4-lava. All the experiments yielded long plateaus (73.2 %–81.8 % of ³⁹Ar released; see [Fig. 8](#) and [S4](#)). Each experiment produced ⁴⁰Ar/³⁶Ar inverse isochron intercepts within uncertainty of atmospheric values ([Supplementary Fig. S4](#)), and therefore the plateau ages are preferred for each sample and used in the subsequent discussion ([Fig. 8](#)).

Tama Seamount lava sample TN426-D12-4-lava yielded a groundmass ⁴⁰Ar/³⁹Ar age of 0.664 ± 0.027 Ma ([Fig. 8a](#)), which is the youngest known age for an igneous rock in the Cook Islands. This is younger than the xenolith (i.e., TN426-D12-4-xenolith) hosted in the same lava, which has a zircon ²³⁸U/²⁰⁶Pb age of 0.74 ± 0.02 Ma; biotite separated from the same xenolith (TN426-D12-4-xenolith) has a ⁴⁰Ar/³⁹Ar age of 0.730 ± 0.007 Ma ([Fig. 8b](#)), which agrees (within uncertainty) with the weighted mean zircon ²³⁸U/²⁰⁶Pb age of 0.74 ± 0.02 Ma. As the xenolith was entrained by the lava, it is appropriate for the age of the xenolith to be older than the host lava.

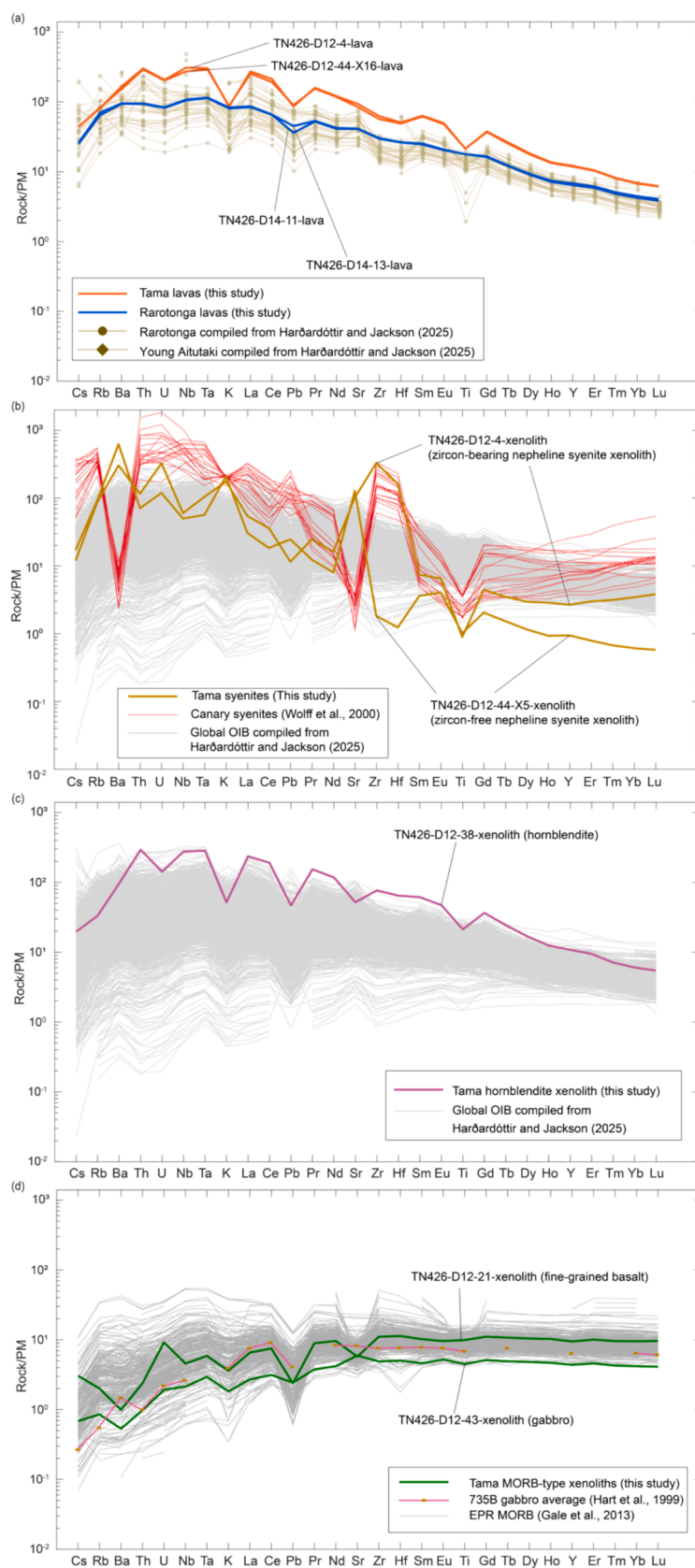
A second Tama Seamount lava sample, TN426-D12-44-X16-lava, yielded a groundmass ⁴⁰Ar/³⁹Ar age of 0.816 ± 0.020 Ma ([Fig. 8c](#)), which is older than the other Tama sample (TN426-D12-4-lava) and the xenolith ages.

The lava from Rarotonga Island (TN426-D14-11-lava) provides a ⁴⁰Ar/³⁹Ar age of 1.493 ± 0.007 Ma ([Fig. 8d](#)). This is within the age range of ⁴⁰Ar/³⁹Ar plateau ages previously reported for subaerial Rarotonga Island lavas (1.157–1.697 Ma; [Rose and Koppers, 2019](#)).

4.3. Radiogenic isotope data

4.3.1. Tama and Rarotonga lavas

The new radiogenic isotope data for the Rarotonga and Tama samples are summarized in [Supplementary Table S2](#). The two lava samples from Tama Seamount—including the 0.664 ± 0.027 Ma lava sample TN426-D12-4-lava and the 0.816 ± 0.020 Ma sample TN426-D12-44-X16-lava—display limited isotopic variation, ranging from 0.704481 to 0.704485 for ⁸⁷Sr/⁸⁶Sr, from 0.512664 to 0.512670 for ¹⁴³Nd/¹⁴⁴Nd, and from 18.235 to 18.237 for ²⁰⁶Pb/²⁰⁴Pb ([Fig. 9](#)). Tama lava samples plot within the fields of published data for lavas from Rarotonga Island. Like lavas from Rarotonga, the two Tama Seamount lavas exhibit



(caption on next page)

Fig. 6. (a) Primitive-mantle normalized trace element pattern or “spider diagram” for lava samples from Tama Seamount and Rarotonga Island analyzed in this study. Published Rarotonga and Aitutaki lava data are shown for comparison and are compiled from [Harðardóttir and Jackson \(2025\)](#). (b) Spider diagram for nepheline syenite xenoliths from Tama Seamount in this study. Syenites from the Canary hotspot ([Wolff et al., 2000](#)) are shown for comparison. (c) Spider diagram for the hornblende xenolith analyzed in this study. (d) Spider diagram for MORB xenoliths analyzed in this study. Tm data for EPR MORB are calculated as follows: $Tm_{MORB,N} = (Er_{MORB,N} \cdot Yb_{MORB,N})^{0.5}$ (N represents normalization to primitive mantle values from [McDonough and Sun, 1995](#)). All data are normalized to primitive mantle values ([McDonough and Sun, 1995](#)). Global OIB data shown in panels (b) through (c) are compiled elsewhere ([Harðardóttir and Jackson, 2025](#)) using a strictly filtered dataset based on trace element measurements (whole rock, glass, or groundmass) by ICP-MS. Specifically, samples were excluded if they had MgO < 5 wt% or no MgO values, no reported values for LOI, Ba/Rb, Ce/Ce*, or Y/Y*, or if they exhibited LOI > 4 wt%, Ba/Rb < 6 or > 50, Ce/Ce* < 0.8 or > 1.2, or Y/Y* < 0.7 or > 1.3. EPR MORB data and 735B gabbro average are compiled from [Gale et al. \(2013\)](#) and [Hart et al. \(1999\)](#), respectively.

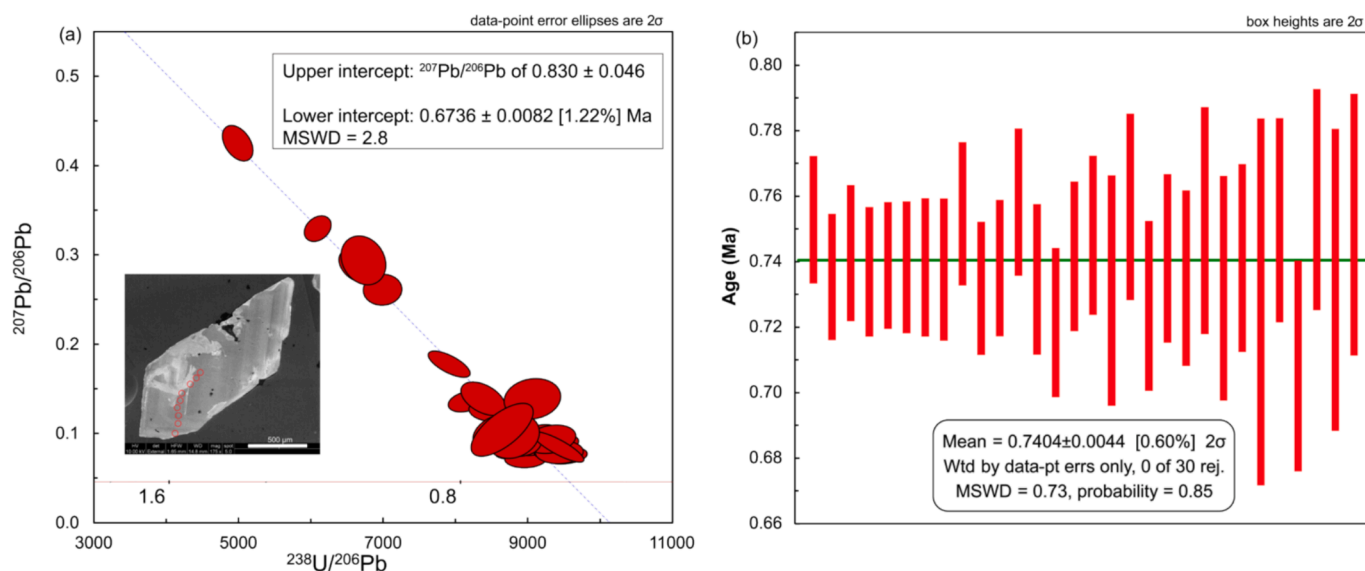


Fig. 7. Zircon U–Pb ages for the Tama Seamount nepheline syenite xenolith (sample TN426-D12-4-xenolith). (a) Tera–Wasserburg diagram for new zircon U–Pb data from sample TN426-D12-4-xenolith; red circles shown on the CL image mark laser ablation spots on a representative zircon grain. (b) ^{207}Pb - and ^{230}Th -corrected weighted mean zircon date using a common Pb composition of $^{207}\text{Pb}/^{206}\text{Pb} = 0.830 \pm 0.046$ from the Tera–Wasserburg plot (calculated in panel a) and assuming a melt Th/U ratio of 5.36 (i.e., the Rarotonga hotspot average; see [Supplementary Materials Section 2](#) and [Supplementary Fig. S5](#) caption), yields a date of 0.7404 ± 0.0044 Ma (MSWD = 0.73, probability = 0.85; see [Supplementary Table S3](#)). Because the upper intercept of the Tera–Wasserburg diagram overlaps with the bulk-rock $^{207}\text{Pb}/^{206}\text{Pb}$ (within uncertainty), we continue to use the upper intercept for common lead correction. When the range in the Th/U ratios (ranging from 4.33 to 7.05) in Rarotonga hotspot lavas is propagated through the reported age—together with the analytical uncertainty and the long-term reproducibility of the secondary standards—the resulting weighted mean age is 0.74 ± 0.02 Ma (2σ , $n = 30$) (see [Supplementary Materials Section 2](#)). All plots were generated using the Isoplot Excel Add-in ([Ludwig, 2012](#)).

Table 1

Summary of geochronological results in this study.

Sample #	Volcano	Method	Age (Ma) $\pm 2\sigma$	MSWD
TN426-D12-4-lava	Tama	Groundmass $^{40}\text{Ar}/^{39}\text{Ar}$	0.664 ± 0.027	0.89
TN426-D12-4-xenolith	Tama	Biotite $^{40}\text{Ar}/^{39}\text{Ar}$	0.730 ± 0.007	0.66
TN426-D12-4-xenolith	Tama	Zircon U–Pb	0.74 ± 0.02	0.72
TN426-D12-44-X16-lava	Tama	Groundmass $^{40}\text{Ar}/^{39}\text{Ar}$	0.816 ± 0.020	0.87
TN426-D14-11-lava	Rarotonga	Groundmass $^{40}\text{Ar}/^{39}\text{Ar}$	1.493 ± 0.007	0.88

moderate EM1 (Enriched Mantle 1) characteristics.

The radiogenic isotope compositions of the two newly dredged lavas from Rarotonga Island—including the 1.493 ± 0.007 Ma sample TN426-D14-11-lava—also exhibit limited radiogenic isotopic variation: $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range from 0.704340 to 0.704341, $^{143}\text{Nd}/^{144}\text{Nd}$ ratios range from 0.512711 to 0.512712, and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios range from 18.460 to 18.461 ([Fig. 9](#)). The two Rarotonga dredge samples plot within the field for previously reported lavas from Rarotonga Island ([Fig. 9](#)).

4.3.2. Tama xenoliths

The xenoliths from Tama Seamount exhibit considerable lithologic and isotopic variability. We categorize the xenoliths into three groups based on their lithology and geochemistry, as discussed above:

OIB-type xenoliths. The first group comprises xenoliths interpreted to be magmatic in origin that have OIB-type signatures. This group includes a nepheline syenite xenolith (TN426-D12-4-xenolith, with a zircon age of 0.74 ± 0.02 Ma), a second nepheline syenite xenolith (TN426-D12-44-X5-xenolith), and a hornblende (TN426-D12-38-xenolith). Their lithologies are summarized in [Supplementary Table S1](#). They have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.704433 to 0.704475, $^{143}\text{Nd}/^{144}\text{Nd}$ ratios ranging from 0.512645 to 0.512664, and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios ranging from 18.272 to 18.277. In Sr, Nd, and Pb radiogenic isotope spaces, all three Tama xenoliths plot within or close to the field for Rarotonga hotspot lavas defined in previous studies ([Fig. 9](#)).

MORB-type xenoliths. The second group of Tama xenoliths is igneous in origin and includes two MORB-type samples, TN426-D12-21-xenolith and TN426-D12-43-xenolith. Both xenoliths exhibit depleted radiogenic Sr and Nd isotope signatures ($^{87}\text{Sr}/^{86}\text{Sr} = 0.702495\text{--}0.702759$; $^{143}\text{Nd}/^{144}\text{Nd} = 0.513010\text{--}0.513126$) and unradiogenic Pb compositions ($^{206}\text{Pb}/^{204}\text{Pb} = 18.547\text{--}18.589$). These two xenoliths have isotopic compositions that plot well outside the field for

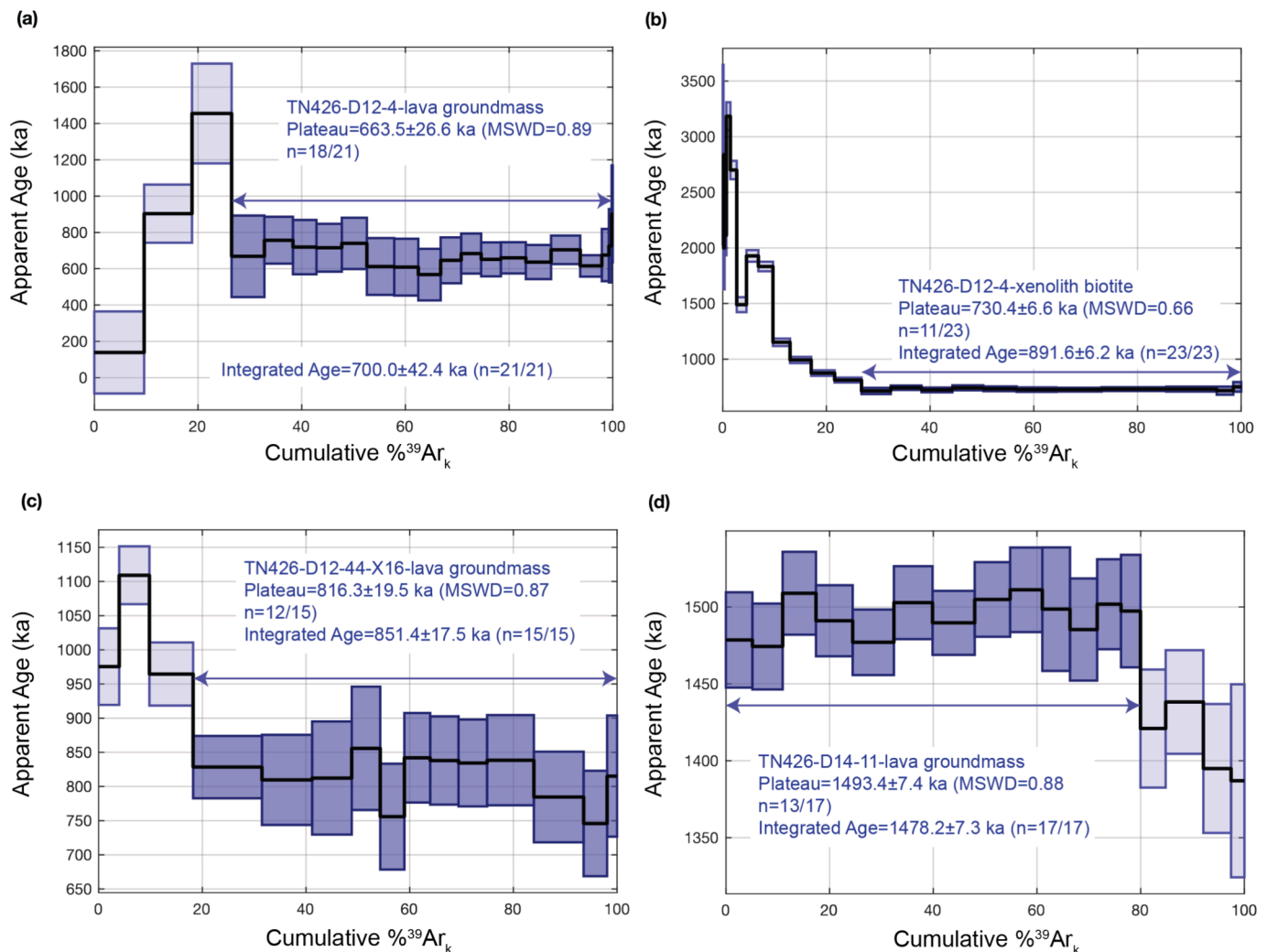


Fig. 8. Apparent age versus Cumulative % $^{39}\text{Ar}_k$ for (a) TN426-D12-4-lava groundmass, (b) TN426-D12-4-xenolith biotite, (c) TN426-D12-44-X16-lava groundmass, (d) TN426-D14-11-lava groundmass. The biotite $^{40}\text{Ar}/^{39}\text{Ar}$ age from TN426-D12-4-xenolith (0.7304 ± 0.0066 Ma) agrees with the U–Pb zircon age (i.e., 0.74 ± 0.02 Ma; Fig. 7) from the same xenolith.

Rarotonga hotspot lavas but overlap with MORB erupted at the EPR (Fig. 9).

Peridotite-type xenoliths. The third group of Tama xenoliths consists of a single harzburgite xenolith, TN426-D12-28-xenolith. The radiogenic isotope signatures for this xenolith include $^{87}\text{Sr}/^{86}\text{Sr} = 0.704470$, $^{143}\text{Nd}/^{144}\text{Nd} = 0.512644$, and $^{206}\text{Pb}/^{204}\text{Pb} = 18.310$. This peridotite xenolith plots within or close to the fields defined by Rarotonga hotspot lavas in Sr, Nd, and Pb radiogenic isotope spaces (Fig. 9).

5. Discussion

We characterized new samples from Tama Seamount and Rarotonga Island to evaluate the three-hotspot hypothesis in the Cook–Austral region. While the Macdonald and Rurutu–Arago hotspot trends are well defined (Fig. 2), suggesting the presence of active hotspots anchoring both hotspot tracks, Rarotonga has been considered a weaker candidate for a hotspot. In prior work (Chauvel et al., 1997; Jackson et al., 2020), the putative Rarotonga hotspot was thought to consist only of Rarotonga Island (and possibly the young-stage volcanism on Aitutaki Island), and thus, to date, there has been no strong evidence to support the existence of an active hotspot near Rarotonga. In the following sections, we discuss the geochemical and geochronological implications of the new samples from Tama Seamount and Rarotonga Island, and the evidence they provide for a Rarotonga hotspot origin.

5.1. Geochemistry of the new Tama lavas and associated xenoliths

The radiogenic isotope compositions obtained for lavas from dredge 12 (Tama Seamount) and dredge 14 (Rarotonga Island) in this study are similar to those of previously reported Rarotonga Island lavas (Fig. 9; Jackson et al., 2020, and references therein). Additionally, the trace element patterns of the new lavas (but not the xenoliths) from both Tama Seamount and Rarotonga Island are similar to published Rarotonga lavas (Fig. 6a). Although isotopic similarity alone cannot confirm a common hotspot origin, the geochemical, temporal, and spatial relationships between Tama Seamount and Rarotonga Island are consistent with derivation from a broadly similar mantle source at the same hotspot (see discussion in Section 5.2).

The OIB-type xenoliths and the peridotite xenolith from Tama Seamount also have similar radiogenic isotopic compositions to those of their host basalts, suggesting that they derived from the same mantle source as Rarotonga Island lavas (Fig. 9). The enriched REE pattern of the peridotite xenolith is consistent with metasomatism, a process commonly observed in the oceanic lithosphere (e.g., Hauri et al., 1993).

It is notable that the Tama Seamount lavas carried a varied xenolith cargo that includes peridotites (sampling the mantle portion of the oceanic lithosphere), MORB-type igneous rocks (crustal portion of the oceanic lithosphere), and coarse-grained OIB-type igneous rocks (sampling the volcanic interior of the seamount). Thus, the Tama xenolith

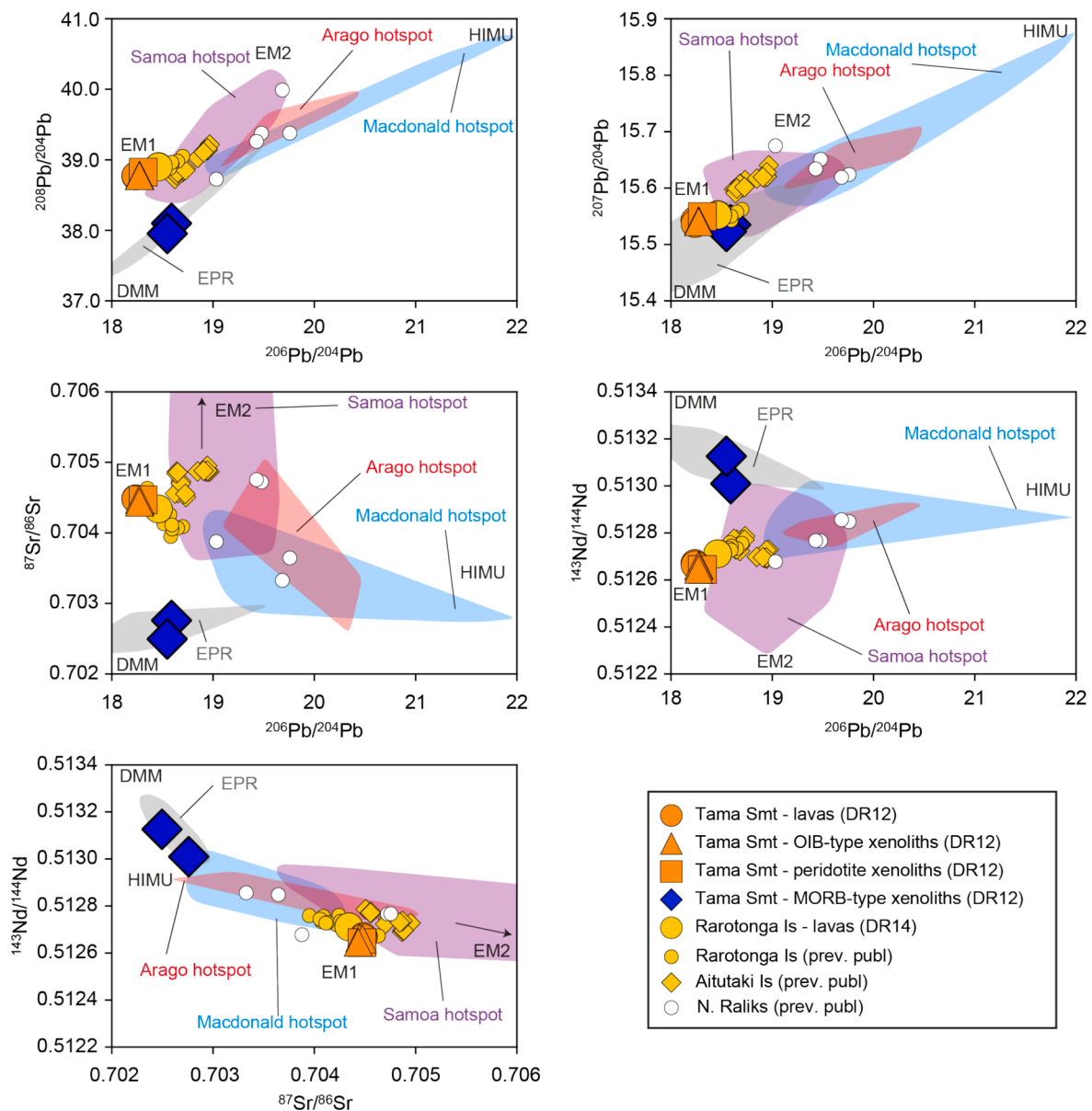


Fig. 9. The radiogenic isotope compositions of samples analyzed in this study. Error bars are smaller than the symbol size. Colored fields for the Macdonald, Rarutū-Arago, and Samoa hotspots represent high-precision data compiled by Harðardóttir and Jackson (2025), restricted to lavas from the younger (<20 Ma) portions of each hotspot track. For $^{87}\text{Sr}/^{86}\text{Sr}$ data, only samples with $\text{MgO} \geq 2$ wt% are included. Lead isotope fields include only double- or triple-spike TIMS analyses and analyses by MC-ICP-MS (both Tl-addition and Pb-spike). For comparison with the proposed Rarotonga hotspot, data are shown for Rarotonga Island lavas (compiled by Harðardóttir and Jackson, 2025), North Ralik seamounts (Konter et al., 2008; Koppers et al., 2007), and young-stage lavas from Aitutaki Island (compiled by Harðardóttir and Jackson, 2025); the same filtering criteria were applied to these datasets. See Supplementary Fig. S10 for datasets with no filters applied. The gray field represents MORB from the East Pacific Rise (EPR), based on the compilation by Gale et al. (2013), with one sample excluded due to an unusually high $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70385).

cargo may represent a complete cross-section of the oceanic lithosphere: mantle lithosphere, MORB basement, and OIB volcano interior. Of particular note is that the presence of MORB-type xenoliths in OIB settings, such as those identified in Tama Seamount, is rare but has been reported from other OIB localities (e.g., Canary Islands [Hansteen and Troll, 2003] and Hawaii [Gao et al., 2016]). These MORB xenoliths provide an opportunity to investigate the composition and hydrothermal alteration history of the lower oceanic crust (Gao et al., 2016), which is rarely sampled—except in rare oceanic drill cores that penetrate deep into the MORB basement. The MORB-type xenoliths recovered from the Tama Seamount are particularly valuable because Tama sits atop lithosphere formed during the Cretaceous Normal Superchron, where magnetic crustal isochron dating is not possible. As a result, future work

on these xenoliths can potentially provide age constraints for the oceanic crust in the Cook Islands region.

5.2. Geochronology of Tama Seamount: a younger expression of the Rarotonga hotspot

We establish a Rarotonga heritage for Tama Seamount based on the geochemical evidence presented above. Here, we use geochronology to show that Tama Seamount may define the younger end of the putative Rarotonga hotspot.

Lavas from Tama Seamount have $^{40}\text{Ar}/^{39}\text{Ar}$ ages that range from 0.664 ± 0.027 Ma to 0.816 ± 0.020 Ma. The xenolith ages (zircon U–Pb: 0.74 ± 0.02 Ma and biotite $^{40}\text{Ar}/^{39}\text{Ar}$ age: 0.730 ± 0.007 Ma) from the

younger Tama lava (TN426-D12-4-lava: 0.664 ± 0.027 Ma) imply that the xenolith was not heated to above the closure temperatures of the U–Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ chronometers because the U–Pb and $^{40}\text{Ar}/^{39}\text{Ar}$ ages on the xenolith agree and because the ages were not reset to that of the host lava. All Tama lavas have ages younger than the youngest known Rarotonga Island lava (i.e., 1.157 ± 0.003 Ma; Rose and Koppers, 2019), and the youngest Tama lava is substantially younger (by ~ 0.5 Ma). Critically, Tama Seamount lies on a Pacific plate flowline to the ESE of Rarotonga Island (Figs. 1 and 4), and the ages of Tama Seamount lavas place it on an age progression through Rarotonga Island defined by the absolute plate motion model from Wessel and Kroenke (2008) (Figs. 1 and 4). These observations are consistent with the hypothesis that Tama Seamount is part of the Rarotonga hotspot track and is a younger expression of the Rarotonga hotspot than Rarotonga Island itself. We acknowledge that not all volcanic chains are generated by hotspots, and that localized non-plume mechanisms may also contribute to intraplate volcanism in the Cook–Austral region and the West Pacific Seamount Province (McNutt et al., 1997; Yan et al., 2021). Nonetheless, the clear age–distance relationship between Tama Seamount and Rarotonga Island, together with their overlapping elemental and isotopic compositions, strongly supports derivation from a common deep-seated mantle plume rather than from non-plume mechanisms.

One outstanding question is whether a seamount even younger than Tama Seamount exists further to the ESE along a Pacific flowline. Using the age range of Rarotonga lavas (1.16 to 1.70 Ma) and the Pacific plate motion velocity (~ 120 km/Ma), we estimate that the current location of the Rarotonga hotspot is approximately 140–200 km ESE of Rarotonga Island (i.e., the intersection of the gray band with the x-axis in Fig. 3). There are several seamounts located to the ESE of Rarotonga Island, including one shown in Fig. 4, which lies ~ 40 km ESE of Tama Seamount. If this volcano, named Pepe Seamount (meaning “baby” in Cook Island Māori), relates to the Rarotonga hotspot, the Pacific plate velocity and its location relative to Rarotonga Island would suggest that Pepe Seamount may be <0.5 Ma in age.

5.3. Aitutaki's relationship with the Rarotonga hotspot?

Aitutaki Island has been suggested to be a volcano associated with the Rarotonga hotspot and exhibits geochemical similarities to Rarotonga Island lavas (Chauvel et al., 1997; Jackson et al., 2020). Volcanic activity on Rarotonga Island (1.157 ± 0.003 to 1.697 ± 0.055 Ma) and the young stage of volcanism on Aitutaki Island (1.382 ± 0.058 to 1.941 ± 0.035 Ma) overlap temporally despite being more than 250 km apart (Rose and Koppers, 2019; Fig. 1). However, the two islands are separated in a north–south direction (i.e., a direction that is nearly orthogonal to the proposed Rarotonga hotspot track; Fig. 1). At the Hawaiian hotspot, concurrently active shield volcanoes—like Mauna Loa and Mauna Kea, or Kilauea and Loihi—are typically separated by 40–50 km. Thus, if Rarotonga and the younger stage of volcanism at Aitutaki are related to the same hotspot, then concurrent volcanism on these two distantly separated Cook Island volcanoes would not conform to this Hawaiian model. In contrast, other oceanic hotspot systems, like the Tristan–Gough–Walvis Ridge, exhibit concurrently active volcanoes (e.g., Tristan Island and Gough Island) that are separated by over 300 km in a direction that is orthogonal to the hotspot track (O'Connor and Jokat, 2015). We cannot conclusively link young Aitutaki volcanism to the Rarotonga hotspot. However, if young Aitutaki volcanism relates to the Rarotonga hotspot, then the geometry of concurrent volcanism at the Tristan–Gough–Walvis Ridge hotspot may serve as a potential analogue for a single hotspot linking concurrent volcanism on two volcanoes as distant from each other as Rarotonga Island is from Aitutaki.

5.4. Rarotonga is a hotspot, but is it long-lived?

Prior work indicated that the Rarotonga trend is “less well expressed” than the other hotspot tracks than in the Cook–Austral volcanic

lineament (Chauvel et al., 1997), and Jackson et al. (2020) even suggested that a non-plume origin for the Rarotonga trend could not be ruled out due to poor characterization of this putative hotspot (Jackson et al., 2020). These new results in this study show that Rarotonga satisfies a key condition for hotspot volcanism: volcanism younger than Rarotonga Island is located at Tama Seamount, to the ESE of Rarotonga Island (Fig. 1), and this young volcanism has an age consistent with absolute Pacific plate motion models (Figs. 2 and 3). However, if Rarotonga is indeed a long-lived hotspot similar to Macdonald and Rurutu–Arago, we would expect the presence of not only volcanoes younger than Rarotonga Island located to the ESE of Rarotonga Island, but also volcanoes older than Rarotonga Island located to the WNW of Rarotonga Island. Unfortunately, the corridor of Pacific seafloor located west of Rarotonga Island is sparsely populated with as-yet-uncharacterized seamounts, and very few of these currently align with the reconstructed Rarotonga hotspot track (Fig. 1).

While there are insufficient data to evaluate the track of the Rarotonga hotspot immediately to the WNW of Rarotonga Island, a more distant lineament of seamounts in the northwest Pacific—the Ralik group—has been tentatively suggested to be the Cretaceous expression of the Rarotonga hotspot based on their geochemistry, location, and age. However, the hypothesized connection between the Rarotonga hotspot and the Cretaceous Ralik Seamount chain remains tenuous (Jackson et al., 2024), given the ~ 75 Myr temporal gap (the youngest Ralik seamount is 75.7 Ma [Koppers et al., 2007] and the oldest Rarotonga Island lava is 1.9 Ma [Rose and Koppers, 2019]) and the uncertainties associated with plate motion models extending back to the Cretaceous. Thus, it is possible that the Rarotonga hotspot formed only recently, and if this model is accurate, volcanism older than Rarotonga Island may not be identified to the WNW of Rarotonga Island. Future seagoing expeditions targeting unsampled seamounts along the modeled path of the Rarotonga hotspot may shed light on the hypothesis of a long-lived Rarotonga hotspot.

6. Conclusions

Submarine lavas dredged from Tama Seamount, located ~ 80 km ESE of Rarotonga Island, have isotopic compositions that overlap with Rarotonga Island and support a genetic relationship with Rarotonga Island volcanism. New geochronological data reveal that Tama Seamount is significantly younger than Rarotonga Island and, at 0.664 ± 0.027 Ma, represents the youngest known volcanism in the Cook Islands. The new age of Tama Seamount combined with new and existing ages for Rarotonga Island form an age versus distance trend consistent with the Wessel and Kroenke (2008) absolute plate motion model for the Pacific, supporting a Rarotonga hotspot origin for Tama Seamount. The geochemical and temporal relationships provide support for the hypothesis that Tama Seamount is related to the Rarotonga hotspot, that Rarotonga may represent an age-progressive hotspot, and that the “three-hotspot” model accurately describes the pattern of volcanism in the Cook–Austral region (Chauvel et al., 1997).

Data availability

All data generated or analyzed during this study are available in the Supplementary Tables and at Mendeley data at <https://doi.org/10.17632/xynx5w858r.1>.

CRediT authorship contribution statement

Yifan Du: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Matthew G. Jackson:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Brian Jicha:** Writing – review & editing, Writing – original draft,

Methodology. **Andrew Kylander-Clark**: Writing – review & editing, Writing – original draft, Methodology. **Benjamin L. Byerly**: Writing – review & editing, Writing – original draft, Methodology. **Michael Bizimis**: Writing – review & editing, Writing – original draft, Methodology. **Sæmundur Ari Halldórsson**: Writing – review & editing, Writing – original draft, Methodology. **Gareth G.E. Seward**: Writing – review & editing, Writing – original draft, Methodology. **Olivia E. Anderson**: Writing – review & editing, Writing – original draft, Methodology. **Matthew Rioux**: Writing – review & editing, Writing – original draft, Methodology. **Kevin Konrad**: Writing – review & editing, Writing – original draft, Methodology. **Sunna Harðardóttir**: Writing – review & editing, Writing – original draft, Visualization, Investigation. **Ruixia Bai**: Writing – review & editing, Writing – original draft. **Andrea Giuliani**: Writing – review & editing, Writing – original draft, Methodology. **Douglas A. Wiens**: Writing – review & editing, Writing – original draft, Investigation. **S. Shawn Wei**: Writing – review & editing, Writing – original draft, Investigation. **Gerald McCormack**: Writing – review & editing, Writing – original draft, Investigation. **John Michael Parianos**: Writing – review & editing, Writing – original draft, Visualization, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge support from NSF grants OCE-1929095 and EAR-2437227 to M.G.J., OCE-1928946 to S.S.W., and OCE-1928914 to D.A.W., which funded the seagoing expedition (TN426) and subsequent sample analyses. We thank the Cook Islands Research Secretariat and Committee (Permit #03-23a), and the Cook Islands National Environment Service (approval #2023/057RAR), for their approval and support. We thank the crew of TN426 for their assistance during the expedition, and the science team—Madeleine Kerr, Judy (Xinmu) Zhang, Fan Wang, Yurong Zhang, Adrea Williams, Diandian Peng, Debosmita Roy, Samisoni Fonomanu 'O Loto Tu'i'ahai 'O 'Afitu Mo Lakepa Tu'i'afitu, Naivins Darcy Lu'uga Chan Kum Tong—for their help with sample collection. Seafloor rock sample dredging was supported by MARSSAM at Oregon State University, funded by the NSF. We thank the Artex 2025 expedition team for collecting the multibeam data, and Ed Herman, Ngatupuna Kae, Keanu Harawira, Gary van Eck, and Kevin Mackay for data processing. We also thank the operator of the MV Anuanua Moana, Kiva Marine. We are grateful to Jóhann Gunnarsson Robin for conducting major and trace element analyses. Y.D. expresses sincere gratitude to Roberta Rudnick and John Cottle for their guidance in writing and editing as members of the Ph.D. committee, and thanks Lee Sharpnack, Todd Penniman, and Christopher Crow for their assistance with sample preparation. We also thank the reviewers—Catherine Chauvel, John Caulfield, and two anonymous reviewers—for their constructive and thoughtful feedback, and we are grateful to Hailiang Dong (Executive Editor) and James Day (Associate Editor) for careful handling of the manuscript.

Appendix A. Supplementary material

The Supplementary Material includes detailed analytical methods, supporting figures, and four supplementary tables containing sample information, geochronological data, and geochemical compositions. These materials provide additional context and data referenced in the main text.

Supplementary material to this article can be found online at <http://doi.org/10.1016/j.gca.2025.12.058>.

References

- Bonneville, A., Dosso, L., Hildenbrand, A., 2006. Temporal evolution and geochemical variability of the South Pacific superplume activity. *Earth Planet. Sci. Lett.* 244 (1–2), 251–269.
- Buff, L., Jackson, M., Konrad, K., Konter, J., Bizimis, M., Price, A., Rose-Koga, E.F., Blusztajn, J., Koppers, A., Herrera, S., 2021. “Missing links” for the long-lived Macdonald and Arago hotspots, South Pacific Ocean. *Geology* 49 (5), 541–544.
- Bao, X., Lithgow-Bertelloni, C.R., Jackson, M.G., Romanowicz, B., 2022. On the relative temperatures of Earth's volcanic hotspots and mid-ocean ridges. *Science* 375 (6576), 57–61.
- Baker, J., Peate, D., Waight, T., Meyzen, C., 2004. Pb isotopic analysis of standards and samples using a ^{207}Pb – ^{204}Pb double spike and thallium to correct for mass bias with a double-focusing MC-ICP-MS. *Chem. Geol.* 211 (3–4), 275–303.
- Chauvel, C., McDonough, W., Guille, G., Maury, R., Duncan, R., 1997. Contrasting old and young volcanism in Rurutu Island, Austral Chain. *Chem. Geol.* 139 (1–4), 125–143.
- Diraison, C., 1991. Le volcanisme aérien des archipels polynésiens de la société, des marquises et des australes-cook, tephrostratigraphie, datation isotopique et géochimie comparées, contribution à l'étude des origines du volcanisme intraplaque du Pacifique central: Brest, p. 413.
- Finlayson, V.A., Konter, J.G., Konrad, K., Koppers, A.A.P., Jackson, M.G., Rooney, T.O., 2018. Sr–Pb–Nd–Hf isotopes and $^{40}\text{Ar}/^{39}\text{Ar}$ ages reveal a Hawaii–Emperor-style bend in the Rurutu hotspot. *Earth Planet. Sci. Lett.* 500, 168–179.
- Gale, A., Dalton, C.A., Langmuir, C.H., Su, Y., Schilling, J.G., 2013. The mean composition of ocean ridge basalts. *Geochem. Geophys. Geosyst.* 14 (3), 489–518.
- Gao, R., Lassiter, J.C., Barnes, J.D., Clague, D.A., Bohron, W.A., 2016. Geochemical investigation of Gabbroic Xenoliths from Hualalai Volcano: implications for lower oceanic crust accretion and Hualalai Volcano magma storage system. *Earth Planet. Sci. Lett.* 442, 162–172.
- Hanyu, T., Dosso, L., Ishizuka, O., Tani, K., Hanan, B.B., Adam, C., Nakai, S.I., Senda, R., Chang, Q., Tatsumi, Y., 2013. Geochemical diversity in submarine HIMU basalts from Austral Islands, French Polynesia. *Contrib. Mineral. Petrol.* 166, 1285–1304.
- Hart, S.R., Blusztajn, J., Dick, H.J., Meyer, P.S., Muehlenbachs, K., 1999. The fingerprint of seawater circulation in a 500-meter section of ocean crust gabbros. *Geochim. Cosmochim. Acta* 63 (23–24), 4059–4080.
- Hauri, E.H., Shimizu, N., Dieu, J.J., Hart, S.R., 1993. Evidence for hotspot-related carbonatite metasomatism in the oceanic upper mantle. *Nature* 365 (6443), 221–227.
- Hansteen, T.H., Troll, V.R., 2003. Oxygen isotope composition of xenoliths from the oceanic crust and volcanic edifice beneath Gran Canaria (Canary Islands): consequences for crustal contamination of ascending magmas. *Chem. Geol.* 193 (3–4), 181–193.
- Harðardóttir, S., Jackson, M.G., 2025. A new geochemical database for ocean island basalts: inferring an OIB mantle source from unevenly sampled oceanic hotspots. *Chem. Geol.*, 122505.
- Jackson, M., Halldórsson, S., Price, A., Kurz, M., Konter, J., Koppers, A., Day, J.M.D., 2020. Contrasting old and young volcanism from Aitutaki, Cook Islands: implications for the origins of the cook–austral volcanic chain. *J. Petrol.* 61, egaa037.
- Jackson, M.G., Finlayson, V.A., Steinberger, B., Konrad, K., 2024. When a plateau suppresses a plume: disappearance of the Samoan plume under the Ontong Java Plateau. *AGU Adv.* 5 (4), e2023AV001079.
- Johnson, R.H., Malahoff, A., 1971. Relation of Macdonald volcano to migration of volcanism along the Austral chain. *J. Geophys. Res.* 76 (14), 3282–3290.
- Konter, J.G., Hanan, B.B., Blichert-Toft, J., Koppers, A.A.P., Plank, T., Staudigel, H., 2008. One hundred million years of mantle geochemical history suggest the retreating of mantle plumes is premature. *Earth Planet. Sci. Lett.* 275 (3–4), 285–295.
- Konter, J., Finlayson, V., Konrad, K., Jackson, M., Koppers, A., Wessel, P., Beeth, S., Bizimis, M., Alverson, A., Kelley, C., 2025. Pacific hotspots reveal a Louisville–Ontong Java Nui tectonic link. *Nature* 1–7.
- Konrad, K., Koppers, A.A., Steinberger, B., Finlayson, V.A., Konter, J.G., Jackson, M.G., 2018. On the relative motions of long-lived Pacific mantle plumes. *Nat. Commun.* 9 (1), 854.
- Koppers, A.A., Staudigel, H., Phipps Morgan, J., Duncan, R.A., 2007. Nonlinear $^{40}\text{Ar}/^{39}\text{Ar}$ age systematics along the Gilbert Ridge and Tokelau Seamount Trail and the timing of the Hawaii–Emperor Bend. *Geochem. Geophys. Geosyst.* 8 (6).
- Ludwig, K.R., 2012. Isoplot, a Geochronological Toolkit for Microsoft Excel. Berkeley Geochronol. Center: Spec. Publ. 5, 75.
- Lassiter, J., Blichert-Toft, J., Hauri, E., Barsczus, H., 2003. Isotope and trace element variations in lavas from Raivavae and Rapa, Cook–Austral islands: constraints on the nature of HIMU- and EM-mantle and the origin of mid-plate volcanism in French Polynesia. *Chem. Geol.* 202 (1–2), 115–138.
- Morgan, W.J., 1971. Convection plumes in the Lower Mantle. *Nature* 230 (5288), 42–43.
- McNutt, M.K., Caress, D., Reynolds, J., Jordahl, K., Duncan, R., 1997. Failure of plume theory to explain midplate volcanism in the southern Austral islands. *Nature* 389 (6650), 479–482.
- Mattinson, J.M., 1973. Anomalous isotopic composition of lead in young zircons: Carnegie Inst. Washington Yearb. 72, 613.
- McDonough, W.F., Sun, S.-S., 1995. The composition of the Earth. *Chem. Geol.* 120 (3–4), 223–253.
- McLean, N.M., Bowring, J.F., Bowring, S.A., 2011. An algorithm for U–Pb isotope dilution data reduction and uncertainty propagation. *Geochem. Geophys. Geosyst.* 12 (6).
- O'Connor, J.M., Jokat, W., 2015. Tracking the Tristan–Gough mantle plume using discrete chains of intraplate volcanic centers buried in the Walvis Ridge. *Geology* 43 (8), 715–718.

- Rose, J., Koppers, A.A., 2019. Simplifying age progressions within the Cook-Austral islands using ARGUS-VI high-resolution $^{40}\text{Ar}/^{39}\text{Ar}$ incremental heating ages. *Geochem. Geophys. Geosyst.* 20 (11), 4756–4778.
- Ryan, W.B., Carbotte, S.M., Coplan, J.O., O'Hara, S., Melkonian, A., Arko, R., Weissel, R. A., Ferrini, V., Goodwillie, A., Nitsche, F., 2009. Global multi-resolution topography synthesis. *Geochem. Geophys. Geosyst.* 10 (3).
- Schärer, U., 1984. The effect of initial ^{230}Th disequilibrium on young U–Pb ages: the Makalu case, Himalaya. *Earth Planet. Sci. Lett.* 67 (2), 191–204.
- Turner, D.L., Jarrard, R.D., 1982. K–Ar dating of the Cook-Austral Island Chain: a test of the hot-spot hypothesis. *J. Volcanol. Geotherm. Res.* 12 (3–4), 187–220.
- Wessel, P., Kroenke, L.W., 2008. Pacific absolute plate motion since 145 Ma: an assessment of the fixed hot spot hypothesis. *J. Geophys. Res. Solid Earth* 113 (B6).
- Wolff, J., Grandy, J., Larson, P., 2000. Interaction of mantle-derived magma with island crust? Trace element and oxygen isotope data from the Diego Hernandez Formation, Las Cañadas, Tenerife. *J. Volcanol. Geotherm. Res.* 103 (1–4), 343–366.
- Yan, Q., Milan, L., Saunders, J.E., Shi, X., 2021. Petrogenesis of basaltic lavas from the West Pacific Seamount Province: geochemical and Sr–Nd–Pb–Hf isotopic constraints. *J. Geophys. Res. Solid Earth* 126 (5), e2020JB021598.