Oxidation of La Réunion lavas with MORB-like $f_{O_2}$ by assimilation

R.W. Nicklas$^1*$, R.K.M. Hahn$^1$, J.M.D. Day$^1$

Abstract

Oxygen fugacity ($f_{O_2}$) is poorly constrained in mantle reservoirs, especially those sampled by ocean island basalts (OIBs). This is partly due to complications from secondary processes acting on $f_{O_2}$ in OIB parental magmas. To investigate these issues in situ trace element data of olivine in lavas from the island of La Réunion are reported. La Réunion lavas are useful for examining post-melting modification due to their limited range in isotopic signatures, indicating a largely homogenous mantle source. Vanadium abundances in olivine were used to constrain the lava $f_{O_2}$ to between +0.2 and +1.5 $\Delta FMQ$, intermediate between that of mid-ocean ridge basalts (MORBs) and other OIBs. The variable $f_{O_2}$ of Réunion lavas results from assimilation processes within the volcanic edifice, and not source heterogeneity. The Réunion mantle plume likely has $f_{O_2}$ similar to that of MORB, despite isotopic evidence for the plume sampling an early-formed isolated mantle reservoir. Assimilation processes can have a pronounced effect on lava $f_{O_2}$ and should always be accounted for when constraining mantle redox.

Introduction

Oxygen fugacity ($f_{O_2}$) of primitive lavas is a proxy for the $f_{O_2}$ of their mantle sources and is useful for constraining mantle redox variability (Carmichael, 1991; Moussallam et al., 2019; Nicklas et al., 2021). Redox constraints are important for testing models of recycling into the deep Earth, as well as for tracking mantle differentiation and mixing (Carmichael, 1991; Frost et al., 2008; Brounce et al., 2017). While $f_{O_2}$ in primitive melts can be modified by processes such as fractional crystallisation (Kelley and Cottrell, 2012), crustal contamination (Grocke et al., 2016) and degassing (Moussallam et al., 2019), the $f_{O_2}$ of erupted basalts is, to a first order, controlled by the $f_{O_2}$ of their mantle source (Birner et al., 2018). Oxygen fugacity varies strongly with tectonic environment (Carmichael, 1991), as arc basalts ($\Delta FMQ \geq +2$) have elevated $f_{O_2}$ relative to mid-ocean ridge basalts ($\Delta FMQ \approx 0$), possibly due to metasomatism of the mantle wedge by oxidised recycled materials (Kelley and Cottrell, 2012), or due to distinct differentiation processes (Tang et al., 2018). Global mass balance calculations show, however, that $\sim$90% of oxidants are not returned in arc volcanism and are instead taken into the deep mantle (Evans, 2012). Ocean island basalts are the result of melting in deep-seated plumes that contain a variety of recycled crustal lithologies (e.g., Hofmann, 1997), and so are expected to contain some of these recycled oxidants, of which Fe$^{3+}$ is the most important (Evans, 2012).

Compared to arc lavas and MORB, OIB $f_{O_2}$ is not as comprehensively documented. This is partly due to the general absence of glassy materials for X-ray near edge absorption spectroscopy (XANES) measurements meaning that alternative oxybarometry methods are required. It has recently been suggested that OIBs could be equally or even more oxidised than arc lavas (Moussallam et al., 2019), possibly resulting from sampling oxidised altered oceanic crust (AOC). Sulfur degassing of OIB melts can also have a variable and large ($\sim$2 log units) effect on the $f_{O_2}$ measured in glasses and melt inclusions (Moussallam et al., 2019), making some OIBs appear to be as reduced as MORBs. In contrast with XANES, the V in olivine oxybarometry method records $f_{O_2}$ as a melt crystallises olivine, which may occur prior to significant sulfur degassing (Nicklas et al., 2021).

In this study, $f_{O_2}$ is measured in lavas from the La Réunion hotspot. Réunion is an island in the south Indian Ocean composed of two major volcanos including the currently active Piton de la Fournaise (Albarède et al., 1997). Lavas from Réunion are remarkable for their uniform He, Nd, Os and Pb isotopic signatures, with elevated $^{3}$He/$^{4}$He and primitive mantle like Pb isotopes suggesting an ancient deep mantle source (Vlastelic et al., 2006; Füri et al., 2011; Peters et al., 2016). Réunion lavas have elevated $^{3}$He/$^{4}$He ratios (up to $\sim$14 R$_{P}$; Füri et al., 2011) and are little influenced by recycled AOC, so Réunion is a key locality at which to characterise $f_{O_2}$.

Methods and Results

The sample set includes seven Réunion olivine-rich lavas, which have been characterised for their bulk rock geochemistry previously (Peters et al., 2016). Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of cores of olivine were performed for 24–36 grains in each sample (Supplementary Information; average olivine trace element concentrations are reported in Table S-1). The V content of the calculated parental melt for each sample was coupled with the V content in olivine to calculate $\Delta D_{\text{olivine/melt}}$ of each sample.
Calculated Δ\textsubscript{O\textsubscript{2}}\textsuperscript{olivine/melt} and temperature (Nisbet \textit{et al.}, 1993) were then used with the empirical equation of Wang \textit{et al.} (2019) to compute the \textit{f}_O\textsubscript{2} for each lava. Parental magma major element and V concentrations and oxygen fugacities are listed in Table 1. Calculation details are in the Supplementary Information. Reported uncertainties of \textit{f}_O\textsubscript{2} values are based on the uncertainties of V concentrations in olivine and parental lavas, as temperature and parental magma major element composition have only a second order effect on the reported \textit{f}_O\textsubscript{2}. Vanadium concentrations in olivine vary between 6.0 ± 1.3 and 8.6 ± 2.1 ppm. Also analysed as a proxy for depleted ocean lithosphere olivine was a depleted harzburgite from the Tonga Trench (Day and Brown, 2021), with olivine containing 0.7 ± 0.2 ppm V.

Réunion olivine shows a broader range in V content than other OIB olivines (Fig. 1). The \textit{f}_O\textsubscript{2} of the lavas show wide variation, between +0.20\textpm0.39 and +1.45\textpm0.31 FMQ, and do not correlate with parental magma composition. The \textit{f}_O\textsubscript{2} values range between MORB at +0.60 ± 0.15 (Nicklas \textit{et al.}, 2019) and the global OIB average at +1.7 ± 0.8 FMQ, both measured using the same oxybarometry method (Nicklas \textit{et al.}, 2021). The Réunion lavas also overlap with MORB \textit{f}_O\textsubscript{2} estimates obtained by other oxybarometry methods (Li and Lee, 2004; Berry \textit{et al.}, 2018; Zhang \textit{et al.}, 2019; Wang \textit{et al.}, 2019; Novella \textit{et al.}, 2020). The V in olivine method assumes that the measured olivine is either phenocrystic or antecrystic, and that olivine has not been diffusively reset since crystallisation (see discussion in Supplementary Information). In short, although the studied olivine grains cannot conclusively be shown to be ubiquitously phenocrysts or antecrysts, it is unlikely that samples such as RU0705 (∼49 % modal olivine; Peters \textit{et al.}, 2016) would have assimilated such high quantities of unrelated olivine.

The pervasively high 3He\textsuperscript{4}He measured in olivine separates from these lavas (Füri \textit{et al.}, 2011) strongly suggests that the olivine grains ultimately originate from recent Réunion magmas reinforcing the concept that the calculated \textit{f}_O\textsubscript{2} variations relate to assimilation processes, rather than reflecting mantle source variations.

![Figure 1](image1.png)

**Figure 1** Average V concentrations in olivine cores plotted against forsterite number (from Peters \textit{et al.}, 2016), along with olivine from a Tonga Trench forearc peridotite, MORB olivine (Nicklas \textit{et al.}, 2019), and olivine from other OIBs (Nicklas \textit{et al.}, 2021).

The pervasively high 3He\textsuperscript{4}He measured in olivine separates from these lavas (Füri \textit{et al.}, 2011) strongly suggests that the olivine grains ultimately originate from recent Réunion magmas reinforcing the concept that the calculated \textit{f}_O\textsubscript{2} variations relate to assimilation processes, rather than reflecting mantle source variations.

### Table 1 Parental magma compositions; oxides are in wt. %, V is in ppm (∼10 % uncertainty). Average ppm V in olivine is also listed. NBO/T – non-bonding oxygens divided by tetrahedrally bonded oxygens in each parental melt. ΔFMQ – oxygen fugacity relative to FMQ buffer. Up – positive uncertainty, Down – negative uncertainty. \textsuperscript{187}Os/\textsuperscript{188}Os are bulk rock values (Peters \textit{et al.}, 2016). Ol add/subtract – the amount of olivine added or subtracted from the bulk rock composition to calculate the parental magma composition. Positive percentages are added olivine, negative percentages are subtracted olivine. Temperature is calculated using the formulation of Nisbet \textit{et al.} (1993).

<table>
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<th>Sample Name</th>
<th>RU0702</th>
<th>RU0703</th>
<th>RU0705</th>
<th>RU0707</th>
<th>RU0709</th>
<th>RU0715</th>
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<td>2.35</td>
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<td>12.5</td>
<td>12.4</td>
<td>12.4</td>
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<tr>
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<td>11.2</td>
<td>11.9</td>
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<td>6.83</td>
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<td>1233</td>
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<td>1250</td>
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<tr>
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<td>0.13328</td>
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<td>+10.7 %</td>
<td>−50.4 %</td>
<td>+11.3 %</td>
<td>+1.4 %</td>
<td>+2.0 %</td>
<td>+28.1 %</td>
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</tbody>
</table>
Oxygen Fugacity of Réunion Lavas

The calculated $f_{O_2}$ of Réunion lavas is highly variable compared with other OIBs (Fig. 2). The more reduced Réunion lavas overlap with the MORB range, unlike other OIBs. The variability of the data is unanticipated given the limited range of isotopic compositions suggesting a homogenous mantle source (Albarede et al., 1997; Vlastelic et al., 2006; Peters et al., 2016). A possibility that can be precluded to explain the variations in $f_{O_2}$ is variable amounts of recycled AOC in the plume, due to the uniform and unradiogenic Pb and Os isotope signatures of lavas (Vlastelic et al., 2006; Peters et al., 2016). Alternatively, the most oxidised Réunion lava (RU0719 at $+1.5$ ΔFMQ) may be representative of the plume with the other lavas being reduced by degassing of SO$_2$. Sulfur degassing can lead to reduction of a melt (Moussallam et al., 2019), with loss of ~4000 ppm S from Canary and Cape Verde OIBs leading to a ~2.5 log unit $f_{O_2}$ reduction. Réunion lavas have been estimated to have degassed at most 1510 ppm S, but likely only 100 ppm (Bureau et al., 1998; Collins et al., 2012). If S degassing has a similar redox effect for Réunion lavas as it does in other OIBs, even maximum loss of 1510 ppm S would cause only a 1.05 log unit reduction in $f_{O_2}$, smaller than the range of the data even in this most extreme case. For this reason, S degassing can only explain part of the $f_{O_2}$ variations, assuming that such degassing took place during olivine crystallisation.

Assimilation of material from within the volcanic edifice is a well known phenomenon in OIB. For Réunion, if the lavas were to be assimilated and oxidised basaltic material, then radiogenic isotopic modification from such assimilation would be minimal due to the young age of Piton de la Fournaise. The whole rock dataset of Peters et al. (2016) includes concentrations of both ferrous and ferric iron, with Fe$^{3+}$/ΣFe ratios varying between 0.03 and 0.90, ranging significantly higher than mantle derived basalts at <0.3 (Moussallam et al., 2019), indicating that many of the basalts have suffered oxidative alteration. Starting from the lowest $f_{O_2}$ Réunion sample (+0.2 ΔFMQ) and using Fe$^{3+}$/ΣFe ratios of 0.14, 0.21, and 0.90, mixing calculations were performed to determine the amount of assimilation needed to oxidise RU0702 to +1.5 ΔFMQ (Fig. 3). This modelling shows that 35 % to 5 % edifice assimilation would be required to explain the range in data if assimilated materials had Fe$^{3+}$/ΣFe = 0.21 and 0.90, respectively. Although 5 % assimilation is reasonable for a high MgO magma, 35 % assimilation will spur extensive fractional crystallisation from cooling and could not plausibly produce primitive magma compositions (~12.5 wt. % MgO), suggesting that assimilation of highly oxidised materials is necessary. The presence of such materials in the volcanic edifice indicates that assimilation is a plausible mechanism for explaining the range in measured $f_{O_2}$. This model requires magmas to either cross the olivine liquidus in edifice level magma chambers or for altered material to be present at depth. Better constraints on the depth of olivine crystallisation beneath Réunion are needed to fully examine the role of edifice assimilation.

Another process potentially operative in Réunion is inheritance of olivine by lavas. Accumulation of olivine is necessary to explain ‘oceanite’ lavas containing up to 49 % modal olivine, which are not realistic parental melt compositions. Whether this olivine is antecryptic (related to the melt) or xenocrystic (unrelated to parental melts) affects the estimated $f_{O_2}$. For example, accumulation of low V olivine xenocrysts would have a profound effect on $f_{O_2}$ in olivine oxybarometry if not properly accounted for. Xenocrystic olivine with low V would artificially drive the calculated $f_{O_2}$ to higher values if included in the sampled olivine data. For a lava at +0.2 ΔFMQ (RU0702), ~62 % xenocrystic olivine with a V content of ~1 ppm, similar to the Tonga Trench olivine, must be added to sufficiently lower the average olivine content so that the calculated $f_{O_2}$ is equal to that of RU0719. None of the ~30 vanadium measurements for olivine cores in RU0702 approach 1 ppm, with a minimum of 4.9 ppm (Supplementary Information). Even if xenocrystic olivine were to re-equilibrate with the carrier magma, 62 % is a high proportion of olivine to be accidentally included within any OIB.

**Implications for V in Olivine Oxybarometry and $f_{O_2}$ in OIBs**

Vanadium in olivine oxybarometry measures the $f_{O_2}$ of a melt early in its evolution and is assumed to record $f_{O_2}$ prior to
secondary processes (Nicklas et al., 2019). Réunion data presented here suggest that this may not always be true. In this setting, assimilation of AOC (~1.3 log unit oxidation with ~5% assimilation) as well as reduction from SO2 degassing likely affected the estimated fO2. A possible complicating factor with the oxybarometry method is xenocrystic olivine; however, such olivine would likely be from within the Réunion edifice. Such xenocrysts may be common in some OIBs (Wieser et al., 2019) and care is therefore needed in oxybarometry studies to account for them. Olivine populations should be examined for both high Ca concentrations (indicating non-mantle origin) and for unimodal trace element systematics. None of the sampled lavas contain mantecrysts, as mantle olivine has much lower V contents (0.7 ± 0.2 ppm, Fig. 1) than any olivine analysed.

Other OIBs have been measured using V in olivine oxybarometry (Fig. 2) but these data are unlikely to reflect the processes shown here for olivine-rich Réunion oceannites as all those samples show consistent fO2 regardless of bulk composition, isotopic signatures or location. Given that secondary processes affected the lavas, the uncontaminated fO2 of Réunion plume is likely to be within the range of contemporary MORB (ΔFMQ=0). This is dissimilar to other OIBs (Fig. 2) and may indicate that the Réunion plume entrains significant MORB source mantle. Isotopic studies, however, have shown a minimal contribution from the MORB source mantle and that Réunion lavas instead come from a primitive source with elevated 3He/4He, low 182W/184W and low, highly siderophile element abundances (Vlastelic et al., 2006; Füri et al., 2011; Peters et al., 2016; Rizzo et al., 2019). This would suggest that upwelling deep mantle material has fO2 similar to that of the depleted upper mantle source of MORB history despite being isolated from the MORB source mantle for much of Earth’s history.

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Additional Information

Supplementary Information accompanies this letter at https://www.geochemicalperspectivesletters.org/article2205. © 2022 The Authors. This work is distributed under the Creative Commons Attribution 4.0 License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. Additional information is available at http://www.geochemicalperspectivesletters.org/copyright-and-permissions.


References


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Supplementary Information

The Supplementary Information includes:

- LA-ICP-MS Analytical Method
- Calculation of Parental Magma Compositions
- Issues Regarding Olivine Equilibrium and Resetting
- Table S-1

LA-ICP-MS Analytical Method

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses were conducted at the Scripps Isotope Geochemistry Laboratory (SIGL), Scripps Institution of Oceanography, University of California San Diego. The analyses were performed using a New Wave UP213 (213 nm) laser, coupled to a Thermo Scientific iCAPq Qc ICP-MS. The spot size for all analyses was 100 µm and the laser operating conditions were 5 Hz, with a laser fluence controlled between 3.0 and 3.5 J/cm². Measured isotopes were $^{25}$Mg and $^{57}$Fe (to verify mineral composition from electron microprobe analyses), $^{29}$Si (for internal normalisation), and $^{27}$Al, $^{43}$Ca, $^{51}$V, $^{59}$Co, $^{60}$Ni, $^{71}$Ga, and $^{89}$Y (trace elements of interest). The count time for all isotopes was 0.01 seconds per cycle, with the exceptions of $^{29}$Si and $^{51}$V at 0.02 and 0.05 seconds, respectively. The USGS standard reference glasses BHVO-2g and BCR-2g were used as external standards while the average Si concentration from the EPMA data of Peters et al. (2016) was used as an internal standard to normalise for ablation efficiency. Analysis of the natural olivine standard MongOL (Batanova et al., 2019) using identical analytical methodology showed that this method can measure V concentrations in natural olivine with a
precision of 5.1% (Nicklas et al., 2021b). Due to the high abundance of Al in all other major phases relative to olivine, Al abundances were used to filter the data for accidental ablation of oxides and glass inclusions. All data showing Al abundances greater than two standard deviations (s.d.) above the mean for the sample were rejected as contaminated by other phases. This process was repeated until all Al abundances were within 2 s.d. of the mean.

**Calculation of Parental Magma Compositions**

Parental magma compositions were determined assuming that bulk compositions were controlled by addition or subtraction of olivine, a good assumption for these olivine-rich (oceanite/picrite) lavas. Bulk lava compositions as well as olivine major-element data were taken from Peters et al. (2016). In general, La Réunion lavas have ranges in olivine major element compositions that are limited (<2 wt. %) and have negligible effect on calculated parental magma compositions. Using $K_{\text{Fe}_\text{Mg}}^{\text{olivine/melt}} = 0.33$ (Toplis, 2005) the parental magma MgO composition was calculated by assuming that FeO in the bulk rock equalled that of the parental magma. The measured olivine composition was then added or subtracted from the bulk rock composition until its MgO content was equal to that of the parental magma. The amount of olivine added or subtracted varied between adding 28.8 % (RU0719) and subtracting 50.4 % (RU0705), with the samples from which olivine was subtracted (RU0702 and RU0705) having a high modal abundance of olivine (~44 % modal olivine in RU0702, ~49 % modal olivine in RU0705) consistent with accumulation of olivine. Parental magma compositions are reported in Table 1 and are all similar in composition owing to similar olivine compositions. The partition coefficient ($D_{V}^{\text{olivine/melt}}$) was calculated for each lava by dividing the average olivine V content by the calculated parental magma V content. Uncertainty of the partition coefficients were propagated in quadrature using the 2 s.d. uncertainties of the average olivine concentrations and assuming 10% uncertainty on parental magma V contents. The partition coefficient was converted into oxygen fugacity in log units relative to the FMQ buffer using equation (1) of Wang et al. (2019), a temperature calculated using the
equation of Nisbet et al. (1993), and the ratio of non-bridging oxygens to tetrahedrally coordinated cations (NBO/T) calculated from the parental magma composition using the algorithm of Mills (1993). The uncertainties of the concentrations of V in olivine have a first order effect on the uncertainties of the reported oxygen fugacity, and other factors such as temperature and NBO/T have a minor second-order effect. For instance, varying the temperature of the most reduced sample, RU0702 (+0.38 ΔFMQ) from 1100 to 1200 to 1300 °C leads to oxygen fugacity ranging from +0.74 to 0.06 ΔFMQ, these variations are insufficient to explain the range of data. Liquidus temperatures of the lavas should not vary by more than 100 °C given their similar major element compositions, as evidenced by the calculated parental magma liquidus temperatures ranging only from 1220–1250 °C. Similarly, varying the NBO/T ratio by ±0.25 changes the calculated fO₂ by +0.23 and −0.24 log units, respectively, smaller than the reported uncertainties. Finally, K_{Fe-Mg}^{olivine/melt} has been found to vary with temperature and melt composition (Toplis, 2005) but varying this value from 0.30 to 0.35, the range reported for basaltic magmas, does not change the data outside of uncertainties, nor does accounting for the presence of Fe^{3+} (predicted to be <23 %; Kress and Carmichael, 1991) in the parental lavas. Similarly, the fitting uncertainties on the experimental regression of Wang (et al., 2019), when propagated in quadrature are only ~0.35 log units. As all the oxygen fugacity data, including the literature MORB data are calculated using the same regression, this 0.35 log unit uncertainty will at least partially cancel between datapoints. For all these reasons, the uncertainties reported in this paper therefore reflect the absolute uncertainties of the data as corrected. More discussion of the effect of NBO/T and temperature of oxygen fugacity using this method can be found in Nicklas et al. (2021a).

**Issues Regarding Olivine Equilibrium and Resetting**

The method of V-in-olivine oxybarometry assumes that measured olivine crystals are either phenocrysts (crystallised from the magma that ultimately forms the bulk rock within which the olivine was found) or antecrysts (crystallised from an earlier, more primitive version of their bulk rock that then re-
entrained the olivine). If the analysed olivine crystals are xenocrysts (unrelated to their bulk rock compositions) then the oxybarometry method are likely to yield results without petrological meaning. All of the olivine grains found in the polished sections have V and Ca contents higher than mantle peridotites, and therefore cannot be mantle xenocrysts. This means that any xenocrystic olivine can only come from crystallisation of the relatively homogeneous Reunion lavas in the lithosphere or crust (e.g., Peters et al., 2016). Given that the calculated $f_{O_2}$ data show the effects of assimilation on the lavas, even if the data are erroneous due to any xenocrystic olivine, the conclusion that assimilation within the edifice affected the lavas remains robust.

Overall, it seems unlikely that the olivine was derived from more than one source, as the olivine populations in each sample shows unimodal and homogenous compositions (Table S-1). In two of the samples, RU0709 and RU0715, olivine crystals are close to Fe-Mg equilibrium with the bulk rock composition (Table 1) and are either best classified as phenocrysts or have experienced very rapid Fe-Mg equilibration (Couperthwaite et al., 2021). The two equilibrium lavas do not show extreme $f_{O_2}$, plotting in the middle of the sample set. The five other samples have olivine out of Fe-Mg equilibrium with their bulk rock compositions and have either accumulated (RU0702 and RU0705) or fractionated (RU0703, RU0707 and RU0719) olivine, making the olivine in those samples either antecrysts or xenocrysts. Given that olivine was entrained from a single source, it is likely that the entraining lavas are related to the olivine as the lava and olivine would be present in a single magma chamber during magma differentiation. Additionally, fractionated olivine would likely be presented as loose, non-lithified cumulates in the magma chamber making it relatively easy to entrain. It is difficult to conclude that the samples could have acquired such large amounts of olivine (~49 % modal olivine in RU0705; Peters et al., 2016) from an unrelated source within the Réunion edifice and none from within the same magma chamber in which it differentiated. It is thermodynamically difficult to assimilate such a large amount of cooler, olivine xenocrysts and maintain a high enough temperature to allow the magma to erupt. For all these reasons, it is concluded that the measured olivine crystals are most
likely antecrysts and not xenocrysts and can be used to estimate the oxygen fugacity of the parental lavas to their bulk rock carriers.

It is also possible that olivine has been diffusively re-equilibrated leading to a decoupling between major element and V systematics. If both major element and V systematics diffusively re-equilibrated with carrier lavas, then the oxygen fugacity data are valid, but if only one of the two re-equilibrated then calculated $f_O^2$ would be erroneous. Although experimental data are scant, it is likely that V diffuses more quickly ($D \approx 10^{-14} \text{ m}^2/\text{s}$) in solid olivine than Fe and Mg ($D \approx 10^{-15}$ to $10^{-18} \text{ m}^2/\text{s}$) (Chakraborty, 2010). It is therefore possible that V concentrations have been re-equilibrated while Fe and Mg concentrations were not changed. If all the olivine were hosted in a deep crystal mush, a homogenous olivine population could have been entrained by diverse unrelated lava compositions. Evidence for the existence of a large, relatively homogenous crystal mush have been presented for other OIB localities, such as Kilauea in Hawaii (Wieser et al., 2019). Such a scenario would explain the relatively homogenous V concentrations in all the samples’ olivine populations (Table S-1). However, the olivine compositions are not entirely homogenous between samples, with olivine from RU0709 being distinct from the other lavas at the 1 s.d. level (Table S-1). Additionally, it is unlikely that assimilation of crystal mush olivine would lead to two lavas (RU0709 and RU0715) in major element equilibrium with their bulk rock compositions without invoking especially fortuitous circumstances. Although the existence of a diffusively equilibrated crystal mush beneath Piton de la Fournaise cannot be ruled out, given the lack of additional evidence for such a scenario, it is not favoured here. If geochemical or geophysical evidence can be found for a diffusively equilibrated olivine crystal mush beneath Piton de la Fournaise, the $f_O^2$ values may not be accurate but the conclusion of assimilation being important for the sample set will still stand.
Supplementary Table

Table S-1  Average concentrations (ppm) of selected elements in primitive olivine cores in Réunion lavas, as well as from a single depleted Tonga forearc peridotite (NOVA-8801). 2 s.d., two standard deviation uncertainties on each average; N, number of olivine analyses included in each average.

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<th>Sample</th>
<th>N</th>
<th>Al</th>
<th>Ca</th>
<th>V</th>
<th>Co</th>
<th>Ni</th>
<th>Ga</th>
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Supplementary Information References


