Effects of mantle flow on the chemistry of Coriolis Troughs
backarc magmas

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Abstract

Ridge subduction along convergent plate margins can cause a tear to develop in the underlying slab, which allows the influx of hot sub-slab mantle materials into the mantle wedge. Such a process has a profound influence on the chemistry of Vanuatu arc magmas, but its effect on the genesis of Vanuatu backarc magmas remains to be assessed. Here we present new geochemical data for samples from the Coriolis Troughs (part of the Vanuatu backarc) and combine our new data with published analyses of samples from the entire Vanuatu arc. Many samples from the Coriolis Troughs have major element systematics, chalcophile element systematics and trace element ratios (i.e., Ba/Nb, Th/Nb) that are more similar to the global MORB array than Vanuatu arc samples. These systematics can be attributed to slab rollback prior to ridge subduction, which caused a progressive decline in the proportion of slab fluxes to the mantle source of the Coriolis Trough magmas. As rollback progressed, deep upwelling of enriched mantle components beneath the North Fiji Basin influenced the compositions of the erupted backarc basin magmas. Melting of this enriched mantle source generated the most recent Nifonea Caldera Floor magmas. In contrast to the other recent Coriolis Trough magmas, the Young Lava Plain samples have geochemical characteristics that are comparable to Vanuatu arc magmas. The Young Lava Plain magmas are situated to the southeast of a slab tear. We therefore suggest that influx of hot sub-slab mantle materials through a slab tear caused southeast flow (i.e., mantle flow away from the trench) of sub-arc mantle (i.e., mantle that was enriched by hydrous and oxidizing components released from the slab at sub-arc depths) and that this sub-arc mantle source generated the Young Lava Plain magmas. In particular, we suggest that this oxidized source can account for the anomalous chalcophile element signatures of the Young Lava Plain samples compared to the other Coriolis Trough samples. Because all of the Coriolis Trough samples have
similar depth-to-slab, we propose that changes in mantle flow patterns caused
by ridge subduction and the development of a slab tear can account for the
genesis of proximal magmas with comparable ages but distinct compositions.

**Keywords:** Coriolis Troughs, Mantle flow, Slab tear, Asthenosphere
upwelling, Chalcophile elements

1. **Introduction**

Backarc basins are extensional regions that form behind volcanic arcs and
are often the sites of magmatism (Grevemeyer et al., 2021; Hasenclever et al.,
2011; Martinez and Taylor, 2002; Pearce and Stern, 2006; Tontini et al., 2019).
Backarc basin formation is often linked to slab rollback, which causes extension
in the over-riding plate and promotes decompression melting (Pearce and Stern,
2006; Schellart, 2008; Schellart et al., 2002). This extension and associated
magmatism causes the mantle to become depleted by melt extraction, prior to
becoming entrained by corner flow and becoming the source of magmatism
beneath the main-arc (Magni, 2019; Pearce and Stern, 2006; Woodhead et al.,
1993). This conceptual model has been used to explain why arc magmas are
often more depleted in incompatible elements (e.g., Nb, Ta, Ti and Zr)
compared to backarc basin magmas (Pearce and Stern, 2006; Woodhead et
al., 1993).

Subduction of buoyant oceanic ridges and plateaus can play a key role in
influencing backarc basin evolution. This is because buoyant ridges typically
subduct at a shallower angle compared to typical oceanic crust, which can
result in a slowing of convergence rates between the subducting plate and the
over-riding plate (Axen et al., 2018; Bergeot et al., 2009; Calmant et al., 2003;
Wallace et al., 2009). Consequently, subduction of ridges can prevent trench
retreat, can lead to over-riding plate shortening and as a result, the occurrence
of backarc thrusting rather than backarc spreading and magmatism (Flórez-Rodríguez et al., 2019; Magni, 2019; Wallace et al., 2005). However, trench retreat and backarc basin magmatism might still take place either side of the subducting ridge. In this scenario, 3D numerical modelling predicts segmentation of the overlying plate and the development of a tear in the underlying subducting slab (Burkett and Billen, 2009; Hu and Liu, 2016; Magni, 2019). The development of a slab tear can be associated with influx of hot sub-slab mantle through the slab tear, first to the arc mantle and then to the backarc mantle (Chen et al., 2021; Confal et al., 2018; Faccenna et al., 2005; Lynner et al., 2017; Magni, 2019; Magni et al., 2014; Menant et al., 2016). The development of slab tears and the influx of hot sub-slab mantle into the mantle wedge have been used to explain the occurrence of seismic gaps (i.e., the lack of intermediate-depth earthquakes occurring in the subducting slab beneath the arc) and low-velocity anomalies (i.e., regions of anomalously hot mantle wedge), respectively, beneath sections of the Peruvian arc (Antonijevic et al., 2015; Hu and Liu, 2016), the Kamchatka arc (Koulakov et al., 2020; Levin et al., 2002), the Izu-Bonin arc (Zhang et al., 2019; Zhao et al., 2017) and the Trans-Mexican Volcanic Belt (Yang et al., 2009). The development of a slab tear can promote a change in mantle flow direction beneath the arc, from corner flow of mantle towards the trench prior to the development of the tear, to mantle flow away from the trench following the development of the tear (Confal et al., 2018; Lynner et al., 2017; Magni, 2019; Magni et al., 2014; Menant et al., 2016). The results of numerical models and geological and geophysical constraints also suggest that the occurrence of a slab tear and the influx of hot sub-slab mantle would result in a pulse of high-volume magmatism in the backarc basin (Bruguier and Livermore, 2001; Lin et al., 2004; Lin et al., 2007; Livermore et al., 1997; Magni, 2019). However, the role of slab tears in promoting complex mantle flow and heat patterns during the genesis of the backarc magmas is
Here we present new major and trace element data for volcanic glasses from the Coriolis Troughs. The Coriolis Troughs are part of the Vanuatu arc system (southwest Pacific) and are one of Earth’s youngest and most active backarc systems (Anderson et al., 2016; Maillet et al., 1995; Monjaret et al., 1991). Previous studies have attributed the anomalously voluminous magmatism in the region to upwelling of fertile mantle from 70–120 km depths beneath the North Fiji Basin. We suggest that the variability in compositions and scale of backarc basin magmatism at the Coriolis Troughs can also be linked to changes in mantle flow and heat patterns in response to subduction of the D’Entrecasteaux Ridge, the development of a slab tear and the resulting influx of hot sub-slab material into the mantle wedge and towards the backarc.

2. Geological background

The Vanuatu arc, which is located in the southwest Pacific (Fig. 1), has a complex evolutionary history (Anderson et al., 2016; Buys et al., 2014; Deng et al., 2022; Haase et al., 2020; Lima et al., 2017; Maillet et al., 1995; Monjaret et al., 1991; Peate et al., 1997; Turner et al., 1999). The initially southward subduction of the Pacific Plate beneath the Australian Plate at the fossil Vitiaz trench produced volcanism along the ancient (35.5–16.2 Ma) Vitiaz arc (Fig. 1a; Buys et al., 2014; Meffre and Crawford, 2001). At ~10–12 Ma, collision of the Ontong Java Plateau caused a subduction polarity reversal (Hall and Spakman, 2002; Schellart et al., 2006) and as a consequence, the Australian Plate started to subduct underneath the Pacific Plate (i.e., beneath what is now referred to as the Vanuatu rather than the Vitiaz arc; Pearce et al., 2007; Peate et al., 1997). Westward rollback of the descending Australian Plate caused clockwise rotation of the Vanuatu arc (Martin, 2013; Schellart et al., 2002). This rotation initiated the opening of the North Fiji Basin at ~11–12 Ma (Martin, 2013;
Schellart et al., 2006) and caused backarc basin rifting to initiate at the Coriolis backarc basin Troughs (Fig. 1b). Volcanic lavas retrieved from the pre-existing crust along the flank of the Coriolis backarc indicate that rifting initiated at ~6.5 Ma in the southern-most Futuna Trough, then propagated northward into Erromango Trough at ~4.1 Ma, and into Vate Trough at ~3.5 Ma (Figs. 2a and 3; Maillet et al., 1995; Monjaret et al., 1991).

At ~3 Ma, subduction of the D'Entrecasteaux Ridge at the centre of the Vanuatu arc caused segmentation of the Vanuatu arc into three blocks: the Northern, Southern and Central Blocks (Figs. 1b and 4; Anderson et al., 2016; Deng et al., 2022; Meffre & Crawford, 2001; Schellart et al., 2006). Eastward movement of the Central Block transmitted stresses away from the trench and resulted in the formation of a backarc thrust belt (Figs. 1b and 4). Deng et al. (2022) suggested that this transmission of stress, together with the shallowing of the subducting slab angle, likely caused the bulldozing of mantle material from beneath the front arc to beneath the main-arc (Fig. 4). Hence, following subduction of the D'Entrecasteaux Ridge, the Central Block experienced a reversal of mantle flow compared to the corner flow that presumably previously dominated across the Vanuatu arc (Fig. 2a). Subduction of the D'Entrecasteaux Ridge caused clockwise rotation of the Southern Block (Bergeot et al., 2009) and shallowing of the slab dip beneath the Central Block, but not the Southern and Northern Blocks (Deng et al., 2022; Hayes et al., 2018). The distributions of intermediate-depth earthquakes in the subducting slab beneath the Vanuatu arc revealed a ~100 km long seismic gap south of the D'Entrecasteaux Ridge (Figs. 2 and 4; Baillard et al., 2018; Deng et al., 2022; Prévot et al., 1991). This seismic gap has been attributed to the development of a slab tear in response to subduction of the D'Entrecasteaux Ridge and the steeper angle of subduction of the slab to the south of the D'Entrecasteaux Ridge (Deng et al.,
Influx of hot sub-slab mantle into the mantle wedge south of the tear has been used to explain the occurrence of magmatism anomalously close to the trench (i.e., at Efate in the forearc, Figs. 2 and 4; Deng et al. 2022).

A combination of sediment cover thickness, magma chemistry and high-resolution geological mapping (Fig. 5) have been used to establish the relative ages of eight volcanic units constituting the Vate Trough (Anderson et al., 2016; Haase et al., 2020). The chemistry of samples retrieved from the crust to the northeast of the Vate Trough indicates that the pre-existing crust was originally part of the main-arc, prior to rotation of the trench and subsequent backarc basin rifting (Anderson et al., 2016; Haase et al., 2020; Maillet et al., 1995; Monjaret et al., 1991). Thus, we refer to this old crust as ‘Remnant Arc Crust’ (Fig. 5a). The lavas constituting the Horst structure to the southwest of the Vate Trough (Fig. 5a) show weaker subduction signatures compared to samples from the Remnant Arc Crust (Haase et al., 2020). This suggests that the Horst structure lavas were generated by decompression melting during rifting of the backarc basin, rather than by subduction-induced hydrous flux melting during the genesis of the volcanic arc (Haase et al., 2020).

Nifonea shield-type volcano is located within the Vate Trough and is a massive ~14 km wide (Anderson et al., 2016). At the summit of Nifonea volcano is an approximately 5 × 8 km wide caldera (Figs. 3a and 5a). The Nifonea Caldera Rim, Sedimented Hummocky Volcanic Terrain, Hummocky Volcanic Terrain and Old Lava Plain are covered by sediment and/or are cut by dyke-like features (Fig. 5a). These units have been interpreted as the oldest backarc volcanic lavas that were erupted onto the basin of the rifted Vate Trough floor (Anderson et al., 2016). On the Caldera Floor are sheet flows, which are
considered to represent a solidified lava lake (Anderson et al., 2016). There are far fewer dyke-like features, volcanic cones and there is no sediment cover associated with the Young Lava Plain or Nifonea Caldera Floor volcanics. Thus, these two units constitute the youngest volcanic products to be erupted within the Vate Trough (Anderson et al., 2016; Lima et al., 2017). Anderson et al. (2016) suggest that the Nifonea Caldera floor volcanics and the Young Lava Plain volcanics represent the first and second major magmatic pulses during the recent evolution of the Vate Trough, respectively. However, it remains to be assessed if influx of hot sub-slab mantle through a slab tear and a consequent change in the direction of mantle flow (pink arrow, Figs. 2a and 4) has contributed to the anomalously voluminous magmatism rates at the Vate Trough.

3. Analytical techniques

Samples analysed for this study were dredged from the basin floor of the Coriolis Troughs during the CoTroVE Voyage (SS06/2004) in 2004. Twenty-five samples were analyzed for major and trace element compositions, including twenty samples from the Vate Trough, two samples from the Erromango Trough, and three samples from the Futuna Trough (Table S1). We supplement this dataset with unpublished data for samples from the Fiji Triple Junction (North Fiji Basin) for comparison (Table S1). With the exception of As and Se data (see below) major, trace and SIMS analyses were undertaken at the same time as analyses of volcanic glasses from the Valu Fa Ridge (see Jenner et al., 2015 for detailed analytical techniques). In summary, fresh volcanic glasses were mounted in epoxy and the major elements were analysed by a JEOL JXA-8900 electron microprobe (EPMA) equipped with five wavelength dispersive spectrometers at the Smithsonian Institution following the techniques outlined in Jenner et al. (2015). Analyses of VG-2, which was used as a monitor of major element accuracy, are within ≤5% of previous analyses of VG-2 glasses (Table
The fresh volcanic glasses were also mounted in indium and the concentrations of volatile elements were measured using the Cameca 6f ion microprobe at the Earth and Planets Laboratory, Carnegie Institution of Washington, following the analytical methods of Hauri et al. (2002) and Hauri et al. (2018). A secondary correction was applied to the SIMS data to account for slight offsets in analyses of reference material ALV519-4-1 from in-house preferred values (i.e., CO₂=165 ppm; H₂O=0.16 wt.%; F=95 ppm; S=950 ppm; Cl=53 ppm). Because some of the volcanic glasses that were mounted in indium had insufficient matrix glass (i.e., were too microlite rich) for SIMS analysis, analyses of S and Cl using the Cameca SX100 EPMA at the ANU (techniques given in Jenner and O'Neill, 2012a) were also undertaken for all glasses that were mounted in epoxy. Average analyses of S (1438 ppm) and Cl (290 ppm) in VG-2, which was used as a reference material during analysis, are in good agreement with previous analyses undertaken at numerous institutions (see compilation in Jenner and O'Neill, 2012a). Additionally, the EPMA and SIMS analyses show excellent agreement (see Table S1), except for the few samples where Cl analyses were close to the detection limits for EPMA.

With the exception of Se and As, the trace element concentrations of the epoxy-mounted volcanic glasses were analysed using laser ablation inductively coupled mass spectrometry (LA-ICP-MS) at the Earth and Planets Laboratory, using a Photon Machines Analyte G2 193 nm excimer laser system coupled to a Thermo iCap-Q ICP-MS, following the techniques described in detail in Jenner and O'Neill (2012b) and Jenner et al. (2015). Analyses of reference material BCR-2G, which was analyzed at the same time as the Coriolis Trough
samples, are presented in Table S3 and are typically within a few percent of preferred values for Ag (Reekie et al., 2019) and compiled preferred values given in Jenner et al. (2015).

To avoid the influence of argide, chloride, hydride and doubly charged REE interferences on Se and As masses, the concentrations of As and Se were analysed at the School of Environment, Earth and Ecosystem Sciences at the Open University using a Photon Machines Analyte G2 193 nm excimer laser system coupled to an Agilent 8800 ICP-MS/MS performing mass-shift oxygen reaction (0.1 ml/min) mode, following the methods described in Reekie et al. (2019) and Wieser et al. (2020). The accuracy of Se and As concentration analyses were monitored using four in-house reference materials, which are natural volcanic glasses from the Northwest Lau Spreading Center (NWLSC samples 39-1, 49-1, 51-1, 41-1; see Jenner et al., 2015 for discussion). Selenium analyses are within 1% to 8% (Table S4) of isotope dilution analyses on these four volcanic glasses (Jenner et al., 2015). Arsenic concentration analyses for samples NWLSC-39-1 and 41-1 (the other two NMWLS glasses have too low As to be reliable monitors of data accuracy and precision) are in agreement (within 8-9% and 2%, respectively; see Table S4) with previous LA-ICP-MS analyses presented in Jenner et al. (2015; where analyses were undertaken without using a reaction cell and instead, the interferences were measured and a correction was applied to the data) and ICP-MS/MS analyses presented in Wieser et al. (2020; where analyses were undertaken in mass-shift oxygen reaction mode, consistent with the data presented here).

4. Results and data compilation methods

On Fig. 5b we plot Na$_2$O+K$_2$O versus SiO$_2$ of samples analysed for this study and on Fig. 5c we combine our analyses (Table S1) with published analyses (see Table S5, data from Haase et al., 2020; Lima et al., 2017; Maillet...
et al., 1995) of samples from the Coriolis Troughs (sample locations given on Figs. 3 and 5a), the Remnant Arc Crust (sample locations given on Fig. 2a), the Horst structure (sample locations given on Figs. 3a and 5a), Efate Group Vanuatu forearc magmatic rocks (Fig. 2a; from the islands of Efate, Pele, Nguna and Emau, see data compilation in Deng et al., 2022), samples from the Vanuatu main-arc (Fig. 2a; see data compilation in Deng et al., 2022), samples from the Fiji Triple Junction (FTJ) and the MORB array (Jenner and O'Neill, 2012a). We excluded samples from our compilation with MgO >10 wt.%, to minimize the influence of cumulate processes.

The aim of this contribution is to track the chemical evolution of the Coriolis Troughs in response to subduction of the D'Entrecasteaux Ridge. Hence, it is convenient to classify samples retrieved from within the Vate Troughs into three groups based on eruption ages: 1) the Old Volcanics (i.e., samples from the Sedimented Hummocky Volcanic Terrain, the Hummocky Volcanic Terrain and the Nifonea Caldera Rim); 2) the Caldera Floor; and 3) the Young Lava Plain groups. Twenty-one samples that were recovered from a 500 m transect up the Horst structure and therefore have variable eruption ages (Haase et al., 2020) are referred to here as the Horst Group. Samples from the Caldera Floor have alkaline compositions, whereas the Old Volcanics have predominantly tholeiitic compositions (Figs. 5b and c), except two alkaline samples from the Southern Rift that might be linked to the Caldera Floor-related magmatism (grey arrows on Figs. 5-9). The Horst Group shows a range in compositions spanning from tholeiitic to alkaline (Fig. 5c). Samples from the Young Lava Plain plot on the alkaline-tholeiitic divide and are the first samples analysed from these units (Figs. 5b and c). Samples collected from Erromango and Futuna Troughs have tholeiitic compositions (Figs. 5b and c).
The Caldera Floor, Old Volcanics, Horst, Erromango and Futuna Trough samples show trends in TiO$_2$ and Na$_2$O concentrations with decreasing MgO that are comparable to tholeiitic samples erupting at Fiji Triple Junction and trends during fractional crystallization that are more similar to the global MORB array than the Vanuatu arc array (Fig. 6). Samples from the Coriolis Troughs show a broad increase in FeO$_T$ concentrations with decreasing MgO (Fig. 6c). The Young Lava Plain samples have lower TiO$_2$ and Na$_2$O concentrations and higher V/Yb ratios at a given MgO compared to the other Coriolis Trough samples (Fig. 6). The major element compositions and V/Yb ratios of the Young Lava Plain samples are comparable to those recovered from the Vanuatu arc and southwest Pacific backarc basin magmas from the Eastern Manus and the Southern Valu Fa Ridge (Lau Basin, Fig. 6).

With the exception of the Young Lava Plain samples, the Coriolis Troughs samples show a decrease in Cu and Ag concentrations with decreasing MgO that is comparable to the MORB array trend (Figs. 7a-b). These samples show approximately constant S and Se concentrations with decreasing MgO (Figs. 7c-d) and have S versus FeO concentrations that are comparable to the MORB array (Fig. 8a). The Young Lava Plain samples are offset to significantly higher Cu, Ag and Se concentrations and lower S concentrations at a given MgO and FeO$_T$ compared to the other Coriolis Trough samples (Figs. 7 and 8). The Cu concentrations of the Young Lava Plain samples are comparable to the Efate Group forearc samples (Fig. 7a). Additionally, at a given MgO (Fig. 7) and FeO$_T$ (Fig. 8a), the Cu, Ag, S and Se concentrations of the Young Lava Plain samples are comparable to those from the Eastern Manus Backarc Basin.

The Coriolis Trough samples show a broad increase in H$_2$O concentrations with decreasing MgO (Fig. 8b). Coriolis Trough samples with 6–8 wt.% MgO
show a large range in $H_2O$ concentrations (Fig. 8b) that span between the compositions of MORB and southwest Pacific backarc basin magmas from the Eastern Manus and the Southern Valu Fa Ridge. The Caldera Floor samples and the Young Lava Plain samples span to higher $H_2O$ concentration than the other Coriolis Trough samples. On plots of Nb/Zr versus Ba/Nb and Th/Nb, the global MORB array and the Fiji Triple Junction samples show a continuum in compositions from low to high Nb/Zr and a narrow range in Ba/Nb (Fig. 9). The Vanuatu arc magmas and backarc basin magmas from the Eastern Manus and the Southern Valu Fa Ridge have higher Ba/Nb and show a narrower range in Nb/Zr compared to the MORB array (Fig. 9). Of the Coriolis Trough samples, the Caldera Floor samples span to the highest Nb/Zr, whereas the Young Lava Plain samples span to the highest Ba/Nb and Th/Nb (Fig. 9). The Caldera Floor samples have Nb/Zr versus Ba/Nb and Th/Nb that are intermediate between the compositions of alkaline and tholeiitic samples from the Fiji Triple Junction (Fig. 9). The Young Lava Plain samples have compositions that are comparable to Vanuatu arc samples, the Remnant Arc Crust samples and backarc basin samples from the Eastern Manus and Southern Valu Fa Ridge (Fig. 9). The Old Volcanics, Horst, Erromango and Futuna Troughs samples show a range in Ba/Nb, Th/Nb and Nb/Zr that are intermediate between the compositions of the Young Lava Plain and the Caldera Floor samples (Fig. 9).

5. Discussion

5.1. Variability in source fertility and slab fluxes

The compositions of subduction-related magmas are generally controlled by two components: the mantle wedge component and the slab-derived component (Elliott et al., 1997; Lima et al., 2017; Noll et al., 1996; Pearce, 2008; Pearce et al., 2005). Nb/Zr can be used as a proxy to trace the fertility of the mantle wedge and/or the degree of melting during magmatism, because Nb
and Zr are immobile during subduction of the slab and the bulk partition coefficient of Nb is lower than Zr (Escrig et al., 2012; Jenner, 2017; Sorbadere et al., 2013). Hence, both melts of fertile sources and low-degree melts have high Nb/Zr. To evaluate the extent of subduction input to the mantle wedge during magmatism requires use of ratios between elements with comparable bulk partition coefficients during melting of peridotite and fractional crystallization (i.e., Ba/Nb and Th/Nb), but different mobilities during subduction. For example, both Ba and Th are more mobile during subduction than Nb (Elliott et al., 1997; Pearce and Stern, 2006; Pearce et al., 2005) and therefore, the Vanuatu arc magmas and backarc magmas from the Eastern Manus and the Southern Valu Fa Ridge have higher Ba/Nb and Th/Nb compared to the MORB array (Fig. 9). Below we use the combination of these ratios to track the controls on the evolution of the Coriolis Troughs.

Samples from the Coriolis Troughs and in particular, the Vate Trough, show a large range in Nb/Zr (Fig. 9). If the degree of melting is the dominant variable controlling the large range in Nb/Zr of the Coriolis Trough samples, then all of the samples should have comparable radiogenic isotope compositions. However, the large range in radiogenic isotope compositions indicate that the mantle source beneath the Coriolis Troughs is heterogeneous (Haase et al., 2020; Lima et al., 2017). The differences in trace element and radiogenic isotope compositions between the Old Volcanics and the more recent Caldera Floor volcanics are consistent with a transition from sampling depleted to progressively more fertile mantle (Lima et al., 2017). However, this transition cannot account for why the most recent magmatism at the Vate Trough appears to be sourced from both depleted (the low Nb/Zr Young Lava Plain) and fertile (the high Nb/Zr Nifonea Caldera Floor) mantle wedge components.
The Old Volcanics, the Horst volcanics and samples from the Erromango and Futuna Troughs have typically higher Ba/Nb and Th/Nb compared to the more recent Caldera Floor volcanics (Fig. 9), but lower Ba/Nb and Th/Nb compared to the Remnant Arc Crust samples (Fig. 9). These systematics have been attributed to a decrease in the proportion of subduction fluxes with time (Haase et al., 2020). Clockwise rotation of the Southern Block of the Vanuatu arc and associated slab rollback is expected to have increased the depth-to-slab beneath the Coriolis Trough (Bergeot et al., 2009; Calmant et al., 2003; Deng et al., 2022; Hall and Spakman, 2002; Martin, 2013; Schellart et al., 2002; Schellart et al., 2006). Hence, a decline in the proportion of slab fluxes to the mantle source of the Coriolis Trough samples is expected (Gianni and Luján, 2021; Grove et al., 2009; Haase et al., 2020). For example, the Lau Basin samples show a systematic increase in Ba/Nb and therefore slab fluxes (Fig. 2f) with decreasing depth-to-slab (Fig. 2g, Escrig et al., 2012). The depth-to-slab estimates for the Coriolis Trough samples are ~210–260 km (pink bar on Fig. 2) and are comparable to those of samples from the Central Lau Spreading Centre (Figs. 2f-g). Hence, it is not surprising that most of the Coriolis Trough samples have similarly low Ba/Nb to the Central Lau Spreading Centre samples.

In contrast to the other Coriolis Trough samples, the Young Lava Plain samples have Ba/Nb, Th/Nb and major element compositions that are more comparable to samples from the Remnant Arc Crust and the Vanuatu arc (Figs. 6 and 9). Notably, the Young Lava Plain samples have Ba/Nb that are most comparable to the Lau Basin samples where the depth-to-slab is estimated to be ~100 km (Fig. 2). However, the depth-to-slab beneath the Young Lava Plain volcanics is ~230–250 km and indistinguishable from the depth-to-slab beneath the Nifonea Caldera (Fig. 2c). The most straightforward explanation for the high Ba/Nb and major element systematics of the Young Lava Plain samples is that
the mantle source region has been strongly overprinted by subduction-related fluxes (Hasenclever et al., 2011; Tontini et al., 2019). However, this hypothesis cannot explain why the comparable age Young Lava Plain and the Nifonea Caldera Floor samples have similar modern-day depth-to-slab, but record evidence for different proportions of slab flux addition to the source region (Figs. 2a-c). In summary, these systematics indicate that the most recent magmatism at the Vate Trough is tapping a depleted (low Nb/Zr) source that shows strong overprints by slab-derived fluxes (Young Lava Plain samples) and a fertile source (high Nb/Zr) that shows weak to negligible overprints from slab-derived fluxes (Nifonea Caldera Floor samples).

5.2. \( f_{O_2} \) variability in the mantle beneath the Coriolis Troughs

When magmas reach their sulfide solubility limits, they fractionate sulfides, which host chalcophile elements, such as Cu, Se and Ag (Chiaradia, 2014; Jenner, 2017; Lee et al., 2012). For example, MORB show a continuous decrease in Cu and Ag concentrations with decreasing MgO, which is attributable to sulfide fractionation (Jenner, 2017; Jenner et al., 2010). Most MORB are sulfide saturated at a high MgO during fractionation, because magmatism at mid-ocean ridges typically leaves residual sulfide in the source (Reekie et al., 2019). The solubility of S increases with increasing \( f_{O_2} \) of a melt (Jugo, 2009). Hence, for a given source composition, mantle sources with a higher \( f_{O_2} \) (e.g., the mantle wedge) exhaust sulfide at lower melt fractions compared to those with a lower \( f_{O_2} \) (e.g., the MORB-source mantle). If partial melting exhausts sulfide, magmas will have insufficient S to precipitate sulfides during fractionation (e.g., Lee et al., 2012; Deng et al., 2022). In this scenario, melts show an initial increase in Cu concentrations with decreasing MgO, such as the Eastern Manus Backarc basin magmas and the Efate Group forearc magmas (Fig. 7a). These Eastern Manus samples only reach sulfide saturation at 3–4 wt.% MgO (apparent from the decrease in Cu, Ag and Se concentrations,
Fig. 7), when magnetite fractionation drives the decrease in $fO_2$ and FeO$_T$ concentrations of the melts (Jenner, 2017; Jenner et al., 2010).

The Old Volcanics, the Caldera Floor, the Horst, the Erromango and Futuna Troughs samples show a similar range in Cu and Ag concentrations at a given MgO to the MORB array (Fig. 7). These systematics indicate that the melting events that sourced the majority of magmatism along the Coriolis Troughs left residual sulfide in the source and consequently, the magmas were sulfide saturated during fractionation. This conclusion is supported by the comparable S concentrations at a given FeO$_T$ of the majority of the Coriolis Trough samples compared to the sulfide-saturated MORB array (Fig. 8a). The Young Lava Plain samples have significantly higher Cu at a given MgO compared to the other Coriolis Trough samples, which indicates that sulfide might have been exhausted during mantle melting and consequently, the magmas were sulfide undersaturated during differentiation. Many of the Coriolis Trough samples and many MORB samples span to lower Nb/Zr than the Young Lava Plain samples (Fig. 9). This suggests that the source of the Young Lava Plain samples should have been fertile enough to contain residual sulfide if the $fO_2$ of the source was similar to, for example, the MORB source mantle during melting. We therefore suggest that the similar chalcophile element systematics (i.e., Cu, Ag, Se and S, Fig. 7), Ba/Nb and Th/Nb (Fig. 9) of the Young Lava Plain samples compared to the Efate Group forearc magmas and the Eastern Manus Backarc Basin magmas might indicate that addition of subduction-fluxes to the source region may have caused an increase in $fO_2$ of the source. Hence, we now evaluate if there is additional evidence for $fO_2$ variability beneath the Coriolis Troughs.

Laubier et al. (2014) proposed that the higher V/Yb ratios of arc magmas compared to the MORB array are attributable to the higher $fO_2$ of the mantle
wedge compared to the MORB-source mantle. This is because V becomes more incompatible in igneous minerals (i.e., olivine and pyroxene) as $fO_2$ increases, and thus, the ratio of V to a redox insensitive element, such as Yb, can be used as a proxy to track source $fO_2$ (Laubier et al., 2014). Hence, the overlapping V/Yb of the Old Volcanics, the Caldera Floor samples, the Horst samples, the Erromango and Futuna Troughs samples and MORB array indicates that the mantle sources of these samples have a similar $fO_2$ (Fig. 6d). In contrast, the Young Lava Plain, the Vanuatu arc, the Efate Group, the Remnant Arc Crust and backarc basin magmas from the Southern Valu Fa Ridge and the Eastern Manus (i.e., the sample suites with higher Cu at a given MgO compared to the MORB array, Fig. 7a) have higher V/Yb than the MORB array. This offset indicates that the mantle source regions of these magmas were more oxidized than the MORB-source mantle. Additionally, Deng et al. (2022) used V/Sc modelling to suggest that the $fO_2$ of the source region of the Efate magmas was higher than the source region of the Vanuatu arc magmas, which are in turn higher than the MORB-source mantle. Hence, differences in $fO_2$ could account for the differences in chalcophile element systematics between the Young Lava Plain compared to the other Coriolis Trough magmas.

Additional evidence for $fO_2$ variability in the mantle source region of the Coriolis Trough magmas can be gleaned from S systematics. The Young Lava Plain, Eastern Manus Backarc Basin and Southern Valu Fa Ridge samples have significantly lower S at a given MgO and FeO^T compared to the other Coriolis Trough samples and the sulfide-saturated MORB array (Figs. 7 and 8). Comparisons between the compositions of mineral-hosted melt inclusions, subaerial and subaqueous matrix glasses from Hawaii show that for a given melt composition, sulfur degassing becomes more pronounced with decreasing pressure of melt inclusion entrapment and depth of eruption (Wieser et al.,
The Young Lava Plain samples were erupted at greater water depths (i.e., higher pressure) than the Caldera Floor samples (Table S1). Hence, differences in eruption pressures cannot account for the loss of S during degassing of the Young Lava Plain samples but not the Caldera Floor samples. Instead, these systematics indicate that at a given pressure, magmas with a stronger subduction-related input (e.g., samples from the Young Lava Plain, the Eastern Manus Backarc Basin and the Southern Valu Fa Ridge) are more likely to degas S during eruption compared to those with only minor (e.g., the Nifonea Caldera Floor and the Vate Old Volcanics) or no (e.g., MORB) subduction-related inputs.

Sulfur is typically degassed as SO$_2$ from volatile containing melts with high $\phi$O$_2$ during eruption (Nilsson and Peach, 1993). This is because the proportion of S dissolved in the melt as S$^{6+}$ rather than S$^{2-}$ increases with increasing melt $\phi$O$_2$, and S$^{6+}$ is more prone to loss via degassing than S$^{2-}$ (Nilsson and Peach, 1993). Hence, the low S concentrations of the Eastern Manus Backarc Basin and Southern Valu Fa Ridge glasses (Fig. 8a) are attributable to degassing and loss of the proportion of S dissolved as S$^{6+}$ during eruption of magmas on the seafloor (Jenner et al., 2015; Jenner et al., 2010). It is therefore likely that the Young Lava Plain, the Eastern Manus and the Southern Valu Fa Ridge magmas had a higher $\phi$O$_2$ and therefore, a higher proportion of S dissolved as S$^{6+}$ than the other Coriolis Trough magmas and global MORB. In contrast to S, the similarities between the behavior of Se, Cu and Ag with decreasing MgO during fractionation of the Eastern Manus and Southern Valu Fa Ridge backarc basin magmas has been used to argue that Se is less prone to loss via degassing than S (Jenner et al., 2015; Jenner et al., 2010). Selenium oxidises to selenite or selenate at higher $\phi$O$_2$ than the sulfide to sulfate transition (Johnson and Bullen, 2004). The retention of Se but loss of S during degassing of the Eastern...
Manus Basin magmas was therefore attributed by Jenner et al. (2010) to the $f_{O_2}$ of the melts not being high enough for Se to be dissolved in the melt as $Se^{6+}$. Hence, we suggest the $f_{O_2}$ of the Young Lava Plain samples was not sufficiently high for loss of Se during degassing. Similarly, analyses of both S and Se in volcanic glasses and melt inclusions from Hawaii (Wieser et al., 2020) and whole rock samples from Chile (Cox et al., 2019; Cox et al., 2020) indicate that concomitant loss of both S and Se only takes place at relatively low pressures (e.g., Se loss immediately prior to or during subaerial eruptions).

In summary, major element systematics, trace element ratios (i.e., Ba/Nb, Th/Nb and V/Sc) and chalcophile element systematics all indicate that the mantle source region of the Young Lava Plain samples is anomalously enriched in slab-derived fluxes and likely had a higher $f_{O_2}$ compared to the mantle source region of the other Coriolis Trough samples.

5.3. Evolution of the mantle source region of the Vate Trough

Volcanoes the size of Nifonea are unexpected during the early stages of backarc rifting, because initial rifting is typically characterized by low rather than high magma supply rates (e.g., Anderson et al., 2016; Ishizuka et al., 2010; Sleeper et al., 2016). Notably, volcanoes as large as Nifonea have not been identified at Erromango and Futuna. The volume of magmas associated with the Young Lava Plain (~16 km$^3$) are also indicative of high magma supply rates (Anderson et al., 2016). Modern GPS measurements indicate that the extension rates in the Coriolis Troughs decrease northward from ~35 mm/yr in the southern parts of the rifting system to ~20 mm/yr in the northern parts of the rifting system (Bergeot et al., 2009). Melt production rates at mid-ocean ridges show a positive correlation with the spreading rates (Dick et al., 2003; Martinez et al., 2006; Michael et al., 2003) and therefore, the volume of magmatism should be greatest at the Futuna Trough, not the Vate Trough. Consequently,
upwelling of enriched mantle components (Fig. 4) from depths of 70–120 km beneath the North Fiji Basin (Zhang and Pysklywec, 2006) is thought to have contributed to: (1) the voluminous magmatism associated with the formation of Nifonea volcano (Lima et al., 2017); (2) the anomalously elevated topography of the North Fiji Basin (Zhang and Pysklywec, 2006) and the shallower water-depths at the Vate Trough relative to the Erromango and the Futuna Troughs (Anderson et al., 2016; McConachy et al., 2005); (3) the high Nb/Zr of the Caldera Floor basalts (Haase et al., 2020; Lima et al., 2017) and (4) the large number of oceanic spreading ridges constituting the North Fiji Basin (Lagabrielle et al., 1997). However, deep upwelling of fertile mantle cannot explain the low Nb/Zr of the Young Lava Plain magmas, the sudden increase in the proportion of subduction-related fluxes that have enriched the mantle source of the Young Lava Plain basalts, or the differences in chalcophile element systematics between the Young Lava Plain samples compared to the other Coriolis Trough samples (Fig. 7).

Our comparison between the Ba/Nb compositions of the Coriolis Trough magmas and the Lau Basin backarc basin magmas indicates that the magnitude of the subduction fluxes that have contributed to the evolution of the Young Lava Plain source are comparable to those of rifts that are situated ~100 km above a subducting slab. Notably, the Vanuatu arc 100 km depth-to-slab contour passes beneath the Southern Block main-arc volcanoes (i.e., Erromango, Tanna and Anatom, Fig. 2). It is therefore also notable that the Ba/Nb and Th/Nb of the Young Lava Plain samples are comparable to the Vanuatu main-arc volcanoes. Because the Young Lava Plain samples share a similar depth-to-slab as the Caldera Floor samples, it is unlikely that the dehydrated slab that is currently beneath the Vate Troughs directly contributed the slab-derived components to the source of the Young Lava Plain magmas.
Deng et al. (2022) suggested that the influx of hot sub-slab mantle into the Vanuatu mantle wedge through a slab tear that is located north of the Efate Group islands (Fig. 2) provided the necessary heat to produce forearc magmatism. Additionally, the influx of hot sub-slab mantle material into the Vanuatu mantle wedge was used to account for the lower Ti/Sc of the samples erupted above the slab tear compared to those that erupted distal from the tear (see Fig. 9 in Deng et al., 2022). Hence, we now evaluate whether influx of hot sub-slab mantle may also have contributed to the genesis of the Young Lava Plain magmas.

On Fig. 2a we show the location of the seismic gap and therefore, the location of the slab tear, together with velocity measurements for the over-riding plate (Bergeot et al., 2009; Calmant et al., 2003; Deng et al., 2022; Prévot et al., 1991). Notably: (1) north of the slab tear the over-riding plate motion is to the east; (2) above the slab tear the over-riding plate motion is to the southeast; (3) beneath the Efate Group forearc islands, the over-riding plate motion is to the south and (4) beneath the Erromango and Futuna Troughs and main-arc volcanoes of Erromango, Tanna and Anatom, the over-riding plate motion is to the southwest. The direction of over-riding plate motion is often considered to be indicative of underlying mantle flow directions (Axen et al., 2018; Currie and Beaumont, 2011; Deng et al., 2022; Magni, 2019). Indeed, the depleted compositions of the Anatom main-arc magmas in the Southern Block compared to Coriolis backarc magmas have been attributed to depletion of the mantle beneath the backarc prior to transport and melting of this depleted source beneath the main-arc Anatom volcano (Fig. 4, cream arrows; Haase et al., 2020). The Vate Trough is situated to the southeast of the slab tear and the Efate Group islands (Fig. 2a) and in the region where over-riding plate motion, and therefore mantle flow, is highly variable. We suggest that sub-slab mantle
that is upwelling through the slab tear might have caused southeast flow of sub-
arc mantle to beneath the Vate Trough, and that melting of this metasomatised
source generated the distinct arc-like compositions of the Young Lava Plain
basalts (purple arrows on Figs. 2a and 4).

Previous studies propose that there is a close relationship between
voluminous volcanism and the inflow of hot sub-slab mantle through a tear in
the subducting slab, for example at the Calabria subduction zone (Cocchi et al.,
2017; De Ritis et al., 2019), the East Scotia Ridge (Bruguier and Livermore,
2001; Livermore et al., 1997) and the Southern Okinawa Trough (Lin et al., 2004;
Lin et al., 2007). Hence, inflow of hot sub-slab mantle might also have
contributed to the voluminous magmatism associated with the genesis of the
Young Lava Plain magmas. Additionally, other studies have also suggested that
the flow of sub-slab mantle through a slab tear towards the backarc can be
detected at other backarc settings. For example, at the Central American
subduction zone, seismicity distributions and seismic tomography have been
used to identify a slab tear beneath the southeast portion of the Central
American arc (Bekaert et al., 2021; Johnston and Thorkelson, 1997). The
development of this slab tear has been attributed to the subduction of the Cocos
Ridge beneath the arc (Bekaert et al., 2021; Johnston and Thorkelson, 1997).
This slab tear allows sub-slab Galápagos-modified asthenospheric materials to
flow into the mantle wedge beneath the backarc, and consequently, produces
the backarc magmas with a prominent ‘Galápagos' signature (e.g., high
$^{206}$Pb/$^{204}$Pb; Abratis and Wörner, 2001; Gazel et al., 2011; Hoernle et al., 2008).

Similarly, at the Ecuadorian subduction zone, various techniques have been
used to identify a slab tear beneath the Sumao backarc volcano (southern
Ecuador), which has been linked to the subduction of Carnegie Ridge
(Rosenbaum et al., 2018). Rosenbaum et al. (2018) suggest that the infiltration
of hot sub-slab mantle through a slab tear provides the necessary heat to melt
the subducting slab, and thus accounts for the genesis of Sumao backarc
volcano, which has distinct geochemical characteristics (e.g., high alkalinity)
compared to other Ecuadorian volcanoes.

6. Conclusion

We propose that subduction of the D’Entrecasteaux Ridge has had a
profound influence on mantle flow patterns beneath the Vanuatu arc (Fig. 4).
Prior to the subduction of the D’Entrecasteaux Ridge, slab rollback caused a
decline in the proportion of slab-derived components that were added to the
mantle source beneath the Coriolis Trough. Melting of this slightly
metasomatised source produced magmas (i.e., Old Volcanics, Horst, Nifonea
Caldera Floor, Erromango and Futuna Troughs) with major element
compositions that are similar to non-subduction related MORB. However, minor
addition of slab fluxes is required to explain the span to slightly higher Ba/Nb
and Th/Nb of these samples compared to the MORB array (Fig. 9). With the
continued rollback of the descending slab, upwelling of hot and enriched
asthenospheric mantle from depths of 70–120 km caused the mantle source
beneath the Vate Trough to become increasingly more enriched. Melting of this
enriched source has been invoked to explain the anomalous size of Nifonea
volcano (Lima et al., 2017).

Collision of the D’Entrecasteaux Ridge at the central portion of the Vanuatu
arc caused the development of a tear in the underlying slab. We suggest that
the influx of hot sub-slab mantle through the tear caused southeast flow of
metasomatised sub-arc mantle. We suggest that melting of this high \( fO_2 \)
metasomatised mantle source generated the Young Lava Plain magmas, which
have geochemical signatures that are comparable to the Vanuatu arc magmas.
A combination of influx of hot sub-slab mantle and contribution of slab-derived
components could account for the large volume of Young Lava Plain magmas. Thus, we propose that changes in mantle flow patterns could explain why the Nifonea Caldera Floor and Young Lava Plain samples have comparable ages and similar modern-day depth-to-slab but distinct compositions.

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Figure caption

Fig. 1. Tectonic settings of the ancient Vitiaz arc and modern-day Vanuatu arc. (a) Reconstruction of the position of the ancient Vitiaz arc before ~12 Ma, which shows the tectonic settings before the subduction polarity change and the westward rotation of the subducting slab. Santo and Malekula are the two volcanoes formed at the ancient Vitiaz subduction zone (enclosed by blue dashed polygon). Tectonic map modified from Martin (2013). (b) Modern-day tectonic map of the Vanuatu arc and North Fiji Basin (modified from Anderson et al., 2016). The Vanuatu arc is segmented into three blocks, with eastward migration of the Central Block, clockwise rotation of the Southern Block and counter-clockwise rotation of the Northern Block (Bergeot et al., 2009; Calmant et al., 2003; Deng et al., 2022; Taylor et al., 1995). The differences in the directions of motion of these three blocks are accommodated by two strike-slips (two pink dashed lines). The brown arrows denote the convergent velocities (mm/yr) with respect to the Australian plate (Bergeot et al., 2009;...
Calmant et al., 2003). The grey lines show the North Fiji Basin spreading centers. The Vanuatu backarc rifts are showed in orange. The black box in panel b shows the expanded area displayed in Fig. 2a.

**Fig. 2. Geological, geophysical and geochemical constraints of the Vanuatu and Tonga regions.** (a) Bathymetric map and modern GPS measurements of the Vanuatu arc and Coriolis Troughs. The GPS vectors of Vanuatu island stations relative to the Pacific plate suggest that the Central Block moves eastward and the Southern Block rotates clockwise (observed, black arrows; model, white arrows; from Bergeot et al., 2009; Calmant et al., 2003). The differences in motion between the Central and Southern Blocks are accommodated by a strike-slip fault (pink dashed line). The blue polygon...
denotes the location of a slab tear (Deng et al., 2022). The wide cream, purple
and green arrows denote mantle flow directions, which are similar to the
direction of overlying plate motion (see main-text and Fig. 4 caption for details).
Slab depth contours beneath the Vanuatu arc and Coriolis Troughs are showed
every 20 km (i.e., grey dashed lines, from Hayes et al., 2018). The 100 km
depth-to-slab contour is highlighted by a purple dashed line. (b) Latitudinal
variation in Ba/Nb ratios of the Coriolis Trough magmas. The grey and blue
shield areas show the range of Ba/Nb ratios of the Caldera Floor and Young
Lava Plain volcanics, respectively. (c) Latitudinal variation in depth-to-slab of
the Coriolis Trough magmas. The pink shield area shows the range of depth-
to-slab of Coriolis Trough samples, which are calculated from the Slab2 model
(Hayes et al., 2018). (d) Tectonic settings of the Tonga region (modified from
Ribeiro et al., 2017). The black dashed line denotes the boundary between the
old and new backarc crust. The orange lines show the Lau Basin spreading
centers. The black box in panel d shows the expanded area displayed in panel
e. (e) Bathematic map of the Tonga arc and Lau Basin. Slab depth contours
beneath the Tonga arc and Lau Basin are showed every 20 km (i.e., grey
dashed lines, from Hayes et al., 2018). (f) Latitudinal variation in Ba/Nb ratios
of the Lau Basin magmas. (g) Latitudinal variation in depth-to-slab of the Lau
Basin magmas. The orange dashed line shows the samples from the Lau Basin
that have a similar depth-to-slab (Hayes et al., 2018) to those from the Coriolis
Troughs. Data for Lau Basin backarc basin magmas downloaded from GeoRoc
geochemical database (Table S6) are used for comparison.
Fig. 3. Bathymetric map of the Coriolis Troughs showing the locations of retrieved samples. (a) Vate Trough, (b) Erromango Trough, (c) Futuna Trough. The orange dashed line delimits the Nifonea volcano caldera.
Fig. 4. Schematic model to illustrate the inferred mantle flow patterns (modified from Deng et al., 2022). Slab rollback beneath the Southern Blocks promotes southwestward corner flow of the mantle (cream arrows). The shallow angle ridge subduction pinches out the asthenospheric mantle and bulldozes lithospheric mantle from the forearc toward the main-arc (eastward mantle flow, green arrows). The vertical upwelling of enriched hot mantle from depths of 70–120 km beneath the North Fiji Basin (orange arrows). The development of a slab tear in response to ridge subduction allows the upwelling of sub-slab mantle, which might have caused southeast flow of sub-arc mantle to beneath the Vate Trough (purple arrows).
Fig. 5. Variation in the composition of different units in the Vate Trough.

(a) The geological map of the Vate Trough. This map is modified after the interpretations of Anderson et al. (2016) and Haase et al. (2020). (b-c) Total alkali against silica diagram (Middelmost, 1994). The boundary between alkalic and subalkalic of MacDonald and Katsura (1964) is showed. Panel b only plots our new analyses. Panel c plots both samples from the Coriolis Troughs analysed for this study and published literature (Tables S1 and S5). The Caldera Floor magmas have alkaline compositions, whereas the Young Lava Plain magmas plot on the alkaline-tholeiitic divide. Samples from the Old Volcanics, the Horst, the Erromango and Futuna Troughs are predominantly tholeiitic, with a few samples showing alkaline compositions. Data used to define the MORB field are from Jenner and O'Neill (2012a).
Fig. 6. Variation in major element compositions of the Coriolis Trough magmas. (a) TiO$_2$, (b) Na$_2$O, (c) FeOTOT, (d) V/Yb systematics during differentiation (i.e., with decreasing MgO) of Coriolis Trough volcanics. Samples from the Caldera Floor, the Old Volcanics, the Horst, the Erromango and Futuna Troughs show a more comparable trend in TiO$_2$, Na$_2$O concentrations and V/Yb ratios with decreasing MgO to the non-subduction MORB and Fiji Triple Junction samples. In contrast, the Young Lava Plain samples have TiO$_2$ and Na$_2$O concentrations and V/Yb ratios at a given MgO that are comparable to the Vanuatu arc samples. Data for Eastern Manus Backarc Basin (EMBB, Jenner et al., 2010, 2015), Southern Valu Fa Ridge (SVFR, Jenner et al., 2015), MORB (Jenner and O’Neill, 2012a) are used for comparison.
Fig. 7. Variation in chalcophile element concentrations of the Coriolis Trough magmas. (a) Cu, (b) Ag, (c) S, (d) Se systematics during fractionation of Coriolis Trough magmas. The inferred liquid lines of decent for samples from the Eastern Manus Backarc Basin and MORB are showed to highlight the trends discussed in the main-text. The systematic decrease in Cu and Ag concentrations with decreasing MgO showed by samples from the Caldera Floor, the Old Volcanics, the Horst, the Erromango and Futuna Troughs is comparable to the sulfide-saturated trend defined by the MORB samples. In contrast, the Young Lava Plain samples display higher Cu, Ag and Se concentrations and lower S concentrations at a given MgO compared to the MORB melts, which is similar to that seen in Efate Group forearc samples and backarc magmas from the Eastern Manus, Southern Valu Fa Ridge. Data plotted in these diagrams are the same as those in Fig. 6.
Fig. 8. Plots of S concentrations versus FeO<sub>T</sub> concentrations (a) and H<sub>2</sub>O concentrations versus MgO concentrations (b) of Coriolis Trough magmas. For panel a, samples from the Caldera Floor, the Old Volcanics, the Horst, the Erromango and Futuna Troughs plotted within the MORB array, indicating these melts were sulfide-saturated. The Young Lava Plain samples are offset to lower S concentrations at a given FeO<sub>T</sub>, implying loss of S during eruption. For panel b, samples from the Coriolis Troughs show an overall increase in H<sub>2</sub>O concentrations with decreasing MgO and in particular, samples with 6–8 wt.% MgO have highly variable H<sub>2</sub>O concentrations. Data plotted in these diagrams are the same as those in Fig. 6.

Fig. 9. Plot of Nb/Zr versus Ba/Nb (a) and Th/Nb (b) of the Coriolis Trough magmas. The Caldera Floor samples are offset to the highest Nb/Zr, whereas the Young Lava Plain samples are offset to the highest Ba/Nb and Th/Nb. Samples from the Old Volcanics, the Horst, the Erromango and Futuna
Troughs have a range in Nb/Zr, Ba/Nb and Th/Nb that are intermediate between the compositions of the Caldera Floor and the Young Lava Plain samples. Data plotted in these diagrams are the same as those in Fig. 6.

**Table S1.** Major and trace element data for volcanic glasses from the Coriolis Troughs

**Table S2.** Compositional data for reference material VG-2

**Table S3.** Compositional data for reference material BCR-2G

**Table S4.** Compositional data for in-house reference materials from the North West Lau Spreading Centre (NWLSC)

**Table S5.** Compiled major and trace element data for samples from the Coriolis Troughs and Remnant Arc Crust

**Table S6.** Compiled major and trace element data for samples from the Lau Basin