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Implications of high-Mg# adakitic magmatism at Hunter Ridge for arc magmatism of the Fiji - Vanuatu region

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ABSTRACT

The mostly submarine Hunter Ridge, located in the SW Pacific records a ∼12 Myr to present history of magmatism related to the opening of the North Fiji Basin and subduction of oceanic lithosphere of the South Fiji Basin. Although the Hunter Ridge is probably composed primarily of an older Vitiaz-related basement, young volcanic features are present from Matthew Island to Kadavu Island. Some dredged volcanic rocks from these features have low-FeO and high-Mg# affinities, ranging from picrites to high-Mg# andesites and dacites. Elevated Sr (500 – 3400 ppm) and Sr/Y (50 – 240) coupled to fractionated (adakitic) rare-earth element patterns (La/Yb = 5 – 40, Gd/Yb = 1.5 – 5.7) indicate a garnet-signature derived from the melting of eclogite-facies basalt. Pacific-type MORB Nd-Hf-Pb isotopic ratios of these rocks contrast with the Indian-type MORB nature of the underlying North Fiji mantle but match closely the subducted South Fiji ocean crust. Low values of Th/La (< 0.15), Ba/La (< 22), unradiogenic $^{87}Sr/^{86}Sr$ (0.7026 – 0.7032) and Pacific-MORB Nd-Hf-Pb isotopic ratios indicate that sediment is a minor contributor to the source. The isotopic data clearly connect Hunter Ridge arc rocks of all compositions (picrites, low- to medium K_2O arc lavas, basalts, high-Mg# andesites and dacites) to source components predominantly within the subducting plate. Unradiogenic $^{87}Sr/^{86}Sr$ (0.7026 – 0.7029) at high Sr abundances (700 – 1400 ppm) are common in hot-slab localities and are interpreted to reflect flux-melting of MORB under eclogite-facies conditions driven by dehydration in the underlying mantle of the subducting plate. Such an adakitic slab-melt component can be detected in more common (non-adakitic) arc rocks along the Hunter Ridge and Vanuatu arc as well. Evidence of slab melting along the western Pacific indicates that melting of subducting oceanic lithosphere is likely a common occurrence at convergent margins.

1. Introduction

Determining the characteristics of primitive arc volcanic rocks helps to decipher the processes controlling magmatism at convergent margins (Kelemen et al., 2003; Grove et al., 2003). The availability of primitive volcanic rock samples is often impeded by thick arc crust, assimilation of crustal rock, and by the absence of a record of the initial stages of arc growth. Therefore, young intraoceanic arcs with thin arc crust are the best targets for study, because primitive magmas minimally affected by shallow processes are likely to be more abundant than in mature arc systems.

Enrichments in large ion lithophile elements (LILE) and depletions in high-field strength elements (HFSE) are a common feature of arc magmas. They are generally explained by dehydration of subducted oceanic crust ± sediment melting, which releases fluids and other low-melting-temperature components that produce enriched compositional characteristics and drive flux-melting within the mantle wedge (Plank, 2005). Melting of subducted oceanic

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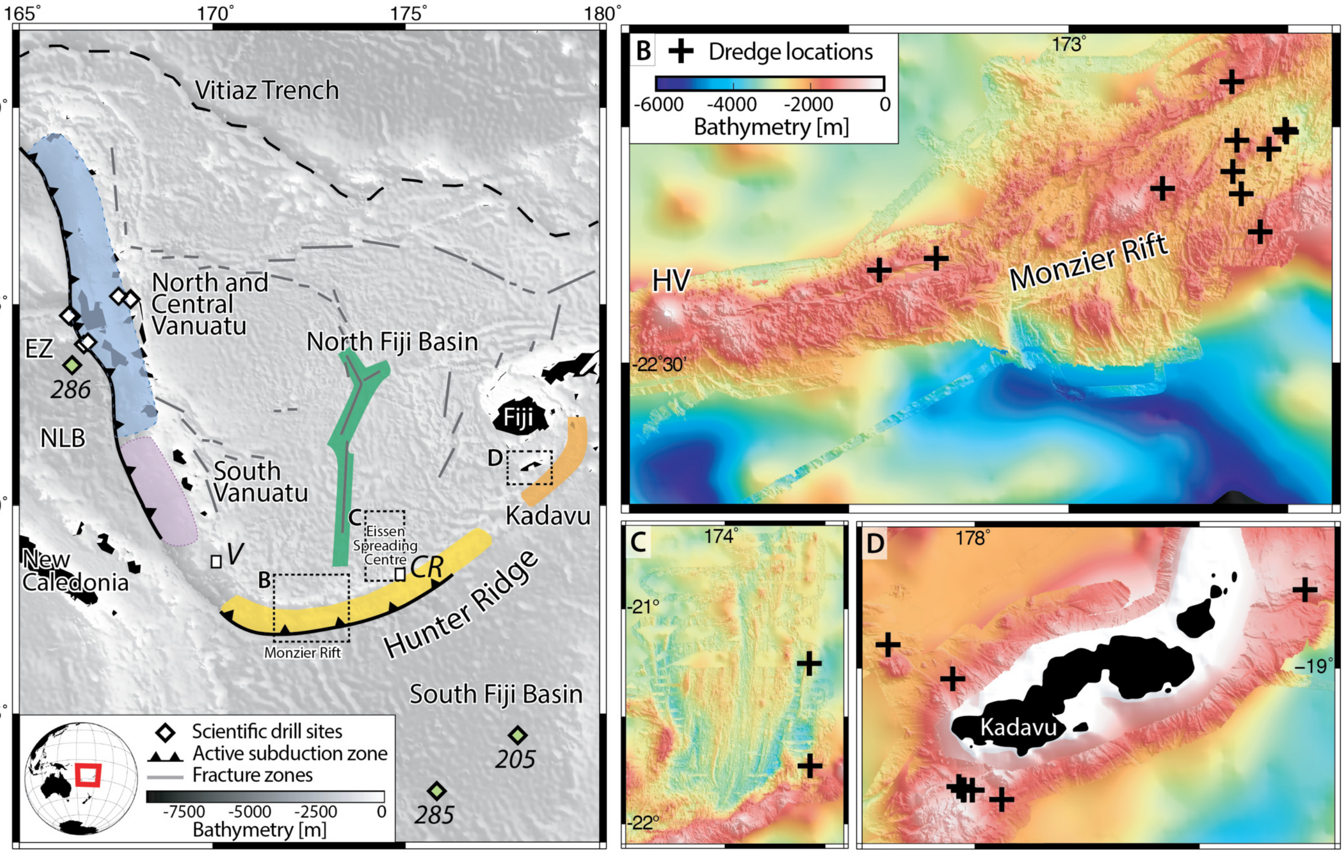

Fig. 1. A) Map with bathymetry and important tectonic features of the Southwest Pacific, with the location of the Hunter Ridge, North and South Fiji Basin, Eissen Spreading Center with the location of DSDP sites and dredged samples. From west to east, dredged samples are from (**B**) volcanic edifices along the western margin of the Hunter Ridge and Monzier Rift, (**C**) Eissen Spreading Center; **(D)** volcanic edifices on the seafloor surrounding Kadavu Island (Fiji). The color code in this map will be used throughout the manuscript: North and Central Vanuatu arc in blue, South Vanuatu arc in purple, Monzier Rift and Hunter Ridge adakitic volcanism in Yellow and Kadavu adakitic volcanism in orange. Green colors represent oceanic lithosphere, with the upper plate in dark green (North Fiji basin and Eissen Spreading Center) and the lower (downgoing) plate in light green squares (drill sites) of the Norfolk Basin and South Fiji Basin). High-resolution shipboard bathymetry data from Expeditions SS200406, SS200410, SS200608, SS200807, SS2012_T02, SS2012_T03, SS2012_V02, ST200601 and IN2016_T01. Tectonic features, such as subduction zone and fracture zones are from Patriat et al. (2019). V: Volsmar seamount; HV: Hunter Volcano (Hunter Island); CR: Conway Reef; EZ: D'Entrecasteaux Zone. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

crust is often thought to occur only in young, hot-slab systems, often around slab windows or along subducting plate edges (Defant and Drummond, 1990; Yogodzinski et al., 2001), leading to arc lavas with adakitic signatures, as defined by Defant and Drummond (1990). The idea that partial melts of subducted oceanic crust do not contribute significantly to the source of common arc magmas was for many years supported by thermal models indicating that slab-top temperatures generally remain below the water-saturated solidus for MORB eclogite at conditions relevant to arc magma genesis (Peacock et al., 1994). As thermal models became more sophisticated, in particular by incorporating temperature and stress-dependent mantle viscosity, slab-top temperatures got hotter but also drier (Syracuse et al., 2010). As a consequence, subducted oceanic crust has continued to be viewed primarily as a source of fluid that drives melting in the overlying mantle. The contrasting behavior of fluid-mobile and fluid-immobile elements has likewise, continued to be interpreted to reflect, respectively, slab-derived and mantle-derived components in the source of arc magmas. This conceptual framework has however been continuously challenged on petrologic and geochemical grounds (Portnyagin et al., 2007; Tollstrup et al., 2010; Marsh, 2015; Walowski et al., 2015; Yogodzinski et al., 2017; McCarthy et al., 2021).

One important location where arc magma sources can be effectively investigated is the intra-oceanic New Hebrides (Vanuatu) subduction zone, especially along the southernmost, young and volcanically active Hunter Ridge segment, which is located between Volsmar seamount to the west and the Conway Reef (Ceva-i-Ra) to the east (Fig. 1) (Mitchell and Warden, 1971; Monzier et al., 1993). This is an important location because primitive submarine lavas are erupted through thin oceanic lithosphere within and around Monzier Rift which has propagated from the backarc into the hanging wall of the subduction zone (Monzier et al., 1993; Patriat et al., 2015, 2019) and because prior geochemical studies have characterized key samples that are representative of both the mantle wedge and the subducting plate sources of the system (Fleutelot et al., 2005; Peate et al., 1997; Pearce et al., 2007).

Here, we present major- and trace element and isotopic data (Sr–Nd–Hf–Pb) for volcanic rocks that comprise a unique set of dredge samples collected by the *RV Southern Surveyor* (2004 – 2009) along Hunter Ridge and around Kadavu Island (Fig. 1). We complement this dataset with Nd and Sr isotope data of back-arc basalts and low- to medium K_2O arc lavas from Monzier Rift whose bulk rock and Pb-isotopic compositions were presented in Patriat et al. (2019). We compare the Hunter Ridge-Kadavu dataset to the Vanuatu arc and to the Aleutian arc and discuss the implications of high-Mg# andesites and related rocks (Mg# = molar Mg/Mg+Fe) for magmatism throughout the broader Vanuatu – Hunter Ridge subduction system.

We show that, as observed in the western Aleutians, Pb–Sr–Nd–Hf isotopic ratios in high-Mg# adakitic rocks at Hunter Ridge have a minimal input from subducted sediment. Instead, these isotopic ratios record a depleted source in largely unaltered

Pacific-type oceanic crust whilst the ambient mantle, which has Indian-type MORB isotopic composition, plays a minor role in controlling the isotopic compositions of Hunter Ridge lavas. Fluids required to drive melting of the subducted plate contributed relatively little Sr, Pb, and Nd to the source mixture that underlies Hunter Ridge volcanism. We show that these results are consistent with a model wherein fluids that drive melting of subducting oceanic crust may be produced by dehydration of serpentinite in the underlying mantle section of the subducting oceanic lithosphere. We show that this model can be applied not only to adakitic arc rocks of the Hunter Ridge but to common arc rocks in general.

2. Geological and tectonic setting

2.1. The Vanuatu – Hunter Ridge subduction system

The southwest Pacific is a tectonically complex area of marginal seas and seafloor ridges that straddles the Southeast Asia, Indonesia and Australia-New Zealand regions (Meffre and Crawford, 2001; Patriat et al., 2015). Of particular interest is the Vanuatu arc, which is produced by the eastward subduction of the Australia Plate beneath the Pacific Plate (MacFarlane et al., 1988) (Fig. 1). Prior to ∼12 Ma, this convergent margin was the location of the Vitiaz arc, which was formed by southward and westward subduction of the Pacific plate beneath oceanic lithosphere east of Australia. At 12 Ma, eastward subduction of former back-arc basin lithosphere (South Fiji Basin and North Loyalty Basin) beneath the Pacific plate (Fig. 1) initiated the growth of the Vanuatu arc. The polarity reversal was followed by a progressive clock-wise rotation of the Vanuatu arc, and later by counter-clockwise rotation of Fiji. This event was accompanied by back-arc spreading and opening of the North Fiji basin. Magmatic growth of Vanuatu arc crust has occurred mostly within the last 6 – 8 Ma (Mitchell and Warden, 1971). Starting at 1.5 – 3 Ma, the northward migrating collision of the D'Entrecasteaux Zone has progressively affected the Central and Northern sections of the Vanuatu arc (Peate et al., 1997).

The recent Hunter Ridge was built initially by shearing of remnants of the old Vitiaz Arc along a STEP fault (Subduction-Transform-Edge-Propagator; Govers and Wortel, 2005) at the southern edge of the New Hebrides subduction Zone (Patriat et al., 2015, 2019). At ∼2 Ma, the Hunter Ridge then experienced a new tectonic and magmatic phase resulting from the initiation of the Matthew and Hunter Subduction Zone (Patriat et al., 2015). Magmatism associated with this nascent subduction zone has been little studied. Monzier et al. (1993) and Patriat et al. (2019) identified in seafloor and island deposits a variety of magma types that are closely linked in space and time. These include back-arc basalts, arc tholeiites, boninites, picrites, and adakitic andesites and dacites. The variety of primitive, high-Mg# compositions produced by Hunter Ridge volcanism appears to be the result of the unusually thin crust of the arc, which is produced by the southward propagation of North Fiji Basin spreading centers into the hanging wall of the subduction zone (Monzier et al., 1993). The compositional shift from common arc and back-arc basalts along the Central and Southern Vanuatu arc (Peate et al., 1997) to high-Mg# andesitic and adakitic compositions at Hunter ridge is striking (Monzier et al., 1993; Patriat et al., 2015, 2019). East of the Hunter Ridge, volcanism within the Fijian Islands expresses shoshonitic and adakitic characteristics (Danyushevsky et al., 2008) that appears to be genetically linked and related to the opening of the North Fiji Basin. Although the evolution of the plate boundary between Vanuatu, Hunter Ridge and Fiji remains imperfectly constrained (Crawford et al., 2003; Patriat et al., 2015), magmatism between Hunter Ridge and Kadavu is characterized by an important component with high-Mg# and low-FeO characteristics (Arculus, 2003) and adakitic affinities which are distinct from the Vanuatu arc.

High-resolution bathymetry along the North Fiji Basin and Hunter Ridge (Fig. 1) reveals active rifting of the Hunter Ridge lithosphere between Conway Reef and Hunter Islands (Hunter Volcano) (Fig. 1b, c) The incipient rifting stage is currently observed over ∼ 100 km to the east of Hunter Island (Figs. 1, 2) in the well-developed Monzier Rift. The north-south oriented ∼150 km long Eissen Spreading Center on the eastern flank of the Monzier Rift (Fig. 1c) likely represents an older oceanic accretion ridge propagating southward into the thicker crust of the Hunter Ridge (Patriat et al., 2015, 2019). The Monzier rift system initiated ∼2 My ago (Patriat et al., 2019), as a consequence of collision further West and initiation of a new subduction zone, the Matthew and Hunter Subduction Zone (MHSZ). This event led to extensive submarine magmatism within the thin crust of the Monzier Rift and along the western Hunter Ridge (Fig. 1b, Fig. 2). The Hunter Ridge volcanic system is associated with a young immature subduction, and therefore unlike large segments of the Vanuatu arc, which are older and are affected by collision of submarine ridges and plateaus (Meffre and Crawford, 2001) or are characterized by volcanic edifices formed atop variably thickened arc crust. Dredges of volcanic edifices within the Monzier Rift have identified a spatial and temporal superposition of adakites (high-Mg# andesites and dacites), common calc-alkaline andesites, and back-arc basalts, with boninites and arc tholeiites comprising the older Hunter Ridge crust (Fig. 2 and Patriat et al., 2019).

Finally, a key geochemical aspect of the Vanuatu – Hunter Ridge system is that it straddles two large mantle domains that produce Pacific-type and Indian-type MORB that are reflected in the isotopic character of basaltic volcanism that created the crust of the North Fiji and South Fiji basins. Geochemical data indicate that the mantle beneath the North Fiji Basin is of Indian-type MORB isotopic affinity, whereas the subducting oceanic crust of the South Fiji Basin is isotopically Pacific-type MORB (Peate et al., 1997; Fleutelot et al., 2005; Pearce et al., 2007; Patriat et al., 2019). For Hunter-Ridge volcanic rocks, this provides the opportunity to distinguish depleted isotopic sources in the subducted plate (South Fiji Basin basalt) from those of the mantle wedge (North Fiji basin mantle) based on contrasting Pacific and Indian-realm isotopes. This point is key to our interpretations of Hunter Ridge geochemistry and the implications for our understanding of magmatism throughout the Vanuatu arc.

2.2. Comparison to the Aleutian arc

Throughout this paper, we draw comparisons with an analogous system in the transition from the eastern to western Aleutian arc (Yogodzinski et al., 2015 and references therein) (*electronic appendix* Fig. DR1). This region is of interest because the architecture of the Aleutians undergoes a transition from orthogonal to slow, and highly oblique subduction along-strike, which creates a linked transition from classical calc-alkaline volcanic rocks produced by volcanic systems of central and eastern Aleutians islands to dominantly submarine volcanism in the western Aleutians (Fig. DR1) that is primitive (high-Mg#) and adakitic with well-defined low-FeO major-element characteristics and distinctive trace element patterns (elevated Sr/Y, La/Yb, Gd/Yb) requiring a role for residual garnet (Yogodzinski et al., 2015). Isotopic data also indicates that there is little to no subducted sediment in the source of the end-member adakitic rocks of the Western Aleutians (Yogodzinski et al., 2017). This means that trace element characteristics of geochemically depleted source components in the subducted oceanic crust – which are typically masked by subducted-sediment components – are clearly expressed in the adakitic end-members and as a result, are more easily recognized when they are present in

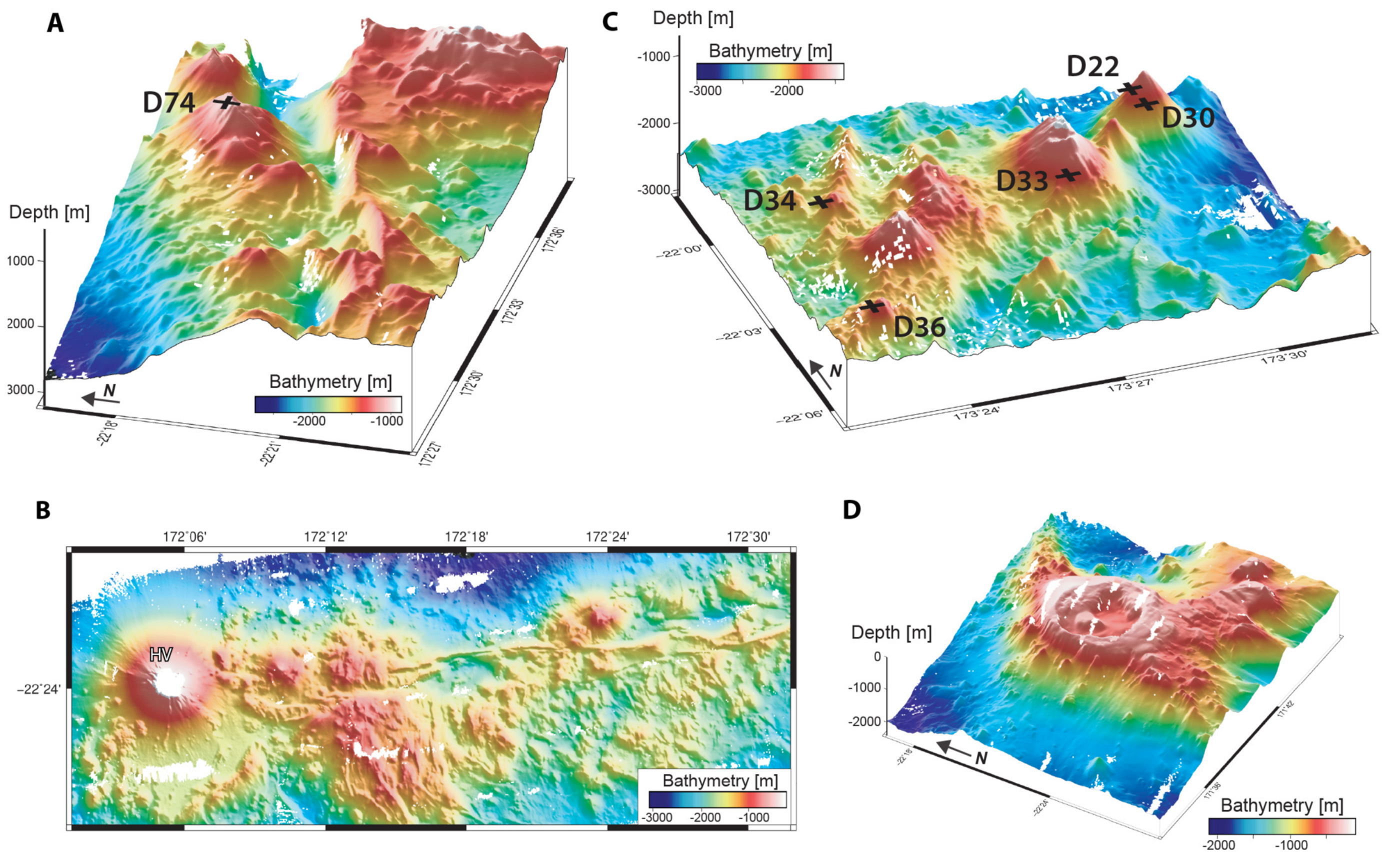

Fig. 2. A-B) Southwest propagation of the Monzier rift along the Hunter Ridge. **A** Large Hunter Island Volcano is located at the tip of the propagating rift system; **C-D)** Large volcanic cones and calderas within the Monzier rift at depth of 2000 – 3000 m (or mbsl, meters below sea-level). Dredges from these volcanic cones reveal strongly heterogeneous magmatism, from back-arc basalts to high-Mg# adakitic volcanism. The Easternmost seamount on which dredges 22 and 30 are located, is composed of high-Mg# adakites (Patriat et al., 2019).

common arc volcanic rocks produced by classical calc-alkaline systems.

3. Analytical methods

Analytical methods used in data generation are summarized below. Detailed descriptions can be found in the electronic appendix.

Major and minor elements of volcanic glasses were acquired on a Cameca SX100 electron microprobe (Central Science Laboratory, University of Tasmania), using a beam energy of 15 keV, beam current of 20 nA, and 30 micron beam diameter. Trace element abundances of glasses were determined using an Agilent 7500cs quadrupole ICP-MS coupled to a RESOlution HR laser ablation microprobe equipped with a 193 nm Coherent COMPex Pro ArF Excimer Laser and an S155 ablation cell with constant geometry design (CODES Analytical Laboratories, University of Tasmania). For bulk rock chemistry, samples were ground in an agate mill to avoid trace element contamination. Whole rock powders were fused with 12 – 22 flux (a pre-fused mixture consisting of 12 parts $Li_2B_4O_7$ and 22 parts $LiBO_2$) using a sample:flux ratio of 1:9 at 1100 °C. Major elements were then determined with a ScMo 3 kW side window X-ray tube and a Philips PW1480 x-ray spectrometer (CODES Analytical Laboratories, University of Tasmania). Additional trace elements were also acquired by solution ICP-MS on duplicate high-pressure $HF–H_2SO_4–HClO_4$ digestions (CODES Analytical Laboratories, University of Tasmania). For radiogenic isotope ratios, 100 mg of handpicked chips and/or rock powders, were leached with 6M HCl (100 °C, 60 min), rinsed with distilled water, and digested on a hotplate (2 days 3:1 HF/HNO_3) (University of Melbourne). Following separation of Sr–Nd–Hf–Pb by column chemistry, isotopic analyses were carried out on a Nu Plasma multi-collector ICP-MS with sample introduction via a low-uptake Glass Expansion PFA nebuliser and a CETAC Aridus desolvator. Total analytical blanks (∼50 pg for Pb and Hf; ≤100 pg for Nd and Sr) are negligible compared to the amounts of Pb, Hf, Nd and Sr processed.

4. Results

In order to compare Hunter Ridge and Kadavu volcanism with the Vanuatu and Aleutian arcs, we restrict our use of Vanuatu and Aleutian data to more primitive compositions with $Mg\#_{Fetot} > 55$ (Kelemen et al., 2003). Glass and bulk-rock samples from Hunter Ridge, Monzier Rift and Kadavu Island vary from picrites and high-Mg# basalts to high-Mg# andesites and dacites, with Mg# typically greater than 50 and often greater than 60 (Fig. 3). These rocks show a wide range of SiO_2 (48–67 wt%) with FeO never more than 9 w%, FeO/MgO < 2, and moderate- to low-K_2O that increases with increasing SiO_2 (Fig. 3a-b). This low-FeO trend is distinctly calcalkaline and as such contrasts with magmatism from the Vanuatu arc, which commonly define tholeiitic igneous series (Miyashiro, 1974), with $FeO^* > 10$ wt%, FeO/MgO > 2, and $SiO_2 < 56$ wt% (Fig. 3a). Hunter Ridge volcanism is shifted to higher MgO at a given SiO_2, FeO and CaO contents, compared to typical arc lavas. Variations in SiO_2, FeO and CaO as a function of MgO and Mg# highlight the distinct compositional trends of Hunter Ridge and Kadavu lavas compared to the Vanuatu arc (Fig. 3c-h).

Basalts and basaltic andesites from the Vanuatu arc typically have flat to slightly enriched REE patterns with widely variable and relatively high abundances of HREE (Figs. 4, 5, 6). Trace el-

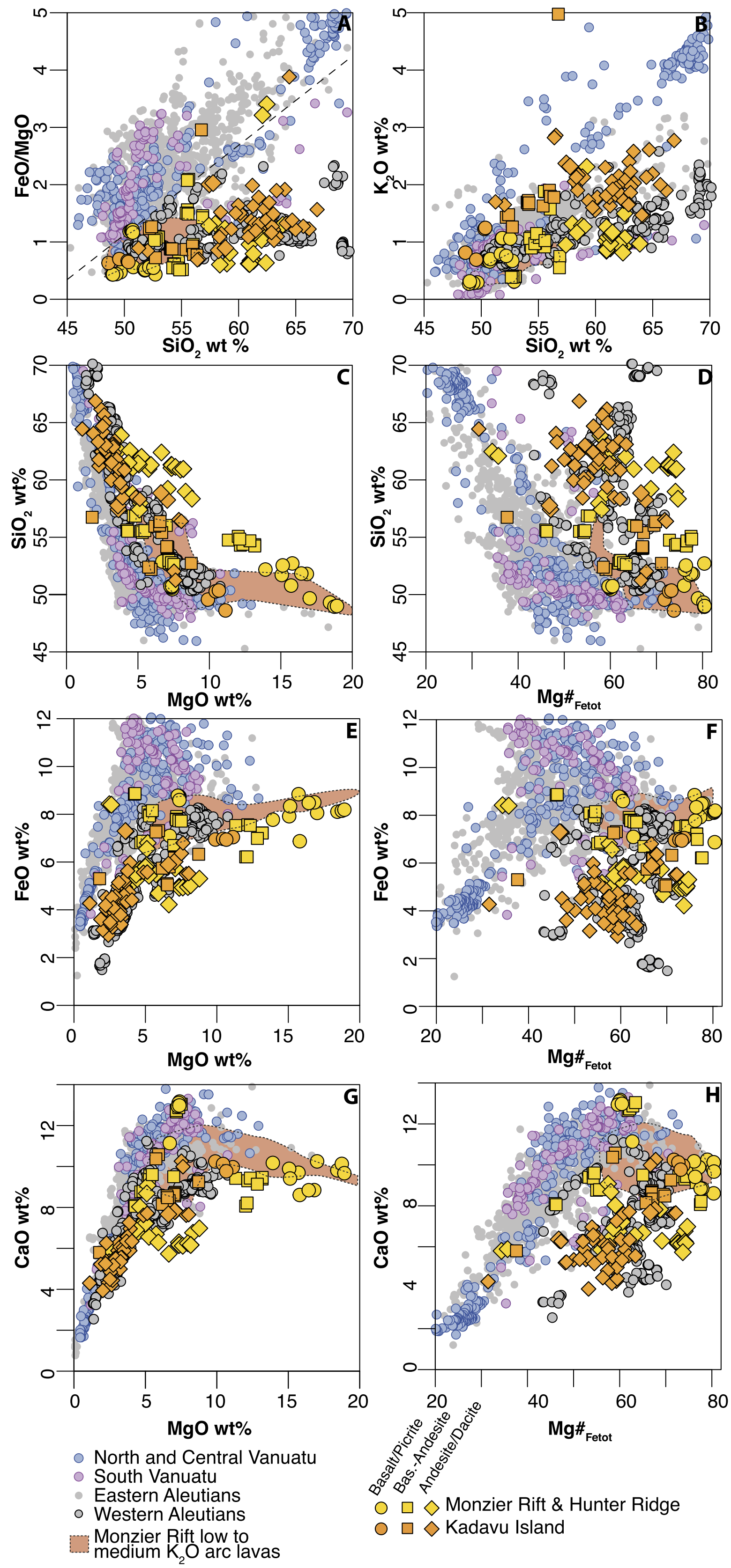

Fig. 3. Major element composition of low-FeO magmatism along the Hunter Ridge, Monzier Rift and around Kadavu Island: **A)** SiO_2 wt% versus FeO/MgO; **B)** SiO_2 wt% versus K_2O wt%; **C-D)** MgO wt% and $Mg\#_{Fetot}$ versus SiO_2 wt%; **E-F)** MgO wt% and $Mg\#_{Fetot}$ versus FeO wt%; **G-H)** MgO wt% and $Mg\#_{Fetot}$ versus CaO wt%. Data compilation for volcanic rocks from Vanuatu can be found in the electronic appendix. The western Aleutians combine submarine and emergent volcanoes from the western Cones, Piip, Ingenstrem Depression, Buldir, Attu, Shemya and Agattu islands. Eastern Aleutians are volcanic rocks between Seguam and Cold Bay (datasets from Yogodzinski et al. (2015) and references therein) (*electronic appendix* **DR1** for a map of the Aleutians). Hunter Ridge lavas also contain volcanic rocks dredged between Volsmar Seamount and Hunter Island from Monzier et al. (1993) (Fig. 1). Kadavu data also contains data from Danyushevsky et al. (2008). In **(A)**, tholeiitic and calc-alkaline discrimination trend from Miyashiro (1974).

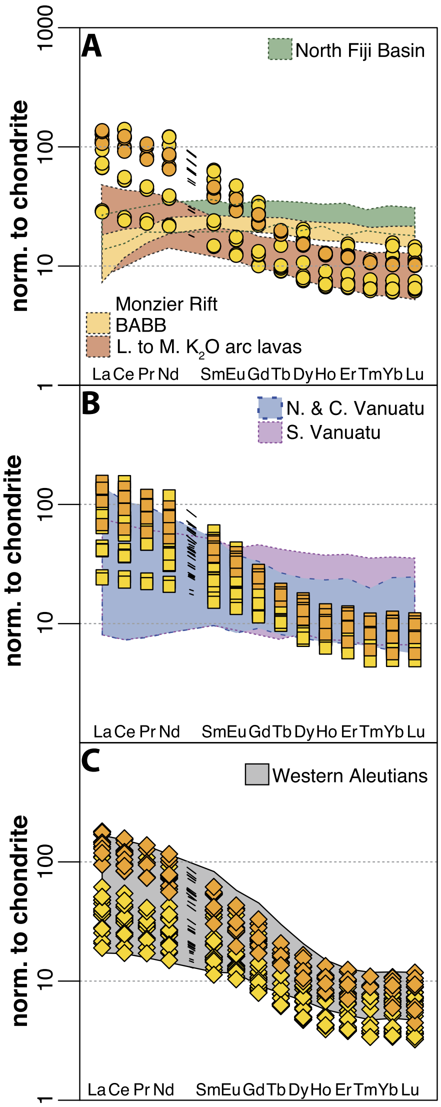

Fig. 4. A, B, C) REE patterns of Hunter Ridge, Monzier rift and Kadavu lavas; REE normalized to chondrite from McDonough and Sun (1995) and separated into **(A)** picrites and basalts **(B)**, basaltic–andesites **(C)** and andesites–dacites. Western Aleutians adakitic volcanism is from the Ingenstrem Depression (Yogodzinski et al., 2015). Monzier Rift BABB (back-arc basalts) and low- and medium-K_2O arc lavas as well as North Fiji Basin basalts (Eissen Spreading Center) are from Patriat et al. (2019).

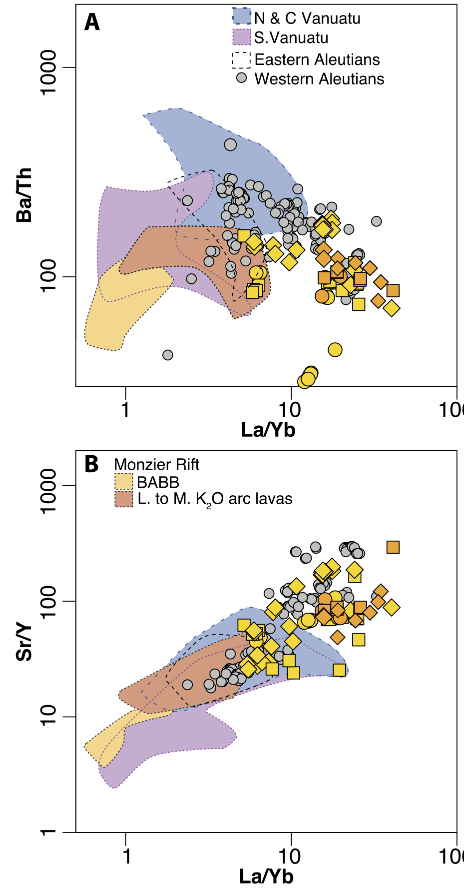

Fig. 5. A) Ba/Th versus La/Yb; **B)** Sr/Y versus La/Y for arc lavas. Data as in Figs. 3, 4.

ement proxies for hydrous fluids, such as Ba/Th, are low in the South Vanuatu arc (Ba/Th $<$ 500) and on average are higher in North and Central Vanuatu samples (Ba/Th up to 800), which are also, on average, more enriched in LREE with La/Yb commonly $>$ 4 (Fig. 5). In contrast, Hunter Ridge and Kadavu rocks have Ba/Th typically $<$ 200 but with strongly enriched LREE patterns, commonly with La/Yb from 6 to 40 (Fig. 5). To summarize, Hunter Ridge – Kadavu samples have distinctive high-Mg# adakitic signatures with elevated, yet heterogeneous, high Sr (500 – 3400 ppm), Sr/Y ($\leq$ 240) and La/Yb ($\leq$ 40) (Figs. 4–6). These patterns are particularly clear when the data are plotted as a function of sample location (Fig. 6).

Neodymium isotopes in Hunter Ridge – Kadavu arc lavas are relatively homogeneous, with radiogenic Nd values (ϵ_{Nd} = 7.2 – 9.6) similar to many Pacific MORB (Gale et al., 2013), with Kadavu lavas showing slightly less radiogenic values (Fig. 7a). Hafnium isotopic data, although sparse, show a narrow range of radiogenic compositions with ϵ_{Hf} of 12.5 – 13.5, which also lie within the field of Pacific-type MORB (*electronic appendix DR2*). Hunter Ridge – Kadavu arc lavas again display characteristics of Pacific-type MORB, with low $^{208}Pb/^{204}Pb$ (38.2 – 38.5) relative to $^{206}Pb/^{204}Pb$ (18.6 – 19.0) (Fig. 7b-c) and with Kadavu rocks showing slightly more homogeneous compositions. Strontium isotopes in Hunter Ridge – Kadavu samples are unradiogenic, with $^{87}Sr/^{86}Sr$ ranging from 0.7026 to 0.7032 (Fig. 7d), with Kadavu volcanism having slightly more radiogenic compositions (Fig. 7d). In contrast, Central Vanuatu arc lavas show relatively radiogenic $^{87}Sr/^{86}Sr$ ($>$ 0.7035) which trend to less radiogenic values along the Southern Vanuatu arc (0.7028 – 0.7035). Epsilon-Nd values are also less radiogenic (typically $<$ 8) along Central Vanuatu and more radiogenic (ϵ_{Nd} = 7 – 10) along Southern Vanuatu. Lead isotope ratios show a gradual shift in both $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ toward more radiogenic values along the entire convergent margin (Fig. 7b, c). Compared to Hunter Ridge lavas, spatially associated back-arc basalts (Fig. 7, Patriat et al., 2019) are more isotopically variable, with Pb, Sr, Nd isotopes overlapping North Fiji Basin basalts, and trending to relatively unradiogenic Nd and radiogenic Sr compositions (Fig. 8).

5. Discussion

5.1. Adakitic high-Mg# magmatism indicates melting of subducting ocean crust

Dredged volcanic cones and escarpments from Hunter Ridge to Kadavu Island reveal a diversity of volcanism formed since the onset of the North Fiji basin opening ∼12 Myr ago (Figs. 1, 2, 3, 4) (Patriat et al., 2019). A large proportion of dredged volcanic rocks from Hunter volcano to Kadavu Island range from picrites to high-Mg# dacites with low-FeO characteristics as described above (Fig. 3). These low-FeO characteristics coincide with elevated Mg# indicating that most lavas are primitive ($Mg\#_{Fetot}$>50) (Kelemen

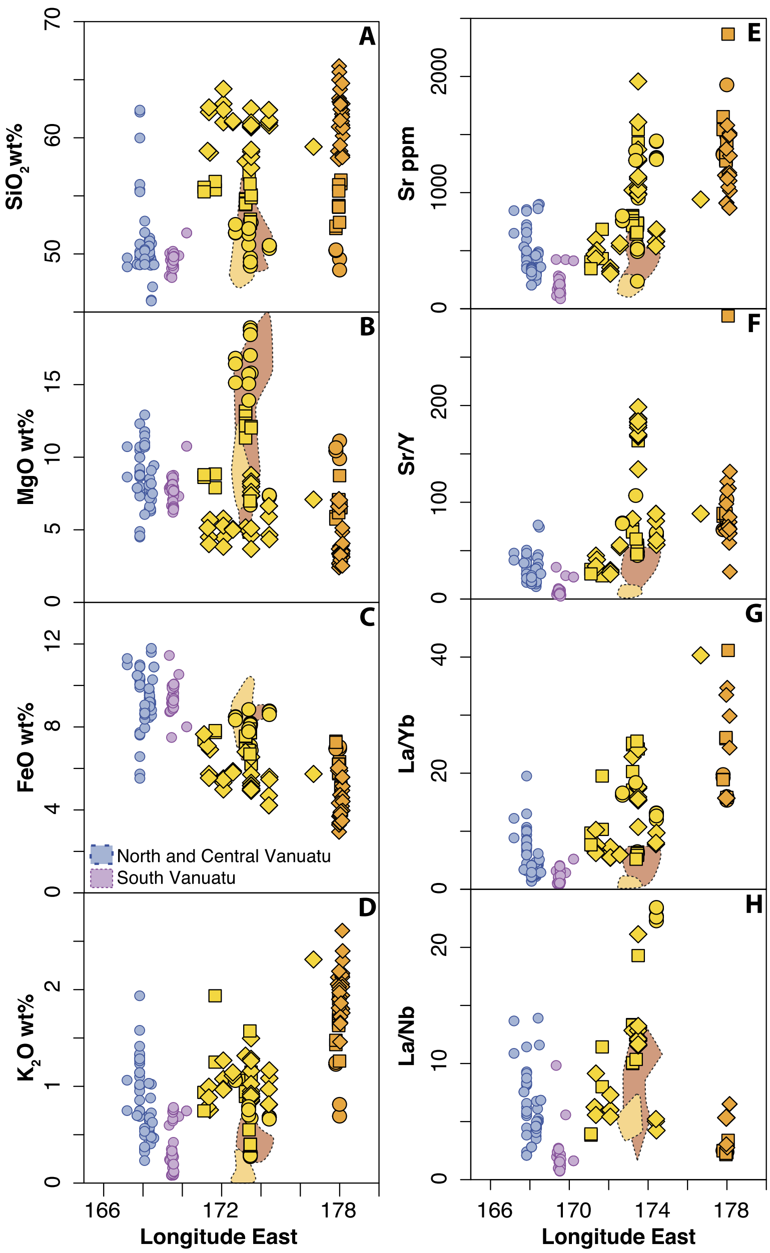

Fig. 6. A-D) Longitudinal evolution of **A-D)** SiO_2 wt%, MgO wt%, FeO wt%, K_2O wt% and **E-F)** Sr ppm, Sr/Y, La/Yb and Gd/Yb of primitive ($Mg\#_{Fetot} > 55$) lavas from Vanuatu, Hunter Ridge and Monzier Rift and Kadavu.

et al., 2003). High-Mg# andesites are often interpreted to reflect hydrous melting of a depleted mantle (Grove et al., 2003) but hydrous partial melting of subducted oceanic crust followed by reactions of the melt with the mantle wedge can explain low-FeO compositions as well (Kay, 1978; Kelemen et al., 2003; Yogodzinski et al., 1995, 2015; Walowski et al., 2015).

Trace element data reveal the ubiquitous presence of high-Mg# magmatism with adakitic characteristics (Defant and Drummond, 1990), as recorded by fractionated MREE/HREE (Gd/Yb = 1.5 – 5.7; Dy/Yb = 1.6 – 3.0), low Y (5 – 22 ppm), high Sr (> ca. 500 ppm) and high Sr/Y (50 – 250) (Figs. 4, 5, 6). These REE patterns contrast with Vanuatu arc magmatism and Monzier rift arc and back-arc magmatism (Figs. 4, 6), which grade from LREE-enriched to flat REE patterns. This contrast in volcanism is also illustrated by along-arc changes in trace element characteristics of primitive lavas which reveal a sharp increase in Sr (500 – 2500 ppm) and Sr/Y (to 50 – 250) along Hunter Ridge and toward Kadavu compared to the Vanuatu arc (Fig. 5, 6). This enrichment in LREE, depletion in HREE and consistently elevated high-Mg# ($Mg\#_{Fetot} > 50$) implies that crystal fractionation of magmatic amphibole is unlikely to be responsible for the development of such trace element patterns, as amphibole fractionation will drive magmas to high-SiO_2 and MREE-depleted patterns (*electronic appendix* DR3, Nandedkar et al., 2016). Instead, such fractionated trace element patterns are symptomatic of the widespread presence of garnet in the magmatic source.

Garnet trace element signatures can result from fractionation of magmatic garnet in the deep crust or melting of garnet-bearing lower crustal rocks (Alonso-Perez et al., 2009), or melting of eclogite-facies subducted oceanic crust (Kay, 1978; Defant and Drummond, 1990). High-resolution bathymetry of the study area reveals eruptions of adakitic magmas both in shallow waters along Hunter Ridge (<1000 mbsl) and in deep water (2000–3000 mbsl) within the Monzier rift (Figs. 1, 2). This implies that, like the western Aleutians, conditions allowing the stabilization of magmatic garnet cannot occur in this region, because the thickness of

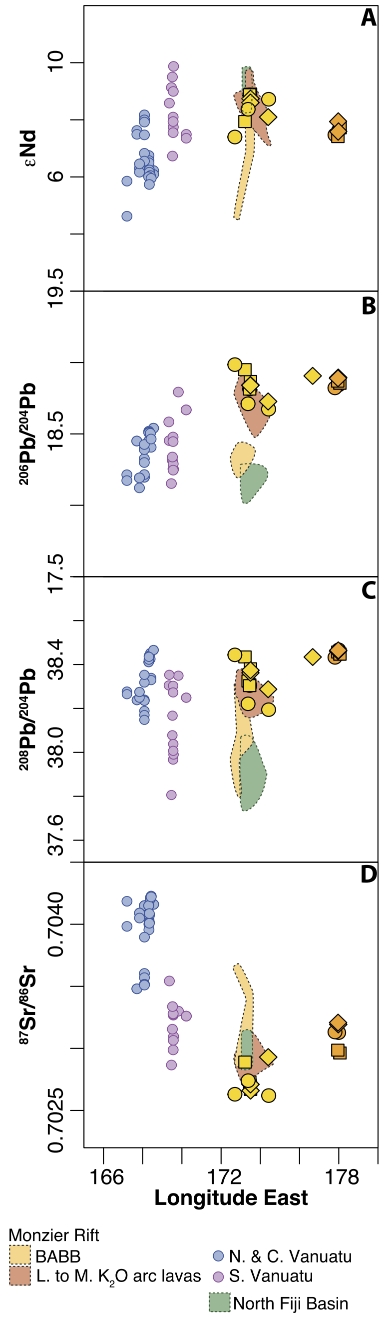

Fig. 7. A-D) Longitudinal evolution of ε_{Nd}, $^{206}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ for primitive (Mg#$_{Fetot}$>55) lavas from Vanuatu, Hunter Ridge and Monzier Rift and Kadavu. For clarity, North Fiji Basin data is restricted to Fleutelot et al. (2005).

the lithosphere is not expected to be greater than that of typical oceanic lithosphere (Yogodzinski et al., 2015). Therefore, only one interpretation remains plausible, namely the melting of subducted oceanic crust under eclogite-facies conditions leading to the formation of a silica-rich hydrous melt and a garnet-bearing residue (Kay, 1978; Defant and Drummond, 1990).

The subsequent migration and interaction of slab melts through the mantle wedge remains somewhat difficult to constrain. At low melt/rock ratios (0.1 – 0.05), hydrous slab melts are likely to react with the overlying depleted mantle at the interface with the subducting slab, forming hydrous high-Mg# andesitic melts within the colder sections of the mantle wedge (Lara and Dasgupta, 2020). These hydrous andesitic melts will ascend and react with the warmer parts of the mantle wedge, and will be diluted by mantle-derived basaltic- to basaltic-andesitic melts, leading to an array of picrites, basalts, basaltic-andesites and high-Mg# andesites retaining slab-melt (adakitic) characteristics (Kay, 1978; Yogodzinski et al., 1995; Kelemen et al., 2003; Lara and Dasgupta, 2020). However, the recovery of high-Mg# andesitic- to dacitic rocks with adakitic signatures suggests that certain melts are not efficiently diluted by mantle melting as they pass through the hot core of the mantle wedge. This situation is not unique to Hunter Ridge and is a common feature of adakitic magmatism along the Western Aleutians (Figs. 3, 4, 5) and a variety of other circum-Pacific locations (Yogodzinski et al., 2015 and reference therein). A possible explanation might reside in the ascent of slab-melts as buoyant diapirs, where slab melts are armored from the mantle wedge by reactive pyroxenites upon ascent (Yogodzinski et al., 2015). At shallow depths, thin crust and upper plate extension likely create pathways for magma ascent. This likely also explains the unusual variety of primitive magma types at the Hunter Ridge (Figs. 1, 2).

The contrast in magmatic composition between the Vanuatu arc lavas on one hand and the Hunter Ridge and Kadavu lavas on the other (Figs. 5, 6) closely resembles the contrasting character of western versus eastern Aleutian magmatism (Yogodzinski et al., 2015). Primitive, high-Mg# magmatism is ubiquitous along the western Aleutians where hydrous, low-FeO magmatism including andesites and dacites with adakitic trace element characteristics closely resembles volcanism along Hunter Ridge (Yogodzinski et al., 1995, 2015), but is distinct from more typical calc-alkaline arc magmatism along the central and eastern Aleutian arc (Figs. 3, 4, 5). Hunter Ridge and Kadavu therefore represent an important end-member in the realm of arc magmatism, wherein trace element and isotopic characteristics are controlled by the presence of residual garnet upon melting of subducted oceanic crust, and where the resulting geochemical signature can be linked to common arc basalts and andesites.

Variation in the adakitic trace element signatures in Hunter Ridge and Kadavu samples, including enrichment in Sr and LREEs coupled to depletion in the HREE (Fig. 4, 5), are unlinked to changes in isotopic compositions (Figs. 8a, b, c, 9a). Neodymium isotopes are not shifted toward unradiogenic compositions as would be expected if the enrichment in trace element patterns was inherited from subducted sediment (Figs. 8a, b, Fig. 9a). This decoupling is particularly clear for Sr isotopes (Fig. 8c) with Hunter Ridge and Kadavu adakites showing persistently unradiogenic compositions ($^{87}Sr/^{86}Sr \leq 0.7032$) in samples with Sr abundances from 500 to 3400 ppm. Increasing LREE and decreasing HFSE/REE have been interpreted to reflect the addition of subducted sediment to the source of arc magmatism (Peate et al., 1997; Plank, 2005). However, increasing sediment contribution to a mantle source must be linked to a marked shift in ε_{Nd} and $^{87}Sr/^{86}Sr$ with increasing REE abundances due to the trace element and isotopic characteristics of sediments (Peate et al., 1997; Pearce et al., 2007) (Fig. 9).

The high-Mg# western Aleutians volcanism, which carries a minimal signature of subducted sediment (Yogodzinski et al., 2015, 2017 and references therein), shows similar compositional trends indicating a decoupling of trace element enrichments and depletions from isotopic compositions (Figs. 8a, b, c, 9a). The data patterns reveal similarly low Ba/Th in samples with elevated Sr/Y and La/Yb (Fig. 5) and similar low-FeO, low-CaO and high-Mg# major element characteristics (Fig. 3, 4). These data patterns clearly show that Hunter Ridge – Kadavu adakites with depleted isotopic compositions must result from the melting of subducted oceanic crust with relatively little influence of subducted sediment. The lack of sediment contribution to Hunter Ridge - Kadavu magmatism is not altogether surprising, considering the thin sedimentary cover along the trench, particularly along the north-western part of the South Fiji Basin (*electronic appendix DR4*).

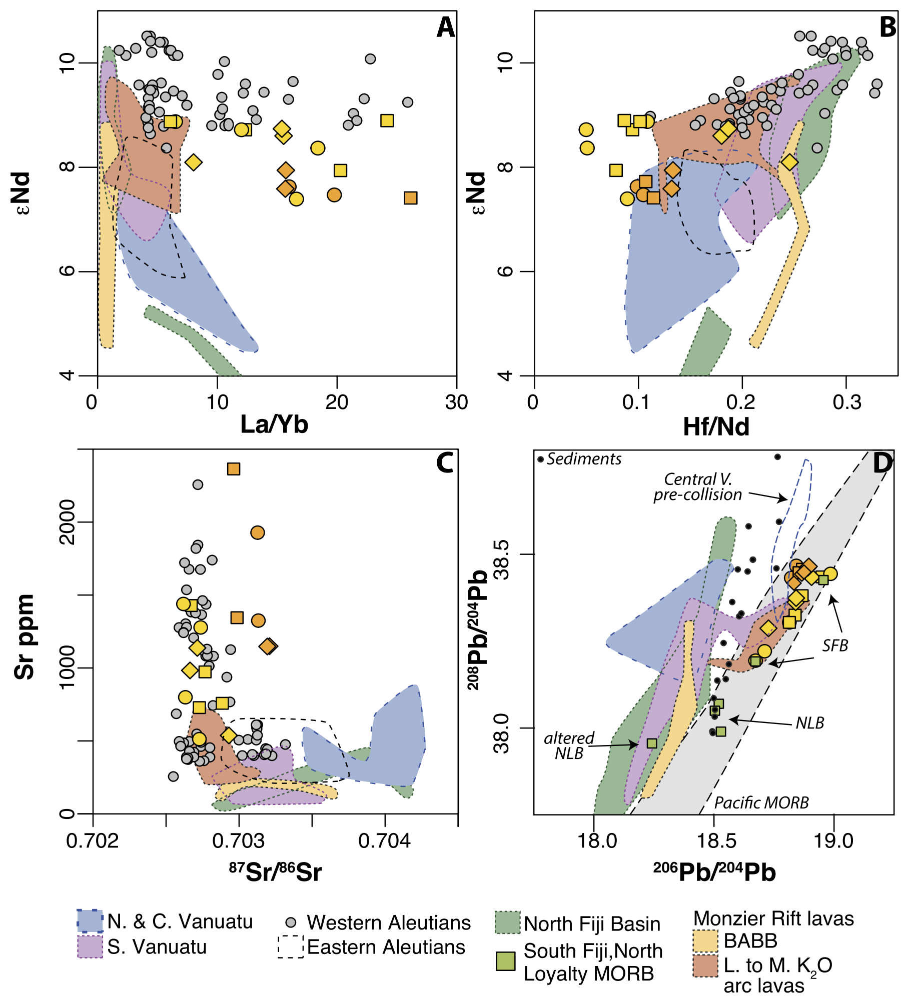

Fig. 8. **A-B)** ϵ_{Nd} as a function of La/Yb and Hf/Nd; **C)** Sr (ppm) as a function of $^{87}Sr/^{86}Sr$; **D)** $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$. Same data sources as preceding figures. Field of Pacific MORB from Gale et al. (2013). South Fiji Basin and North Loyalty Basin oceanic crust (MORB basalts and gabbros) from Peate et al. (1997), Pearce et al. (2007) and Fleutelot et al. (2005). Sediments from the North Loyalty Basin are from Peate et al. (1997). In (D), the field of Central Vanuatu volcanism prior to the collision of D'Entrecasteaux Ridge is from Peate et al. (1997).

5.2. Melting of subducted MORB ocean crust controls the Pb–Nd–Sr of adakitic lavas

The isotopic composition of the mantle below the Hunter Ridge and Kadavu is recorded in the North Fiji Basin, Eissen spreading center, and back-arc basalts from the Monzier Rift (Fleutelot et al., 2005; Patriat et al., 2019) Figs. 8, 9). The underlying mantle may be heterogeneous, but it has well-defined Indian-MORB characteristics, including elevated $^{208}Pb/^{204}Pb$ and low $^{206}Pb/^{204}Pb$ (Fig. 8d), as well as somewhat radiogenic $^{87}Sr/^{86}Sr$ compared to Pacific-type MORB (Fig. 8c, 9b, c) (Fleutelot et al., 2005; Pearce et al., 2007; Patriat et al., 2019; Table 1).

Subducting sediment from the North Loyalty Basin sampled by drilling at DSDP Site 286 (Fig. 1) show a wide range in ϵ_{Nd} with somewhat radiogenic compositions (10.7 – 3.6) which have been interpreted to reflect volcaniclastic sediments shed from the arc (Peate et al., 1997). Strontium isotopes are variable but typically show radiogenic values ($^{87}Sr/^{86}Sr$ = 0.7036 – 0.7078). Sediments are variable in Pb-isotopic ratios (Fig. 8d), but an average sediment component was estimated by Peate et al. (1997) as $^{206}Pb/^{204}Pb$= 18.7, $^{207}Pb/^{204}Pb$=15.59, and $^{208}Pb/^{204}Pb$=38.5. In contrast, the South Fiji Basin basaltic section of oceanic crust, which subducts below the Hunter Ridge, has a Pacific-MORB isotopic composition, as shown by elevated $^{206}Pb/^{204}Pb$, unradiogenic $^{87}Sr/^{86}Sr$ (~0.7025) and relatively radiogenic Nd (ϵ_{Nd}=8–9, DSDP Sites 205, 285, Pearce et al., 2007) (Fig. 8d, 9b). Isotopic compositions of the ocean crust of the North Loyalty Basin are more variable and straddle Indian–Pacific MORB affinities, with lower (ϵ_{Nd}=5.2) at a given ϵ_{Hf} (13.2), and lower $^{206}Pb/^{204P}b$ at low $^{208}Pb/^{206}Pb$ (Peate et al., 1997; Pearce et al., 2007, Figs. 8, 9, Fig. DR2).

As previously stated, isotopic data require that fractionated trace element patterns of adakitic lavas along Hunter Ridge and Kadavu are controlled by melting of subducted oceanic crust. Changes in HFSE/REE ratios with no concomitant shift towards unradiogenic ϵ_{Nd} cannot be explained by melting of subducted sediments or significant interaction with an Indian-MORB mantle source (Fig. 9a; Yogodzinski et al., 2015; McCarthy et al., 2021). The near-constant radiogenic ϵ_{Nd} values with increasing LREE abundances require a source with ϵ_{Nd} values matching those of MORB but with enriched REE patterns (Fig. 9a, b). The isotopic composition of the Hunter Ridge adakites is unlike the underlying Indian-MORB mantle but has Nd and Pb isotopic ratios nearly identical to the Pacific-MORB reflected in the basaltic section of South Fiji ocean crust (Figs. 8, 9). Isotopic data therefore tell us that Pb and Nd in Hunter Ridge adakites are primarily derived from the basaltic section of subducting oceanic lithosphere of the South Fiji Basin. The low abundances of Pb in the depleted mantle and its incompatible and fluid-mobile nature imply that unradiogenic Pb in arc magmas must be derived dominantly from sources within the sub-

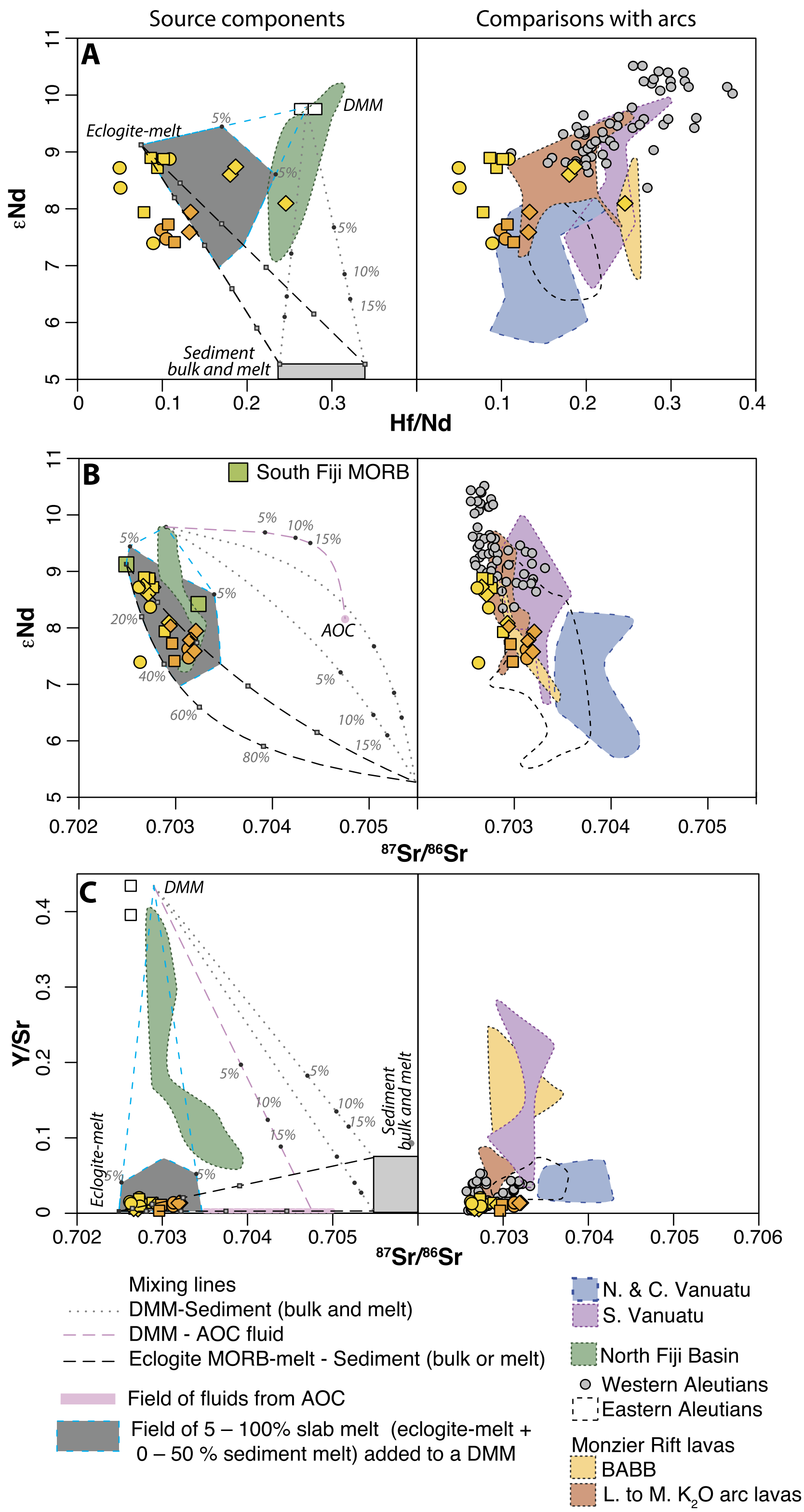

Fig. 9. Mixing lines for source components: **A)** Hf/Nd as a function of ϵ_{Nd}; **B)** ϵ_{Nd} as a function of $^{87}Sr/^{86}Sr$; **C)** Y/Sr as a function of $^{87}Sr/^{86}Sr$. DMM from Workman and Hart (2005). Mixing end-members and details for calculations can be found in Table 1. In **(A)**, the reason for the Hf/Nd discrepancy is the higher Nd of the Hunter Ridge melt compared to an eclogite MORB melt. This is likely a consequence the dependence of Hf-Nd partitioning during slab melting on distinct P-T-H_2O conditions (Kessel et al., 2005; Yogodzinski et al., 2015; Carter et al., 2015).

ducted oceanic lithosphere (Straub et al., 2009; Straub and Zellmer, 2012).

The unradiogenic $^{87}Sr/^{86}Sr$ of Hunter Ridge adakites is surprising considering that Sr abundances vary by $\geq$ 2000 ppm (Fig. 8c). Typically, arcs show radiogenic $^{87}Sr/^{86}Sr$ = 0.7030 – 0.7045 (Straub and Zellmer, 2012; Nielsen and Marschall, 2017) which is widely interpreted to reflect mixing of sources of Sr in the depleted mantle, subducted sediment, and altered oceanic crust (Fig. 9). The unradiogenic $^{87}Sr/^{86}Sr$ of Hunter Ridge adakites however precludes significant addition of fluids (or melting) of

Table 1
Endmember compositions and mixing models. The isotopic composition of the mantle wedge **(i)** beneath the Hunter Ridge is inferred from erupted lavas from spreading center from the North Fiji basin (Pearce et al., 2007; Patriat et al., 2019) with trace element abundances from a DMM (Workman and Hart, 2005). Values for bulk sediments **(ii)** are average sediments from DSDP Site 286 (Peate et al., 1997; Pearce et al., 2007). A sediment melt **(III)** is calculated by multiplying these sediment values by an enrichment factor. This enrichment factor is derived from averaging experimental melt compositions divided by the bulk composition of the starting sediment composition of experimental runs from Hermann and Rubatto (2009) and Skora and Blundy (2010) at conditions of 800 – 900 °C, 2.5 – 3.5 GPa ($\pm 1\sigma$ are also shown for comparison). The eclogite-facies MORB melt endmember **(IV)** is defined by the isotopic composition of subducted MORB oceanic crust from the south Fiji Basin (DSDP 205, 284, Peate et al., 1997; Pearce et al., 2007). Trace element abundances of an eclogite melt, based on experimental datasets at 900 °C and 4 kbar from Kessel et al. (2005) are from Yogodzinski et al. (2015). Y is estimated on the basis of Sr abundances in order to have a Y/Sr ca. 0.002 (Yogodzinski et al., 2017), which is within the range of Y/Sr of experimental eclogite melts from Carter et al. (2015) (Y/Sr=0.001-0.019). For altered ocean crust fluids **(V)**, values are from Tollstrup et al. (2010), with Sr abundances from Staudigel et al. (1995). The ^{87}Sr/^{86}Sr isotopic ratios of fluids are from Yogodzinski et al. (2017) (^{87}Sr/^{86}Sr of 0.7035 – 0.7050).

Endmembers	^{143}Nd/^{144}Nd	^{07}Sr/^{06}Sr	^{176}Hf/^{177}Hf	Sr ppm	Hf ppm	Nd ppm	Y ppm
I. Mantle Source	0.51313	0.70290	0.28325	7.66	0.16	0.58	3.33
II Bulk sediment DSDP Site 286	0.51290	0.70548	0.28312	338.00	3.48	14.60	25.00
III. Calculated sediment melt	0.51290	0.70548	0.28312	725.50	3.29	9.69	2.17
IV. Eclogite-facies MORB melt	0.51310	0.70249	0.28312	1500.00	0.86	11.50	4.00
V. Altered ocean crust (fluid)	0.51305	0.70475	0.28325	180.00	0.10	0.70	0.90
Average sediment melt enrichment factor	-	-	-	2.15	0.94	0.66	0.09
+1σ sediment melt enrichment factor	-	-	-	1.38	0.67	0.34	0.02
-1σ sediment melt enrichment factor	-	-	-	2.92	1.22	0.98	0.15

seawater-altered oceanic crust (Figs. 8, 9). This source of unradiogenic Sr, even more unradiogenic than the North-Fiji mantle (Fig. 7d), is only found in the relatively unaltered basaltic crust of the South Fiji Basin (DSDP Sites 285 and 205; Peate et al., 1997; Pearce et al., 2007) (Figs. 8c, 9b, c). Based on Sr–Nd isotopic ratios and Y/Sr, most Hunter Ridge adakites can be explained by a slab melt composed of 90 – 70% of melt from unaltered mafic portions of South Fiji ocean crust and 10 – 30% sediment melt (± altered ocean crust) (Fig. 9b, c, Table 1). Such a contribution of unradiogenic Sr leads to a systematic shift in adakitic rocks toward less radiogenic ^{87}Sr/^{87}Sr at nearly constant and radiogenic ϵ_{Nd} compared to the underlying Indian-MORB mantle (Fig. 9b). It is therefore reasonable to conclude that Sr, similar to Pb, is also primarily derived from the mafic section of the subducting plate, efficiently diluting any subducted sediment signal and mantle wedge heterogeneity, as is required by mass balance (Straub and Zellmer, 2012).

5.3. Unradiogenic Sr in arc magmas

Alternative models requiring melting of mechanically mixed subduction mélanges have been proposed to explain shifts in Hf/Nd trace element ratios (Nielsen and Marschall, 2017). As shown along the Hunter Ridge (Figs. 7, 8, 9), contributions of Pb–Nd–Sr from the Indian-type mantle wedge are overwhelmed by contributions from the Pacific-type mafic crust from the downgoing slab. It is particularly notable that primitive picrites, basalts and andesites with adakite signature all have similar isotopic compositions which resemble those of Pacific MORB (Figs. 8, 9). This implies that despite interaction with the mantle wedge, as expressed in the major element and high-Mg# characteristics of these adakitic rocks (Fig. 3), isotopic characteristics derived from melting of South Fiji MORB appear to have remained unaffected by interaction with and melting of North Fiji mantle (Figs. 8, 9). Thus, the depleted isotopic character of adakitic rocks along both the Hunter Ridge and western Aleutians are best explained by deriving Pb, Nd, Sr (and likely Hf, *electronic appendix DR2*) from the unaltered mafic section of the subducted oceanic crust, as also shown by mass balance calculations in Straub and Zellmer (2012) and Yogodzinski et al. (2015, 2017).

Serpentinized suboceanic mantle lithosphere can store up to 13% H_2O but only minor amounts of Sr when compared to partial melts of a basaltic source at eclogite-facies conditions (Scambelluri et al., 2004; Carter et al., 2015). This is important because Sr is highly mobile in fluids (Kessel et al., 2005) and seawater-altered oceanic lithosphere has radiogenic Sr (Fig. 9) (Staudigel et al., 1995), which implies that a fluid source containing significant amounts of H_2O but relatively little Sr is required. Thermal models of subduction zone have shown that early dehydration of altered ocean crust and sediments implies that the top section of the slab is dry and therefore unlikely to melt (Syracuse et al., 2010; Bouilhol et al., 2015). Instead, these models predict that eclogite-facies mafic crust might melt as a consequence of flux-melting driven by dehydration of subducted oceanic mantle at higher pressure (Bouilhol et al., 2015). Tectonically controlled infiltration of seawater during ocean spreading (Andreani et al., 2007) or upon bend-faulting (Grevemeyer et al., 2018; Kendrick et al., 2020) will lead to serpentinized mantle underlying unaltered mafic ocean crust. This is consistent with halogen compositions in Hunter Ridge volcanic rocks, expressed as ratios of Br/Cl and I/Cl in volcanic glasses (Kendrick et al., 2020), which indicate a fluid origin from altered oceanic lithosphere and serpentinites and not from overlying sediments.

The isotopic evidence recording the breakdown of oceanic serpentinites at subarc depth and concomitant flux-melting of unaltered mafic eclogite is consistent with geophysical evidence showing first an initial pulse of dilute, water-rich fluids from pore-water and sediments being expulsed at shallow (forearc) depth prior to a second pulse of fluids with elevated concentrations of silicate components at higher depth below the arc (Manning and Frezzotti, 2020). We therefore conclude that the addition of H_2O from the breakdown of serpentinites in the mantle section of subducted lithosphere is a key factor driving flux-melting of dehydrated eclogite and is likely to be a more widespread process at convergent margins than typically thought (Prouteau et al., 1999; Portnyagin et al., 2007; Spandler and Pirard, 2013; Walowski et al., 2015; Yogodzinski et al., 2017).

5.4. The slab-melt component in common arc magmas

Mantle melting remains an important contributor to magmatism along the Hunter Ridge, as shown by back-arc basalts and low- to-medium K_2O arc lavas with no adakitic signatures both along South Vanuatu and Hunter Ridge (Figs. 3–6). Even if extensive decompression- and flux-melting of the mantle wedge will dilute slab-melt components (Bouilhol et al., 2015), we show that non-adakitic arc rocks record isotopic and trace element trends compatible with such components. Increasing LREE and depletion in HREE from back-arc basalts to low- and medium-K_2O arc lavas (Figs. 4, 5, 6) are linked to a shift in Pb-isotopes from Indian-type to Pacific-type MORB (Patriat et al., 2019) (Figs. 7, 8d). Increasing Sr abundances from back-arc basalts to arc lavas are correlated with a shift to more unradiogenic and more homogeneous

$^{87}Sr/^{86}Sr$ (Fig. 8c). On the other hand, increasing enrichment in LREE which drives changes in La/Yb and Hf/Nd is not accompanied by shifts toward less radiogenic Nd (Fig. 8a, b and Fig. 9a). Small shifts toward more radiogenic Nd occur at nearly constant unradiogenic $^{87}Sr/^{86}Sr$, forming a compositional field between that of an ambient North Fiji mantle and Hunter Ridge adakites (Fig. 8b). These low- to medium-K_2O lavas thus overlap the trace element and isotopic field controlled by the addition of $\geq$ 5% of a slab melt component (Fig. 8a, b, c) forming a field connecting mantle-derived melts originating from an Indian-MORB mantle (back-arc basalts) with slab melts derived from Pacific-MORB South Fiji crust (adakites).

South Vanuatu volcanism, dominated by back-arc magmatism and with a limited slab component (Figs. 4, 8), shows a compositional shift in Pb-isotopes toward Hunter Ridge and Monzier Rift rocks from an Indian-type mantle typical of the North Fiji Basin, toward Pacific-type MORB (Fig. 8d). Variations in ϵ_{Nd} (6.5 – 10.0) and Y/Sr (0.05 – 0.3) occur at near-constant and unradiogenic $^{87}Sr/^{86}Sr$ (ca. 0.7030 – 07035) similar to Hunter Ridge samples (Fig. 8). Consequently, South Vanuatu volcanism reflects both heterogeneities in mantle chemistry, as reflected in the heterogeneity of North Fiji MORB and erupted back-arc basalts, and addition of a slab melt component.

Contributions from subducted sediment and altered oceanic crust in the isotopic evolution of Central and Northern Vanuatu arc magmatism are shown by more radiogenic $^{87}Sr/^{86}Sr$ and higher Ba/Th (200–800) (Figs. 5, 7, 9) (Peate et al., 1997; Raos and Crawford, 2004). However, there is a systematic shift towards lower Hf/Nd with invariant and relatively radiogenic Nd (ϵ_{Nd} ~7-8) partially overlapping Kadavu and Hunter Ridge arc rocks, compared to Southern Vanuatu arc and the underlying Indian-MORB mantle (Fig. 9a). Consistent with the addition of subducted sediment, these lavas are shifted toward slightly more radiogenic $^{87}Sr/^{86}S$ and less radiogenic Nd within a field controlled by slab melting (Fig. 9b). We stress that mixing lines between a DMM and subducted sediments (± fluids from AOC) would require arc lavas to be shifted toward significantly more radiogenic $^{87}Sr/^{86}Sr$ at a given unradiogenic ϵ_{Nd} and Y/Sr (dotted lines, Fig. 9b, 9b,c). Prior to the collision of the D'Entrecasteaux Zone, magmatism of Central Vanuatu was shifted toward higher $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ (Fig. 8d), similar to Pacific-type South and North Vanuatu and Hunter Ridge volcanism (Peate et al., 1997). However, post-collisional volcanism along the D'Entrecasteaux Zone shifts toward a more heterogeneous Indian-MORB signature (Fig. 8d). Again, in arc magmas, mass balance dictates that the Pb-isotopic signature of the mantle is overwhelmed by the contribution of the subducting slab (Straub et al., 2009; Straub and Zellmer, 2012) as also highlighted by the compositional trends of Hunter Ridge magmatism (Fig. 8d). Therefore, the Pb isotopic shift in Central Vanuatu arc lavas upon collision might reflect an increasing contribution of melting of altered ocean crust (AOC), an interpretation supported by the presence of medium-K_2O basalts along the Central Vanuatu arc (< 0.7 Ma) with adakitic characteristics, including elevated Sr/Y (45 – 87), elevated Sr abundances (720 – 1220 ppm), radiogenic $^{87}Sr/^{86}Sr$ (0.7039 – 0.7042) and Indian-type Pb isotopes (Raos and Crawford, 2004). Volcanism along the Central Vanuatu arc likely records the subduction of an isotopically heterogeneous lithosphere transitioning from Pacific-type MORB (pre-D'Entrecasteaux collision, Fig. 8d) toward Indian-type MORB affinity, as the origin and composition of the D'Entrecasteaux Ridge remains largely unconstrained (Meffre and Crawford, 2001).

Contributions to the arc magma source from partial melts of subducting MORB will generally be masked and diluted by source mixing with subducted sediment and melting of mantle rock (Kelemen et al., 2003). For example, Wheeler et al. (1987) identified a geochemical component with unradiogenic Sr that is also relatively K-rich, and which is responsible for the most marked geochemical variation expressed in volcanic rocks of the Sunda-Banda Arc (Indonesia). Wheeler et al. (1987) did not clearly identify the source of this component, but data patterns in the Vanuatu transition to Hunter Ridge and from eastern to western Aleutians indicate that it was likely produced by melting of subducting MORB under eclogite-facies conditions. Moreover, trends in Nd–Hf isotopic ratios indicate that melting of the subducted oceanic lithosphere below the Izu-Bonin arc persisted for at least 20 Ma after subduction initiation (McCarthy et al., 2021), whilst Tollstrup et al. (2010) recorded present-day melting of the subducted oceanic lithosphere below the Izu-Bonin rear-arc. Finally, such a slab melt component is also identifiable along the Kamchatka arc (Portnyagin et al., 2007) as well as along the eastern Aleutian arc, albeit considerably more diluted than along the western Aleutians (Kelemen et al., 2003; Yogodzinski et al., 1995, 2015, 2017, and Figs. 8, 9). The widespread presence of a slab-melt component in common (non-adakitic) arc rocks from a variety of subduction settings appears to be inconsistent with thermal models indicating that subducting plates are either too cold or too dry to make even modest contributions in the form of partial melts (e.g. van Keken et al., 2011). This inconsistency is resolved if fluids that drive melting of the slab originate in the mantle section of the subducting plate which (due to an inverted geothermal gradient of >200-300 °C) will undergo dehydration at approximately the point along the subduction path when the overlying oceanic crust has become hot enough to melt under water-saturated conditions (Poli and Schmidt, 2002). These constraints from experiments combined with geochemical patterns observed in a variety of circum-Pacific arc systems indicate that this is likely an important mechanism of elemental transfer to the mantle wedge at convergent margins (e.g. Prouteau et al., 1999; Poli and Schmidt, 2002; Portnyagin et al., 2007; Spandler and Pirard, 2013; Walowski et al., 2015; Bouilhol et al., 2015; Yogodzinski et al., 2017).

6. Conclusions

Recent volcanism along the Hunter Ridge and Kadavu (Fiji) is characterized by picrites and basalts to high-Mg# andesites and high-Mg# dacites with adakitic characteristics erupted at submerged volcanic cones along the Monzier Rift and on the western part of the Hunter Ridge. This adakitic volcanism is characterized by highly unradiogenic Sr compositions at elevated Sr abundances, which precludes melting of oceanic sediments as the source of arc magmatism. The Nd–Pb–Sr–Hf isotopic characteristics of this volcanism are distinct from the Indian-type MORB affinity of the North Fiji basin mantle, but have its origin in the melting of subducted South Fiji basin oceanic crust of Pacific-type MORB affinity. Sediment contribution to arc magmatism is overshadowed by the addition of Pb–Sr–Nd from unaltered subducted oceanic lithosphere. We show that magmatism along the Vanuatu – Hunter Ridge arc system has similar compositional patterns as the eastern and western Aleutians respectively, and that a slab-melt component, which has its origin in the melting of basaltic ocean crust, is likely to be a contributor to the trace element and isotopic diversity of classical (non-adakitic) Vanuatu – Hunter Ridge arc rocks. Such slab melt components are identified in non-adakitic rocks throughout the western Pacific, indicating that flux-melting of subducted oceanic lithosphere, caused by serpentinites dehydration, is a more ubiquitous process than typically thought.

CRediT authorship contribution statement

L.D. and T.F.: Shipboard proposals, shipboard scientists, laboratory analysis, supervision; R.M., J.W. J.M.M: laboratory analysis; I.S.:

Visualisation; Bathymetry; Sediment-thickness analysis; A.M.: conceptualization, design and isotope modeling; drafting of original manuscript; M.P., A.M., L.D., T.F., I.S., G.Y., J.M.M.: Writing, Reviewing and Editing.

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.

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Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.epsl.2022.117592.

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