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GEOCHEMICAL CONSTRAINTS ON MANTLE
SOURCES AND MELTING CONDITIONS IN PACIFIC
BACK-ARC BASINS

BY
MARION LYNN LYTLE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
OCEANOGRAPHY

UNIVERSITY OF RHODE ISLAND

2013

DOCTOR OF PHILOSOPHY DISSERTATION
OF
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2013

ABSTRACT

The effect of water in the mantle has been well studied and has well-known effects on the behavior and properties of magmas and the mantle including an increase in the extent of melting, suppression of plagioclase during crystallization, and a general reduction of seismic parameters and viscosity. At mid-ocean ridges, magmatic and mantle H₂O contents are relatively low, and a reasonable understanding of the behavior of H₂O has been obtained (Dixon and Stolper, 1995; Dixon et al., 1995; Dixon et al., 2002; Asimow and Langmuir, 2003). However, at back-arc basins, H₂O can also be added to the mantle source by the subducting slab, changing the melting behavior and the mantle source composition (Stolper and Newman, 1994; Taylor and Martinez, 2003). Quantitative constraints on these factors lag behind, and this thesis will test hypotheses related to the role of volatiles in these three major processes at back arcs: (1) tracing mantle source compositions and flow vectors, (2) refining mantle melting models, and (3) constraining the origin of back-arc slab-derived fluids.

Tracing mantle source compositions is done best in places where mantles of starkly contrasting compositions are juxtaposed, as in the case of plume-ridge interaction. The NW Lau Basin, a back-arc with little influence from the slab, provides an ideal setting to address mantle flow where the mantle source contrast is potentially well made with the interaction of relatively depleted mantle with the Samoan plume. Geochemical tests of the interaction between the Samoan Plume and the Lau Basin mantle have relied on one tracer (³He/⁴He), but the addition of volatiles (H₂O, CO₂), trace elements (e.g., La, Nb), and other radiogenic isotopes (Sr, Nd, Pb, Hf) provides further constraints on tracing the enriched Samoan mantle composition. Our new data

suggest two-component mixing of MORB-like mantle with an enriched mantle source, similar to Samoa, although consideration of a complete regional data set suggests there may be other sources of heterogeneity in the mantle beneath NW Lau.

Aside from tracing mantle flow, volatiles and trace elements provide constraints on mantle melting as H_2O has an effect on where and how much melt can be made in the mantle, recorded in incompatible trace element signatures (e.g., Ti, Nb). Observations based on geochemical data suggest two possibilities: mixing of end-member melts or a continuous melting regime, but most models of mantle melting are restricted to isobaric-isothermal conditions and offer unrealistic tests of the competing hypotheses of back-arc magma generation. We developed a robust adiabatic, hydrous melting model and combined with a well-constrained mantle source composition, we model back-arc magma generation.

The release of slab fluids is also an important part of subduction systems, as the fluid composition and the extent of its addition to back-arc mantle sources affects enrichment of resultant basalts. The composition of slab fluids reaching back-arc basins will differ from arc fluids depending on the pathway traveled by the fluid/melt, and the conditions of their release from the plate. Combining geochemical data with recent geochemical models of slab conditions (e.g., H_2O/Ce) and geodynamic models for slab surface temperatures (SST) at each subduction zone provides a robust test of the depth origin of back-arc slab-derived fluids. Average SSTs for these global back arc basin spreading segments, referenced to 4 GPa, range from ~ 775 - $1000^\circ C$, hotter on average than global arc SSTs (730 - $850^\circ C$), suggesting that back-arc basin fluids originate at warmer temperatures than their respective arcs.

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PREFACE

This dissertation consists of in-depth analyses of geochemical data from samples from Pacific back-arc basins. The dissertation is written in manuscript format and consists of the following three manuscripts:

The first manuscript, “Tracing mantle sources and Samoan influence in the northwestern Lau back-arc basin,” covers the relationship between mantle sources present in the northwestern Lau back-arc basin and provides better constraints on tracing the influxing Samoan mantle plume. An abstract pertaining to this research was presented at the American Geophysical Union (AGU) annual conference in 2010 under the title “*Influence of the Samoan Plume in the Northwestern Lau Back-arc Basin.*” This chapter was published online under the title “*Tracing mantle sources and Samoan influence in the northwestern Lau back-arc basin*” in *Geochemistry, Geophysics, Geosystems*, October 2012.

The second manuscript entitled “The influence of volatiles on crystallization, mantle melting, and trace element systematic of back-arc basin magmas” covers a broader dataset than the first manuscript and investigates the role of water in back-arc magmas and the resulting effect of melting and crystallization processes. An abstract pertaining to this research was presented at the American Geophysical Union (AGU) annual conference in 2008 under the title “*The Influence of Volatiles on Trace Element Systematics of Back-arc Basin Magmas and Sources.*” A second abstract pertaining to this research was presented at the AGU annual conference in 2009 under the title “*The Influence of Water on Mantle Melting and Crystallization in Back-arc Basin Systems.*” Submission for publication in *Journal of Petrology* is anticipated.

The third manuscript is entitled “Determining the origin of slab-derived fluids beneath back-arc spreading centers,” and covers a global back-arc basin dataset and investigates the origins of the slab-derived fluids in the back-arc basin magmas and compares the origins with arc slab-derived fluids. An abstract pertaining to this research was presented at the American Geophysical Union (AGU) annual conference in 2012 under the title “*Determining the origin of slab-derived fluids beneath back-arc spreading centers.*” Submission for publication in the journal *Earth and Planetary Science Letters* is anticipated.

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INTRODUCTION

Water is the central component that distinguishes back-arc spreading ridges from normal mid-ocean ridges. Water is known to have a strong influence on melting within the mantle, yet the role that water plays is dependent on the tectonic setting (e.g. Danyushevksy et al., 1993). Specifically, the addition of water from the subducted plate to back-arc basin magma sources strongly influences mantle melting, magmatic crystallization processes, and mantle source composition (Stolper and Newman, 1994; Taylor and Martinez, 2003, Sisson and Grove, 1993). This thesis will develop a comprehensive picture of the specific roles of water and other volatiles in (1) identifying mantle heterogeneity as a tracer of mantle flow beneath back-arc spreading centers, (2) influencing mantle melting along realistic adiabatic ascent paths, and (3) controlling the composition of the fluid released from the slab to back-arc sources.

Chapter 1 focuses on the geochemistry and mantle sources in the Lau Basin, a unique area for studying plume interaction on back-arc spreading. The Lau Basin is a back-arc spreading center behind the Tonga arc in the western Pacific, one of the fastest known subduction systems. A number of studies have focused on the northern boundary of the Lau Basin, a region with complex tectonic activity and a unique area to study the influence and contributions of mantle plumes to the background depleted mantle commonly found in Mid-Ocean Ridge (MOR) or Back-arc Basin (BAB) environments. Northeast of the Tonga-Kermadec subduction system is the Samoan plume, which is hypothesized to be migrating into the NW Lau basin through a tear in

the subducting plate. Previous studies, using He isotopes as a tracer of the distinctive Samoan mantle composition, show the extent to which the plume may have infiltrated into the back-arc basin (Poreda and Craig, 1992; Hilton et al., 1993; Turner and Hawkesworth, 1998; Lupton et al., 2009). MORBs have a relatively homogeneous He isotope ratio ($\sim 8 R_a$; where R_a is the isotope ratio normalized to the atmospheric ratio), but Samoa is one of the global highs in He isotopes (up to $33 R_a$). Elevated $^3\text{He}/^4\text{He}$ ratios in the NW Lau Basin are classically interpreted as evidence of the Samoan plume leaking through the plate boundary (Poreda and Craig, 1992; Hilton et al., 1993; Turner and Hawkesworth, 1998; Lupton et al., 2009). If the elevated $^3\text{He}/^4\text{He}$ signatures are indicative of the Samoan plume influencing the NW Lau basin, there should be additional indicators such as: 1) clear mixing and correlation between $^3\text{He}/^4\text{He}$ and trace elements and other isotopes and 2) elevated mantle temperature.

Poreda and Craig (1992) first looked at He and Sr isotopes in a very limited set of samples from the northern Lau Basin. Samples in the Rochambeau Bank region were found to have both higher He isotope ratios and enriched Sr isotope signatures, suggestive of mixing between enriched mantle in Samoa and depleted mantle in Rochambeau Bank. The Samoan plume is proposed to be drawn into the Lau Basin by mantle flow influenced by crustal extension at the spreading centers. Turner and Hawkesworth (1998) investigated this hypothesis following previous work (Poreda and Craig 1992; Hilton et al., 1993; Turner and Hawkesworth, 1997), by compiling a greater, but still limited, data set. Samples were analyzed for He, Sr, Nd, Pb isotopes and the enriched He isotopic signature of Lau Basin lavas was taken as conclusive evidence for the presence of the Samoan plume down to the Peggy Ridge. Lupton et

al., (2009) looked at the He isotopic signatures of the new, high resolution sample set from the voyage SS07/2008 of the R/V Southern Surveyor, indicating with this singular tracer that the Samoan plume had infiltrated down to Peggy Ridge. However, no trace elements or other isotopes have been measured on these samples, once again constraining the presence of the Samoan plume solely on He isotope measurements.

In this study, new major element (EMP), dissolved volatiles (H_2O , CO_2 , S, Cl, F; SIMS), trace elements (ICP-MS), and Sr-Nd-Pb isotope data are measured for new samples from the plume-influenced region of the Lau Basin. The newly collected data set provides a more robust test of the Samoan Plume hypothesis and provides a much broader geochemical base from which to assess pressure and temperature conditions and mantle sources in the NW Lau Basin, using ratios such as volatiles and $(\text{La}/\text{Sm})_{\text{N}}$ to track mantle enrichment and Sr-Nd-Hf-Pb isotopes to compare source compositions and mantle source mixing. The Samoan plume has an enriched mantle, indicated by $(\text{La}/\text{Sm})_{\text{N}} > 1$ and unique isotopic composition with high Sr isotope ratios (Pearce et al., 2007). Mixing between the Samoan plume and depleted mantle in the NW Lau Basin results in variably enriched basalts, although enrichment does not scale with the elevated $^3\text{He}/^4\text{He}$ signatures. Trace element ratios (e.g. Th/La vs. Sm/La) separate out mixing between Samoan Plume and depleted, background mantle, as different elements and ratios trace different aspects such as mantle enrichment (e.g. La/Sm, Th/La), or subduction influence (e.g. $\text{H}_2\text{O}/\text{Ce}$, Ba/La) or source composition (Sr-Nd-Hf-Pb isotopes). The simplest model involves mixing between a MORB-like mantle (e.g., CLSC) and an enriched mantle component with trace element and isotopic characteristics similar to Samoa, although this model requires He to migrate

independently of trace elements from their Samoan source into the Lau mantle. Three alternative, though not mutually exclusive, hypotheses are presented to explain the observed geochemical characteristics of NW Lau basalts, invoking both a contribution from an isotopically recognizable component of Samoan mantle and (1) a separate, noble-gas-only component that causes enrichment in He isotopes without a proportional contribution from Samoan trace elements, (2) inherent mantle heterogeneity in the NW Lau mantle, unrelated to Samoa, or (3) a previously unidentified volcanic hotspot to the west of NWLSC.

Chapter 2 focuses on the role of volatiles within back-arc basin settings, and the effect on both the melting process and conditions under which melting takes place. There are many models concerning the relationship between H_2O and melt fraction (F) at back-arc basins. One model from Langmuir et al., (2006) suggests that back-arc lavas record mixing trends between a dry, MORB-like melt and a wet, arc-like melt, while another model propose that basalts record a continuum between wet and dry melting (Kelley et al., 2006). These two processes have different consequences for melt compositions, but studies attempting to resolve between these models have been limited by poor data coverage and the lack of a realistic hydrous melting model to constrain the melting process. While the Mariana Trough and East Scotia Ridge have been well studied (Stolper and Newman, 1994; Fretzdorff et al., 2002), there are three back-arc basins (N. Fiji, Lau, Manus) in the Western Pacific that are less well investigated. Although these basins have been well-sampled, the central role of volatiles has never been comprehensively addressed in these regions (e.g. Hawkins, 1976; Perfit et al., 1987; Johnson et al., 1987, Sinton et al., 2003).

Using glass from BABBs from N. Fiji, Lau, and Manus Basins, the collection of major, trace element and volatile data, provides the first comprehensive data set for each of the three basins. With these new data, the role that the subducting slab and fluid components play in back-arc basin melting can be constrained. Determination of the influence of water on the liquid lines of descent (LLD), specifically plagioclase and clinopyroxene fractionation, allows for more accurate corrections of the data back to equilibrium with the mantle at Forsterite 90 (FO_{90}), which is essential for constraining mantle melting. Combining the data sets with modeled LLDs (Petrolog3; Danyushevsky and Plechov, 2011) provides necessary additional constraints on the influence of water on melt composition during crystallization. Using the model- and data-based LLDs to project compositions back to equilibrium with the mantle, constraints on the influence of volatiles on mantle melting were determined.

Using the tighter constraints on mantle equilibrium (FO_{90}) composition provided by the LLDs, a more accurate constraint on source composition and extent of melting was obtained from trace elements. Well constrained values for titanium source concentrations (C_{Ti}^0) are important because C_{Ti}^0 is often used to estimate the melt fraction (F) for lavas (Kelley et al., 2006). Better estimates for C_{Ti}^0 and F reduce source concentration errors and better constrain an accurate value for F, an important aspect for modeling mantle melting. Langmuir et al. (1992) developed an adiabatic melting model for a typical MOR scenario, but does not account for a more hydrous mantle as found in back-arc basin settings. A hydrous back-arc melting model was developed by Kelley et al., (2010), and while providing estimates for hydrous melting, the models are isobaric and isothermal, which does not account for changing water concentrations

or realistic adiabatic melting paths. Combining the approaches of Langmuir et al. (1992) with Kelley et al., (2010) produces a well constrained, realistic polybaric hydrous back-arc basin melting model against which the inversion of natural melt compositions are tested to resolve the competing hypotheses of mixing vs. melting processes to generate back-arc basin basalt compositions.

There remain many questions about the relationship between water and trace elements in back-arc basin basalts, especially concerning the compositions of the subducted inputs, the effect of dehydration of the subducting slab, and fluid pathways through the mantle wedge. Chapter 3 focuses on how these factors combine to create the fluids that modify back-arc mantle sources, by taking an integrated modeling approach, combining new geochemical data (e.g., $\text{H}_2\text{O}/\text{Ce}$; Plank et al., 2009) with petrological modeling (e.g., Stolper and Newman, 1994) and geodynamic models for each back-arc basin (subduction zone geometry and thermal structure Syracuse and Abers, 2006; Syracuse et al., 2010). Using the global back-arc data set generated as described in Chapter 2, the pressure and temperature conditions of slab dehydration are constrained using the $\text{H}_2\text{O}/\text{Ce}$ ratio of the fluid, which is a sensor of slab surface temperature. Back-arc lavas have higher $\text{H}_2\text{O}/\text{Ce}$ ratios than the average MORB or plume $\text{H}_2\text{O}/\text{Ce}$ ratio of ~ 200 (Dixon et al., 2002; Plank et al., 2009) because of additions from the subducting plate to the back-arc source, but the relative contributions of H_2O and Ce from the mantle and the slab must be resolved in order to apply the $\text{H}_2\text{O}/\text{Ce}$ thermometer. The mantle contribution to each basalt were separated out from the fluid component using Nb-Ce systematics (Cooper et al., 2012), and the $\text{H}_2\text{O}/\text{Ce}$ ratio of the fluids were translated into slab surface temperature using the

model of Plank et al., 2009 and Cooper et al., 2012. Armed with temperature constraints, these are related to the depth of origin of the back-arc fluid by comparison with computational models of slab thermal structure (e.g. Syracuse et al., 2010). However, these models do not provide absolute constraints on exact positions of the fluid origin, instead providing a guide with enough resolution to test the first-order question of whether the fluids come from deep or shallow, and the relative contrast of conditions among the various back-arcs.

MANUSCRIPT I

**TRACING MANTLE SOURCES AND SAMOAN INFLUENCE IN THE
NORTHWESTERN LAU BACK-ARC BASIN**

by

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Abstract

Helium isotopes are commonly used as a diagnostic fingerprint of Samoan mantle in the northern Lau Basin, but the extent of input from Samoan sources can only be clearly resolved by coupling $^3\text{He}/^4\text{He}$ with other geochemical tracers such as trace elements and other isotope systems. We present new major element, dissolved volatile (H_2O , CO_2 , S, Cl, F), trace element, and Sr-Nd-Pb-Hf isotope data for new samples from the NW Lau Basin from five distinct regions (Rochambeau Rifts [RR], Northwest Lau Spreading Center [NWLSC], Peggy Ridge [PR], Lau Extensional Transform Zone [LETZ], and Central Lau Spreading Center [CLSC]) that range from distinctively elevated to normal mid-ocean ridge basalt $^3\text{He}/^4\text{He}$. Helium isotope variations are not correlated with radiogenic isotopes or trace element abundances. Our new data suggest two-component mixing of MORB-like mantle with an enriched mantle source, similar to Samoa, although consideration of a complete regional data set suggests there may be other sources of heterogeneity in the mantle beneath NW Lau. Models of mantle potential temperature (T_p) and primary melt equilibration temperatures indicate similar T_p of $\sim 1400^\circ\text{C}$ for NW Lau, suggesting no strong temperature gradient. The pressure of melt equilibration deepens towards the north ($\sim 1.1\text{-}1.2$ GPa at PR, LETZ, CLSC; $\sim 1.3\text{-}1.4$ GPa at RR, NWLSC), consistent with melting mantle of a constant T_p but variable H_2O content. Samoan and MORB-like sources are clearly present beneath the NW Lau basin, but geochemical diversity among the existing data suggest that more than two mantle sources may contribute to mantle enrichment beneath NW Lau.

1. Introduction

Tracing long-term movements of the Earth's mantle through direct observation of the Earth itself is tremendously difficult, given the enormous contrast in time scales over which tectonic/dynamic motions occur relative to the brief periods over which observations may be made. Studies of shear wave splitting provide characterizations of mantle anisotropy and flow, as olivine *a*-axes align with mantle flow vectors [e.g., Silver and Chan, 1991; Zhang and Karato, 1995]. Beneath volcanic arcs, shear wave splitting studies suggest a range of potential vectors, from arc-normal to arc-parallel [e.g., Russo and Silver, 1994; Smith et al., 2001; Conder and Wiens, 2007], challenging conventional ideas about the coupling of plate and mantle wedge flow. Geochemistry provides another tool to image mantle flow, particularly in places where mantle sources of contrasting geochemical characteristics are juxtaposed.

Using geochemistry to trace mantle flow has been successfully applied in the Mariana subduction system, where four primary contributions to the mantle source have been identified using Nb/Ta and Ta/Yb ratios, including a depleted mantle asthenosphere and enriched lithosphere that are modified by at least two distinct subduction-derived components [Pearce et al., 2005]. Additionally, while Pb isotopes distinguish two different mantle domains (Pacific and Indian) in the southwest Pacific, Pb mobility during subduction makes tracing the flow of these distinct mantle domains challenging [see Heyworth et al., 2011]. The use of less mobile Hf-Nd isotopes provides alternative geochemical tracers of the two mantle domains, showing the influx of the Indian mantle into the Fiji Islands and the N. Fiji and Lau Basins [Pearce et al., 2007].

The Lau Basin has been a particular focal point for efforts to trace mantle domains and movements using geochemistry. Extensive work at the Eastern Lau Spreading Center (ELSC), has shown a regional connection between decreasing subduction influence in the back-arc with increasing distance from the Tonga Arc [Escrig et al., 2009]. The ELSC also shows evidence of mixing between a number of mantle components, including Indian-like mantle and an enriched mid-ocean ridge basalt (MORB) mantle, with materials derived from the subducted slab [Bezous et al., 2009; Escrig et al., 2009]. The NW Lau Basin, on the other hand, comprises several spreading centers and rift zones that are located far west of the active subduction zone and are not likely to be influenced by modern subduction. The elevated He isotopic signature of the nearby Samoan Plume has long been viewed as a diagnostic tracer of enriched Samoan mantle, and following this rationale, basalts erupted in the NW Lau Basin with $^3\text{He}/^4\text{He}$ ratios higher than MORB suggest influence from a Samoa-like source in the mantle beneath NW Lau [e.g., Hawkins and Melchior, 1985; Poreda, 1985; Wright and White, 1987; Farley et al., 1992; Poreda and Craig, 1992; Lupton et al., 2009]. Reliance on a singular geochemical tracer as evidence of the regional movement of Samoan mantle however, leaves room for doubt about the origin of the elevated $^3\text{He}/^4\text{He}$ isotope ratios in the Lau Basin, particularly since other western Pacific back-arc basins have similarly elevated $^3\text{He}/^4\text{He}$ in the absence of a known nearby mantle plume [e.g., Manus basin; Shaw et al., 2004]. Do the Lau helium isotopes correlate with other geochemical signatures of Samoan mantle? Is there corroborative evidence, such as elevated mantle temperature, of hot spot influence

beneath NW Lau? These questions must be addressed before the presence or scale of Samoan mantle migration into the NW Lau Basin can be clearly resolved.

With this work, we aim to address these outstanding questions with new geochemical data for major and trace elements, dissolved volatiles, and radiogenic isotopes for a suite of glasses from a high-density sampling of spreading centers and rift zones in the NW Lau Basin. These samples have been previously analyzed for $^3\text{He}/^4\text{He}$ ratios [Lupton et al., 2009], and our work thus adds essential geochemical constraints on the genesis of NW Lau magmas that we use to test the identity of the enriched He signature, both through trace element/isotopic systematics and their relationships (or lack thereof) to He isotopes, and through petrologic modeling of mantle melting conditions beneath NW Lau spreading centers. We show that, surprisingly, He isotopes do not correlate with trace element or isotopic signatures in NW Lau, and that a portion of the mantle signature in this region, though elevated in $^3\text{He}/^4\text{He}$, is otherwise uncharacteristic of Samoa in its trace element and isotopic composition. Moreover, mantle temperature in the region, although high, does not decrease towards the south as it would if hot mantle were infiltrating from the north. We explore the consequences of these observations for models of mantle flow in this complex region, and present alternative hypotheses that could explain the data.

1.1 Tectonic Setting

The Tonga-Lau system is an oceanic subduction zone in the southwest Pacific, where the Pacific Plate subducts beneath the Indo-Australian Plate (Figure 1.1). Behind the Tonga Arc, back-arc spreading initiated at ~6 Ma in the Lau Basin [Taylor

et al. 1996], which is a V-shaped basin with several actively spreading segments that impinge on the Tonga Arc towards the south. The rates of both plate convergence and back-arc spreading are highest at the north end of the subduction zone [Hawkins 1995], which exhibits the fastest back-arc opening on Earth, spreading at a rate of 160 mm/yr, decreasing southwards to rates of 60 mm/yr [e.g., Bevis et al., 1995; Taylor et al., 1996; see Figure 1.1]. At the northern end of the Tonga Arc, the plate boundary bends 90° and the Pacific Plate ceases to subduct. This northern boundary of the system is the Vitiaz Lineament, interpreted to be a paleo-subduction zone that is now a transform boundary separating the Pacific and Indo-Australian plates [Hawkins 1995], and is likely the locus of a tear in the Pacific Plate at depth [Millen and Hamburger, 1998]. To the northeast of Tonga lies Samoa (Figure 1.1), an ocean island hot spot with an age-progressive volcanic chain on the Pacific Plate [e.g., Hart et al., 2004; Koppers et al., 2008] that may be the surface expression of a deep-rooted mantle plume [e.g., Montelli et al., 2004; Jackson et al., 2007a].

1.2 Prior Work

Several previous studies have attempted to assess the nature and extent of interactions between Samoan mantle and the Lau Basin through a tear in the Pacific Plate at the northern end of the Tonga/Lau system. Gill and Whelan [1989] first used Nd isotopes to show that enriched Ocean Island basalt (OIB) source mantle had reached Fiji by 3 Ma. Poreda and Craig [1992] first analyzed He and Sr isotopes in a small population of samples from the Rochambeau Bank (RB), a shallow submarine volcanic center near the Vitiaz Lineament (note that RB is distinct from the region of

rifting, Rochambeau Rifts [RR], immediately to the east; Figure 1.1b-c). They showed that some samples from RB have elevated $^3\text{He}/^4\text{He}$ ratios (up to 22 R_a ; where $R = ^3\text{He}/^4\text{He}$ and $R_a = R_{\text{air}} = 1.39 \times 10^{-6}$) and enriched Sr isotopic signatures relative to lavas from further south in the Lau Basin that are more typical of normal mid-ocean ridges ($^3\text{He}/^4\text{He} = 8\text{-}10 R_a$; Peggy Ridge [PR], Central Lau Spreading Center [CLSC]). Because Samoan lavas can have very high $^3\text{He}/^4\text{He}$ ratios [up to 33.8 R_a ; Jackson et al., 2007b] and very radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$, the elevated He and Sr isotope ratios at RB were used as evidence of mixing between enriched Samoan mantle, which was proposed to be drawn into the Lau Basin by mantle flow influenced by crustal extension at the spreading centers, and “ambient” depleted mantle beneath RB [Poreda and Craig, 1992].

Further work [e.g. Hilton et al., 1993; Turner and Hawkesworth, 1998; Lupton et al., 2009] has refined these initial hypotheses, although until very recently, none have involved a focused regional survey and comprehensive sampling of spreading centers in northwestern Lau. Turner and Hawkesworth [1998] reviewed data for the northern Lau Basin, including Niuafo’ou island (NF) and the Mangatolu Triple Junction (MTJ; Figure 1b), concluding that elevated He isotope ratios were sufficient evidence for the presence of Samoan mantle beneath the Lau Basin despite radiogenic isotope signatures that were not conclusively related to Samoa. Lupton et al., [2009] analyzed $^3\text{He}/^4\text{He}$ ratios of 41 new glass samples from a comprehensive survey and sampling of spreading centers in the NW Lau Basin (a subset of the samples in this study). Their study found that all lavas north of the PR had $^3\text{He}/^4\text{He}$ ratios higher than MORB but, surprisingly, found no clear correlation between $^3\text{He}/^4\text{He}$ ratios and

latitude or ridge morphology. Recent work by Tian et al. [2011] reported trace element and Sr-Nd radiogenic isotope data for northern Lau Basin samples from RB, PR, MTJ, and NF, including the RB samples from Poreda and Craig [1992]. Their results suggested a geochemically heterogeneous mantle source with both a subduction signature (in the east) and an enriched mantle source signature (in the west) from two Samoa-like end-members. Hahm et al. [2012] built upon this data set by analyzing volatiles and noble gases in these samples. Their results suggest hotspot influence in the NW Lau magmas. Moreover, further analyses of samples from the Lupton et al. [2009] study were conducted for Ne isotopes [Lupton et al., 2012] and chalcophile elements [Jenner et al., 2012]. The Ne isotopes correlate with $^3\text{He}/^4\text{He}$, providing additional evidence for influence from the Samoan Plume [Lupton et al., 2012]. The chalcophile element data showed Cu and Ag enrichment uncharacteristic of MORB or Samoan sources, suggesting the presence of an additional high-Cu mantle source in the region. The lack of a simple trend of decreasing $^3\text{He}/^4\text{He}$ in NW Lau with distance from the northern plate boundary [Lupton et al., 2009], coupled with a scarcity of supportive data for these samples (e.g., major, trace, volatile elements or radiogenic isotope ratios), raises questions about the simple hypothesis of plume migration into the Lau Basin mantle. With the present study, we provide new data to accompany the He isotopes for these samples and use these data to assess the identities of mantle sources beneath the Lau Basin and the consequences for interpretations of mantle flow in this region based on lava geochemistry.

2. Samples and Methods

The basaltic glass samples reported here are new samples from the Northern Lau Basin that were collected from 63 bottom dredges during voyage SS07/2008 of the R/V *Southern Surveyor*. Sample locations and rock descriptions including phenocryst information are given in Table 1.S1. The samples were analyzed for major elements by electron microprobe, trace elements by laser ablation and solution inductively coupled plasma mass spectrometry, volatiles by secondary ionization mass spectrometry, and radiogenic isotopes by multicollector inductively coupled plasma mass spectrometry (see supplementary information for more detailed information on sample selection and analysis methods).

3. Results

3.1 Effects of Degassing

As magma ascends from the mantle to the surface, dissolved volatiles will exsolve into a vapor phase at low pressures, resulting in volatile loss from the melt. Major volatile species (e.g., H₂O, CO₂) have different vapor/melt solubilities, enabling an assessment of volatile loss from each glass. Carbon dioxide has lower solubility in silicate melt at low pressure and is expected to begin degassing before H₂O [Dixon and Stolper, 1995], and the mixed CO₂-H₂O content of a glass reflects the minimum pressure of final equilibration of vapor-melt if the latter was volatile-saturated. Figure 1.2a shows CO₂ vs. H₂O in the glasses from NW Lau, which indicate vapor saturation at pressures of 200-400 bars. Model degassing paths show that CO₂ is more sensitive to the early stages of degassing, and that H₂O loss is not significant until most CO₂ has been removed from the melt [Newman and Lowenstern, 2002]. Based on this analysis,

most glasses have likely lost variable amounts of CO₂, but H₂O concentrations are relatively unmodified from the original magmatic values, with the exception of three andesite-composition glasses from NWLSC that have lost virtually all of their CO₂. Figure 1.2b compares the calculated pressure at H₂O-CO₂ saturation with the hydrostatic pressure at the mean collection depth of each sample. Most samples are found to be vapor-oversaturated or saturated at the pressure of collection, which is typical of mid-ocean ridge basalts and reflects relatively fast transport and eruption of magma from mid-crustal depths [Danyushevsky et al., 1993].

3.2 Effects of Crystallization

Assessing the extent of H₂O degassing is important because H₂O influences magmatic crystallization and the liquid line of descent (LLD). Water suppresses plagioclase and clinopyroxene crystallization [e.g., Sisson and Grove, 1993a; Sisson and Grove, 1993b] and its effects can be seen in the major element systematics of the NW Lau basalts. The basalts can be segregated into two major groups on the basis of H₂O content, which we reference here to H₂O_(8.0) (i.e., glass H₂O concentration corrected for fractional crystallization to the equivalent concentration at 8 wt.% MgO; Table 1.S2), calculated using the expression of Taylor and Martinez [2003]. Figure 1.3a shows the functional form of the expression for H₂O_(8.0), and the discriminating curve between glasses with low H₂O (<0.3 wt.% H₂O_(8.0)) and those with high H₂O (>0.3 wt.% H₂O_(8.0)). The contrast in LLDs of end-member parent magmas for H₂O-rich and H₂O-poor groups show the effects of H₂O on plagioclase and clinopyroxene suppression in hydrous magmas during crystallization. Figure 1.4b-d show variations

in Al_2O_3 , CaO , and $\text{CaO}/\text{Al}_2\text{O}_3$ ratio as MgO decreases, which track the appearances of plagioclase and clinopyroxene on the liquidus during crystallization. The wetter magmas are consistent with later saturation of both plagioclase and clinopyroxene, an observation that is matched well by fractional crystallization models generated using Petrolog3 software for two parental magmas with different H_2O contents [Danyushevsky & Plechov, 2011; see figure caption for details]. These modeled shifts in saturation of plagioclase (plag) and clinopyroxene (cpx) due to melt H_2O content can be referenced to the MgO content of the model melts at the point of mineral saturation. For the drier melts, MgO content at plag-in (i.e., $\text{MgO}_{\text{plag-in}}$) is 9.2 wt.% and $\text{MgO}_{\text{cpx-in}}$ is at 8.6 wt.%, whereas for the wetter melts, $\text{MgO}_{\text{plag-in}}=8.9$ wt.% and $\text{MgO}_{\text{cpx-in}}=7.1$ wt.%.

The differences in major element composition of the two end-member parental magmas likely reflect differences in melting processes and/or source composition. Specifically, the wetter parent magma has higher Na_2O and Al_2O_3 , lower CaO , and a lower $\text{CaO}/\text{Al}_2\text{O}_3$ ratio than the dry parent magma. Higher concentrations of incompatible elements (e.g., Na_2O , Al_2O_3 , H_2O) could reflect lower extents of melting of more hydrous mantle (e.g., Langmuir et al., 1992; Asimow and Langmuir, 2003), although all incompatible elements should be affected similarly if this were the case, and no difference is required in TiO_2 , K_2O , or P_2O_5 for the parental magmas. The difference may instead reflect variation in the modal cpx content of the mantle source, which will tend to drive melt compositions to higher Na_2O and Al_2O_3 , and lower $\text{CaO}/\text{Al}_2\text{O}_3$ ratio with increasing source fertility (i.e., higher modal cpx; Klein and Langmuir, 1987). It is important to note, however, that the parent magmas were

chosen to bracket the majority of the data, which represent more of a compositional continuum rather than two discrete populations of melts.

3.3 Trace Element Variability

The NW Lau Basin basalts span a wide range of trace element enrichment, as shown on Figure 1.4. The RR basalts (Figure 1.4a) range from highly depleted to highly enriched, but none fall completely within the fields defined by either Samoan shield-stage or rejuvenated magmatism. At the NWLSC, basalts are less enriched overall compared to RR (Figure 1.4b), although two samples (NLD-44-01, NLD-44-02) have distinct trace element patterns and are significantly more enriched than other samples from NWLSC or RR. These samples nearly overlap the Samoan field, although they have flat rather than sloping heavy rare earth elements, and are also encompassed by the field for basalts from the neighboring North Fiji Basin (NFB), which lies to the west of the study area (Figure 1). Trace element patterns for PR/LETZ and CLSC basalts show that these are less enriched than either RR or NWLSC, and are likely to be representative of the background depleted MOR-type mantle beneath the Lau Basin.

3.4 Isotope Variability

The Sr and Nd isotopes of two RR samples, NLD-07-01 and NLD-20-01, overlap the least radiogenic part of the Samoan field (Figure 1.5c). Tian et al. [2011] report Sr-Nd isotopes for two other similar samples from RB. These are the only basalts in the NW Lau Basin with radiogenic enough Sr to match Samoan basalts. Our

samples, especially NLD-20-01, also overlap the Samoan field in Hf-Nd and Pb isotope space (Figure 1.5d and supplementary information). The Sr, Nd, Hf, and Pb isotopes of all other samples from both the RR and NWLSC are much more depleted than Samoa, with MORB-like ratios similar to the CLSC, although $^3\text{He}/^4\text{He}$ ratios in all of these samples range from 12-28 and show no correlation with any of the radiogenic isotopes (Figure S5d-e).

4. Discussion

Trace element abundances and $^3\text{He}/^4\text{He}$ ratios show that the mantle beneath the NW Lau Basin is geochemically enriched relative to normal MORB or the proximal CLSC. Here, we explore the geospatial patterns of mantle enrichment, and the relationships between $^3\text{He}/^4\text{He}$ and these new data, in order to assess the identities and locations of distinct mantle components contributing to magmatism in the NW Lau Basin. In addition, we model the pressure and temperature conditions of mantle melting beneath NW Lau in order to test for a regional thermal gradation possibly associated with the Samoan Plume.

4.1 The spatial distribution of enrichment in NW Lau

The NW Lau samples span a wide range of enrichment, as shown on Figure 1.4, with a general trend of enrichment in incompatible trace elements broadly decreasing from the north (RR) to the south (CLSC). If Samoan material were simply migrating into the Lau Basin, the expectation would be that “Samoa-like” affinity or enrichment should decrease with latitude towards the south. Looking at the main tracer

for Samoan affinity, the $^3\text{He}/^4\text{He}$ ratio, Lupton et al. [2009] compared $^3\text{He}/^4\text{He}$ ratios to latitude, showing a broad distribution of elevated $^3\text{He}/^4\text{He}$ ratios in the north and MORB-like ratios in the south (Figure 1.6c). Because Samoan lavas are enriched in light rare earth elements (LREE) and large ion lithophile elements (LILE), these indices of mantle enrichment (e.g., La/Sm, Ba/La) should also show a similar distribution of enrichment from north to south.

Indices of enrichment do broadly decrease towards the south, as does the $^3\text{He}/^4\text{He}$ ratio (Figure 1.6), but neither a simple, secular change in these ratios with latitude exists, nor is the contrast purely bimodal (i.e., enriched in the north, depleted in the south). For example, Figure 1.6a shows two samples from NWLSC that are more enriched than any samples from RR to the north, whereas the Ba/La ratios in Figure 1.6b span the same range of values (5-15) for both RR and NWLSC. The RR and NWLSC span large ranges, from highly enriched to highly depleted, with no apparent geographic trends, and the PR and CLSC are uniformly similar to MORB. Furthermore, the trace elements do not clearly correlate with $^3\text{He}/^4\text{He}$ (Figure 1.6d), as would be expected if the source of enrichment were a single mantle component.

4.2 Constraining the influence of subduction on NW Lau mantle sources

One source of enrichment that could perturb correlations of trace elements with He isotopes is subduction, which is not known to significantly modify $^3\text{He}/^4\text{He}$ ratios of magmas [Poreda and Craig 1989], but can enrich light REE and Ba/La ratios by way of fluid and sediment melt additions to the mantle source. Although the NW Lau Basin is located ~530km from the active Tonga subduction zone, the basin is opening

in a region of paleo-subduction and the possibility for lingering influence from the past subduction along the Vitiaz Lineament remains. We test for effects of subduction on the mantle source beneath NW Lau by examining classic fluid- and sediment melt-mobile elements (i.e., Ba, Pb, H₂O, LREE).

Extensive study of the ELSC provides a framework for comparing the NW Lau lavas with other regional lavas with well-established subduction influence [e.g., Bezos et al. 2009; Escrig et al. 2009]. Figure 1.7a compares two important ratios that are sensitive to subduction influence, Ba/La and H₂O/Ce. As slab-derived fluids rich in H₂O and Ba are added to the mantle, both of these ratios will increase, as both La and Ce partition less strongly than Ba into aqueous fluid released from the subducting slab. Although the lavas from RR and NWLSC extend to higher Ba/La ratios than Samoa, they show no coincident increase in H₂O/Ce such as the trend shown by the ELSC.

Other ratios sensitive to subduction influence are Nb/Nb* and the Ce/Pb ratio, shown in Figure 1.7b. Negative Nb anomalies ($\text{Nb/Nb}^* < 1$, where Nb* is the projected concentration of Nb based on neighboring Th and La abundances) are characteristic of subduction-influenced magmas and correlate, as defined here, with increasing Th and La additions relative to comparatively immobile Nb from the slab to the mantle source. The Ce/Pb ratio also decreases as fluids are added from the slab to the mantle source, as both elements behave similarly during mantle melting (normal MORB Ce/Pb = 15-28), but fluid-mobile Pb is preferentially transported by the slab-derived mass flux resulting in lower Ce/Pb for arc magmas [Miller et al. 1994]. The NW Lau basalts from RR and NWLSC have no significant negative Nb anomalies ($\text{Nb/Nb}^* \geq 1$) and Ce/Pb ratios ≥ 15 , consistent with the range for normal MORB

[Miller et al. 1994] and inconsistent with the trend among subduction-influenced basalts from the ELSC, which have both $\text{Nb}/\text{Nb}^* \leq 1$ and Ce/Pb in most samples < 15 (Figure 1.7b). Based on these observations, we find no evidence for subduction influence on the composition of the mantle beneath the NW Lau Basin.

4.3 Geochemical characteristics of NW Lau mantle sources

Since we have ruled out subduction as a possible process for adding contaminants to the mantle source, and Figure 1.6d rules out simple two-component mantle mixing, more complex processes may be required to explain the variations seen in the NW Lau basalts. Here, we explore the trace element and isotopic signatures of the NW Lau basalts, and attempt to identify the number of possible mantle sources beneath NW Lau and their geochemical characteristics.

Although developed for exploring mixing between Th and LREE-enriched subducted sediment and LREE-depleted mantle components beneath arc volcanoes [Plank 2005], Figure 1.8a can also be more generally applied to explore mixing between any two relatively enriched and depleted mantle components. In the case of NW Lau, possible mantle sources include MORB mantle (low Th/La, high Sm/La) and an enriched source like Samoa (high Th/La, low Sm/La). The NW Lau basalts fall on straight-line mixing trajectories between an enriched mantle that lies within the Samoan field and two distinct components of background depleted mantle that are spanned by the data array for the CLSC. The Sm/La ratio can, however, be fractionated by melting a common mantle source to variable extents, so the variation in the MORB component from RR and NWLSC may be inherent variation in the

MORB mantle source beneath NWLSC. In contrast, Figure 1.8b suggests possible variation in the enriched component, as traced by Rb/Zr and Nb/Zr ratios. The field for Samoa is constrained by $\text{Nb/Zr} = 0.12\text{--}0.25$ and $\text{Rb/Zr} > 0.05$, whereas normal MORBs have very low Nb/Zr and Rb/Zr ratios. The most enriched samples from RR point towards mixing with a Rb and Nb-enriched component that may be similar to Samoa. Two samples from dredge 44 on the NWLSC, are most extreme, fall outside the field for Samoa, and are similar to some samples from the neighboring NFB. In addition, samples from Rochambeau Rifts define a separate trend from NWLSC in Figure 1.8b as well as Figure 1.8a, indicating a different enriched component, and the samples that are most similar isotopically to the Vai Trend in Samoa lie on this trend. Initial interpretations drawn from Figure 1.8 thus suggest that there are a minimum of two, but possibly up to four mantle components involved in magma production beneath NW Lau, with trace element characteristics similar to regional basalts erupted at the CLSC (both enriched and depleted), Samoa, and NFB.

The number of possible mantle components may be further refined using He, Sr, Nd, Pb, and Hf isotopes, which are particularly important geochemical tracers of mantle sources, as isotopes are insensitive to fractionation by melting and crystallization processes. Figure 1.5a [data from Poreda and Craig 1992] shows the relationships between $^3\text{He}/^4\text{He}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ in regional lavas from Samoa, RB, and our new samples from NW Lau. The low $^3\text{He}/^4\text{He}$, high $^{87}\text{Sr}/^{86}\text{Sr}$ component of Samoa is considered an end-member mantle composition termed EMII [e.g., Workman et al., 2004]. The high $^3\text{He}/^4\text{He}$, low $^{87}\text{Sr}/^{86}\text{Sr}$ component of Samoa was initially dubbed “primitive helium mantle” [PHEM; Farley et al. 1992], although other work has

shown that a similar mantle component may be common to most global hot spots [“FOZO”; Hart et al., 1992]. Depleted MORB mantle (DMM) is characterized by both low $^3\text{He}/^4\text{He}$ (7-9 R_a) and low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7022-0.7026). Four samples from the RB region [Poreda and Craig 1992] originally suggested a straight-line trend between DMM and Samoa (Figure 1.5a). Tian et al. [2011] found that samples from RB consist of two groups, one that is depleted with a MORB-like, minor subduction signature and one that is enriched by a Samoa-like shield magmatism signature. Our new data show that two samples from RR do plot with Samoa in He, Sr, and Nd isotopes, although six others from RR and NWLSC do not (including the highest $^3\text{He}/^4\text{He}$ sample at 28 R_a). On Figure 1.8a, these six samples instead point to greater enrichment in $^3\text{He}/^4\text{He}$ at a given $^{87}\text{Sr}/^{86}\text{Sr}$, which are characteristics more typical of other hot spots like Iceland or Loihi, suggesting an alternate mantle source for some of the high $^3\text{He}/^4\text{He}$ beneath NW Lau.

Strontium isotopes coupled with trace element ratios and Nd isotopes tell a similar story. Figure 1.5b-c show the La/Sm and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios vs. $^{87}\text{Sr}/^{86}\text{Sr}$, and the NW Lau data show two fairly distinct behaviors. The RR samples with the highest $^{87}\text{Sr}/^{86}\text{Sr}$ point towards a Samoa-like composition. These, coupled with two RB samples from Tian et al. [2011], are the only basalts from anywhere in the northern Lau Basin that have clear Samoan isotopic traits. The remaining samples from both the NWLSC and RR cluster with MORB-like LREE, $^{143}\text{Nd}/^{144}\text{Nd}$, and $^{87}\text{Sr}/^{86}\text{Sr}$, with the exception of the strongly trace-element enriched sample from NWLSC, which is isotopically similar to the other samples, but similar in LREE to lavas erupted in the NFB. Taken alone, the isotopic data from our study require at least two mantle

components beneath NW Lau, but do not clearly resolve any other isotopically distinct source. Tian et al. [2011] found isotopic variations at RB that appear to require a third mantle component of sorts, with lower $^{87}\text{Sr}/^{86}\text{Sr}$ at a given $^{143}\text{Nd}/^{144}\text{Nd}$, that they linked to the “rejuvenated” component of Samoan magmatism (Figure 1.5c). Lead isotopes (Figure 1.5d) also suggest mixing between a minimum of two mantle sources beneath NW Lau. One component is an Indian-type MORB mantle, the other is strongly enriched in Pb isotopes in the direction of Samoan basalts, with one RR sample falling within the Samoan field. If a third source, similar in composition to that beneath the NFB, were involved beneath NW Lau, it would not be clearly discriminated by Pb isotopes because enriched NFB basalts overlap with Samoa in Pb isotopic composition (Figure 1.5d).

4.4 Modeling Mantle Melting Conditions beneath the NW Lau Basin

Hotspots such as Samoa are characterized by elevated mantle potential temperature, [e.g., Putirka, 2008] resulting in higher extents of melting of an adiabatically upwelling mantle. Subduction influence within the mantle source of NW Lau appears largely absent, thus magma production in this region should therefore be a simple function of mantle potential temperature coupled with the inherent composition of the mantle source. Melting beneath mid-ocean spreading ridges is driven by adiabatic upwelling of the mantle over a range of mantle potential temperatures [Klein and Langmuir, 1987, 1989]. If a hot plume were infiltrating the Lau Basin, however, we may also expect elevated mantle temperature in the region, possibly cooling off with distance from the plate boundary. Recent estimates of the

Samoan mantle potential temperature place it at $\sim 1720^{\circ}\text{C}$ [Putirka et al., 2007], whereas previous constraints from the Northern Lau Basin indicated a regional mantle potential temperature of $\sim 1460^{\circ}\text{C}$ [Falloon et al., 1999] to $\sim 1400^{\circ}\text{C}$ [Kelley et al., 2006]. The seismic structure beneath the CLSC shows low velocity zones (V_p and V_p/V_s), interpreted as melt regions, located 30-50 km beneath the CLSC, consistent with a regional T_p of $\sim 1400^{\circ}\text{C}$ [Conder and Wiens, 2006].

Accurate petrological constraints on mantle temperatures and melting conditions require that basalt compositions be corrected for the effects of fractional crystallization and referenced to a common point along the liquid line of descent (LLD). The LLD modeling done here (see section S.5) allows reconstruction of melts to their primary compositions by using the modeled fractionation slopes to project melt compositions back to the points of cpx-in and plag-in (Table 1.S6, Figure S4) before adding equilibrium olivine to each melt until it is in equilibrium with Fo_{90} (Table 1.S7). A detailed summary of the correction procedure is provided in the electronic supplement. The pressures and temperatures of last equilibration of each reconstructed primary melt with the mantle are calculated using a thermobarometer based on the Si, Mg, and Fe contents of primary melts in equilibrium with olivine + orthopyroxene [Lee et al., 2009]. The model requires an estimate of the iron oxidation state [i.e., $\text{Fe}^{3+}/(\text{Fe}^{3+} + \text{Fe}^{2+})$] in the magma, which here is taken as a normal MORB value [0.16; Cottrell and Kelley, 2011].

The results of this modeling show that melt equilibration pressure increases towards the plate boundary in the north (RR 1.38 GPa; CLSC 1.08 GPa; Figure 1.9a). The higher pressures of equilibration could be the result of a hotter mantle intersecting

the solidus at greater depth beneath RR and NWLSC. The modeled equilibration temperatures, however, show that the higher pressure melts at RR are cooler, not hotter, than basalts from NWLSC or CLSC (Figure 1.9c, inset), suggesting that temperature may not exert the main control over the melting pressure. Alternatively, mantle composition variations in the north may be responsible for melting at a deeper mantle solidus.

Among a number of compositional factors known to lower the peridotite solidus is the H₂O content [e.g., Kushiro, 1968]. We calculated the water content of the NW Lau mantle sources using the batch melting model and Ti/Y source composition model from Kelley et al. [2006], using TiO_{2(F090)} concentration as a proxy for melt fraction (see supplementary information). The water content of the mantle source (i.e., $C_{\text{H}_2\text{O}}^0$) beneath NW Lau increases northwards, towards the plate boundary, in a manner similar to the melt equilibration pressure (Figure 1.9b). Higher $C_{\text{H}_2\text{O}}^0$ lowers the mantle solidus temperature, allowing hydrous melting to take place at lower temperatures and higher pressures relative to dry peridotite, shown on Figure 1.9c, modeled using the parameterization of Kelley et al. [2010]. Adiabatic melting paths (see figure caption for details) for mantle of a constant potential temperature ($T_p = 1400^\circ\text{C}$) are shown on Figure 1.9c intersecting dry and hydrous peridotite solidi for a range of $C_{\text{H}_2\text{O}}^0$ relevant to the Lau samples. Melting of a mantle with homogeneous T_p but heterogeneous H₂O content may explain the spread in the modeled P-T conditions, and explain the higher average pressures of melt equilibration in the northern part of the basin. Additionally, RR have lower HREE relative to MgO and other trace elements, consistent with more residual garnet present and greater depth of melting as

a result of a wetter source. A constant mantle T_p of 1400°C from the northern plate boundary to the CLSC seems inconsistent with the model of migration of a hot plume into the NW Lau Basin. Kelley et al. [2006] inferred a much cooler mantle ($T_p \sim 1300^\circ\text{C}$) in the southern part of the Lau Basin, suggesting that the scale of thermal variation may be different from that of geochemical variation. It is also possible that hot Samoan mantle could be thermally equilibrated with its surroundings by the time it reaches the plate boundary [Druken et al., 2009].

4.5 Hypotheses for sources of enrichment and mantle flow beneath NW Lau

4.5.1. Mixing between Two Mantle Source Components

Samoan geochemical data shown on Figures 5-8 are restricted to the Vai trend [Tau and Ofu islands and Vailulu'u seamount; Workman et al., 2004], which encompasses the high $^3\text{He}/^4\text{He}$ (>15) and low $^{87}\text{Sr}/^{86}\text{Sr}$ component of Samoan lavas. This is the classically-hypothesized component contributing elevated $^3\text{He}/^4\text{He}$ in the Lau basin. Our detailed sampling and analysis of regional volcanism in the NW Lau Basin reveals the influence of a minimum of two mantle sources beneath the NW Lau Basin, as originally proposed by Turner and Hawkesworth [1998], to explain the majority of the trace element and isotopic data reported here. Lead, strontium, and neodymium isotopes (Figure 1.5d) require two end-members: a Samoa-like enriched mantle source and a depleted “Indian” MORB-like mantle source. The first mantle source is similar to Samoa with respect to both trace elements and radiogenic isotopes, with elevated $^3\text{He}/^4\text{He}$ and radiogenic isotopic compositions similar to the Vai trend in Samoa (e.g., Figure 1.5, 6, 8, and S5). The second mantle source is a depleted, CLSC-

type MORB source, with LREE depletion and MORB-like radiogenic isotopes indicative of an origin in the Indian mantle domain (Figure 1.5, 6, S5).

Following the same approach for calculating $C_{H_2O}^0$ (see section 4.4 above and supplement), we also calculate the source trace element compositions of the NW Lau lavas (Figure S6) to test whether two component mixing is evident in the source compositions for the NW Lau samples. The samples from NW Lau show evidence for binary mixing between an enriched source and DMM [Workman and Hart, 2005]. The modeled theoretical enriched source, determined from the most enriched RR samples, is enriched in certain trace elements relative to Ta'u source (e.g., Ba, Nb, La, Th) but has Samoan-like isotopes (Figure 1.5, Figure S6). The enriched source infiltrating NW Lau thus may represent part of the Samoan Plume that is not observed in the Samoan islands, but rather part of the plume that has been deflected towards NW Lau from depth.

Figure 1.10a illustrates this scenario of a two component mixture of mantle sources beneath the NW Lau basin, with an important caveat. A simple two-component model satisfies the majority of trace element and Sr-Nd-Pb-Hf isotopic data, but fails to explain the He isotopes. The two-component model therefore must include an “invisible” third component that transports He from Samoa independent of geochemical characteristics or elevated T_p of the Samoan Plume. The Samoan mantle is known to be heterogeneous [e.g. Jackson et al., 2010], but this scenario requires NW Lau to be sampling an enriched Samoan source with two components, a known Samoan source in trace element and isotopic composition related to the Vai trend, and a separate Samoan helium component that causes elevated $^3\text{He}/^4\text{He}$ ratios in lavas that

are distinctly non-Samoan (e.g., MORB-like) in trace element and isotopic composition.

4.5.2 A Third Mantle Component?

Although the majority of our trace element and isotopic data suggest only two mantle sources, a distinct, third mantle source could be present, following several other lines of evidence. In particular, the highly enriched samples from NWLSC, the coupled He-Ne isotope systematics, the chalcophile element contents, and some radiogenic isotope data point to alternate sources of compositional diversity in the mantle beneath NW Lau. Here, we discuss the data and reasoning behind these additional constraints, and consider the implications for mantle source models in the NW Lau region.

We first explore whether variable degrees of melting of a binary mantle source can explain the observations that suggest more than two mantle sources for our samples (i.e., the most Nb-enriched NWLSC samples, and the differences between RR and NWLSC trends in Figure 1.8). The gray dashed line in Figure 1.8b shows the trajectory of variable percent melting of the Ta'u Samoan source [Jackson et al., 2007a; see Figure 1.4 caption for details of the model]. The model can explain our and Tian et al. [2011]'s most Nb-enriched samples from the NWLSC but cannot explain the steeper trend for RR which is more like Ta'u isotopically. Figure 1.4b shows that although a 6% melt of the Ta'u source can approximate the Rb to La portion of the spider diagram for our most enriched NWLSC samples (NLD-44-01 and NLD-44-02), it predicts much higher middle and heavy REE concentrations. The match is even

worse for the samples that are most like Tau isotopically (NLD-07-01 and NLD-20-01) because they have the lowest HREE contents and steepest REE patterns (Figure 1.4a). We conclude, therefore, that just varying percent melting of two mantle sources cannot explain our observations, and at face value, these enriched melts appear to require melting of a mantle source with similar isotopic composition, but different trace element characteristics, relative to the Ta'u source. Such an alternate mantle source, however, is restricted to these two samples and thus is highly localized beneath the NWLSC, and could not be responsible for broad, regional source heterogeneity.

We next summarize observations that suggest involvement of additional mantle sources. Jenner et al. [2012] observed unusual enrichment in Cu and Ag relative to MORB at the NWLSC, RR, and CLSC. They explained the data by mixing between a high Cu source and at least one low Cu source (Samoa and MORB are indistinguishable and low in Cu). The origin of the high Cu source was not identified, but we show on Figure 1.8c that enrichments in Cu over Zn correlate regionally with the La/Sm ratio. The most Cu-enriched samples from both the CLSC and NWLSC have the lowest La/Sm ratios, suggesting that the high Cu source is the highly depleted MORB mantle that is most prominent beneath the NWLSC (Figure 1.8a). From this perspective, a third mantle source, dispersed throughout the NW Lau Basin, with depletions in lithophile trace elements and enrichments in chalcophile elements is needed to explain the data (e.g., Figure 1.10b).

Although He does not correlate with trace elements and other isotopes, there is correlation between He and Ne. Recent studies by Hahm et al. [2012] and Lupton et al. [2012] found that He-Ne systematics identify the noble gas signature of the NW

Lau lavas as a mixture of MORB and OIB, with characteristics similar to Samoan noble gases. Although Hahm et al. [2012] and Lupton et al. [2012] model the noble gas mixing using different OIB and MORB end-members, the mixing arrays from both studies suggest different contributions from, and possibly different compositions of, OIB and MORB sources among NW Lau samples (Figure S5). Samples from RB [Hahm et al., 2012] plot with or below the trend defined by Samoa [Jackson et al., 2009], whereas samples from RR and NWLSC [Lupton et al., 2012] define an array above Samoa (Figure 1.S5), effectively requiring different $^3\text{He}/^{22}\text{Ne}$ ratios in either the MORB or OIB end-members (or possibly both) beneath RB relative to the rest of the NW Lau Basin.

Tian et al. [2011] explained the complex relationships among trace elements and radiogenic isotopes at the RB seamount by the impingement of Samoan Plume-related mantle upon the local subduction-metasomatized Indian-type mantle. They propose that two different Samoan components are required to explain the isotopic diversity of their data at RB. We find, however, that only two isotopically distinct components (one Samoan, and one MORB-like) are required to explain variations in our data set for these areas. If an additional enriched component, of the type identified by Tian et al., [2011], is present beneath the NW Lau Basin, our data indicate that it must be localized to the area beneath RB and is not widely dispersed through the regional mantle.

We also note that the Manus Basin is another Pacific back-arc basin with elevated $^3\text{He}/^4\text{He}$ signatures, that is associated with locally elevated mantle temperature [e.g., Kelley et al., 2006] and with a diffuse regional mantle plume [e.g.,

Shaw et al., 2004; Shaw et al., 2012]. The Manus Basin provides a regional example of elevated $^3\text{He}/^4\text{He}$ signatures without the presence of a clearly identified mantle plume, thus suggesting that the Samoan mantle is not the only possible source of high $^3\text{He}/^4\text{He}$ in the NW Lau Basin, and its proximity to the enrichments in NW Lau could simply be coincidence. In this view, the enriched component beneath the NW Lau Basin could be sourced by a diffuse local plume (e.g., Figure 1.10c), as has been suggested for the Manus Basin. Some basalts from the NW Lau Basin do, however, have trace element and isotopic characteristics in common with Samoan sources, making this hypothesis less likely.

Models involving just two mantle sources cannot explain the lack of correlation between noble gases and other isotopes (Figure 1.5a), the details of trace element patterns (Figure 1.4b), and the differences in trace element trajectories between RR and NWLSC (Figure 1.8a-b). The consequences of these combined observations effectively suggest some alternate hypotheses to explain the diversity of trace elements, noble gases, and radiogenic isotopes. All hypotheses must include a known Samoan plume composition that is isotopically similar to Ta'u, and the alternate hypotheses presented here need not be mutually exclusive; indeed, a combination of these models may be required to explain all of the available data. The simplest model (Figure 1.10a) involves mixing of a MORB-like mantle with an enriched Samoan-like mantle composition, although a physically separate component carrying noble gases must move independently of the trace elements and isotopes from the Samoan Plume. In addition, to explain the enriched samples at NWLSC, as well as both the chalcophile element constraints [Jenner et al., 2012] and the noble gas and

radiogenic isotope constraints [Tian et al., 2011; Hahm et al., 2012; Lupton et al., 2012] there may be inherent mantle heterogeneity beneath NW Lau Basin (Figure 1.10b). The Manus Basin model, where the basalts have a geochemical plume signature without an identified plume in the region [Shaw et al., 2004; Shaw et al., 2012], would permit a third hypothesis (Figure 1.10c), which invokes a previously unidentified regional hotspot with high $^3\text{He}/^4\text{He}$ located to the west of NW Lau Basin, to explain the similarities in trace element and isotopic signatures between some NW Lau basalts and NFB basalts.

4.5.3 Independent Behavior of Helium

Although $^3\text{He}/^4\text{He}$ ratios do broadly correlate with trace elements and radiogenic isotopes at Samoa (e.g., high $^3\text{He}/^4\text{He}$ ratios are restricted to a narrow range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios; Figure 1.5a), there is an obvious lack of correlation between $^3\text{He}/^4\text{He}$ and trace elements and radiogenic isotopes within the NW Lau Basin. The majority of samples from RR and NWLSC that have $^3\text{He}/^4\text{He} = 10\text{-}20 R_a$ are otherwise isotopically similar to MORB, whereas Samoan samples in the same range are isotopically enriched. Helium isotopes similar to Samoan ratios largely do not correlate with trace element or radiogenic isotopic enrichments characteristic of Samoan influence in the NW Lau Basin, although the combination of He and Ne isotopes fingerprint the noble gas signature as a mixture of MORB and OIB [similar to Samoa; Hahm et al., 2012; Lupton et al., 2012]. Processes such as degassing of the enriched melts [Hahm et al., 2012] or diffusion of the noble gases [He and Ne; Lux, 1987] could explain the lack of correlation between He and other radiogenic isotopes

and trace elements. Helium and Ne degas faster than the other noble gases, which may result in an observed lack of correlations in enriched melts between He (and Ne) and other isotopes or noble gases [Lux, 1987; Niedermann et al., 1997]. Another process that could result in He moving independently in the mantle is a “leaky lower mantle” scenario induced by rapid spreading rates [Shen et al., 1995; Niedermann et al., 1997]. This model was developed for fast spreading ridges (e.g., the East Pacific Rise), where fast spreading is associated with deep induced mantle flow that could pick up material introduced into the upper mantle by miniature plumes leaking upward from the lower mantle at the 670 km boundary. The NW Lau Basin is opening with extremely fast spreading rates (160 mm/yr in the north), and this process could thus also apply at NW Lau, causing elevated noble gas signatures, with normal MORB Sr-Nd-Pb isotopes. Another possibility is the Samoan Plume could be entering the NW Lau Basin in a chaotic manner due to the complex tectonics (e.g, fast subduction, tear in the subducting plate, and rapid upwelling of the mantle beneath the back-arc; Hawkins 1995, Millen and Hamburger 1998). If the Samoan Plume is not entering the back-arc basin smoothly then a clean latitudinal decrease of the geochemical tracers might not be expected [Spiegelman 1996].

5. Conclusions

Our geochemical data for new samples from the NW Lau Basin suggest that two-component mixing of mantle sources is the simplest model required to explain magma generation beneath the NW Lau basin, although more complexity and several alternate sources may be permissible given the full range of available data. The

simplest model involves mixing between a MORB-like mantle (e.g., CLSC) and an enriched mantle component with trace element and isotopic characteristics similar to Samoa, although this model requires He to migrate independently of trace elements from their Samoan source into the Lau mantle. Mantle potential temperature is relatively homogeneous throughout NW Lau, from RR to CLSC ($\sim 1400^{\circ}\text{C}$), although possibly hotter than the ELSC and Valu Fa ridges further south, but variations in primary melt equilibration pressure show increasing depth of equilibration towards the north (~ 1.08 GPa at CLSC; ~ 1.38 GPa at RR) that are explained by melting mantle of constant T_p but variable H_2O content. We present three alternative, though not mutually exclusive, hypotheses to explain the observed geochemical characteristics of NW Lau basalts, invoking both a contribution from an isotopically recognizable component of Samoan mantle and (1) a separate, noble-gas-only component that causes enrichment in He isotopes without a proportional contribution from Samoan trace elements, (2) inherent mantle heterogeneity in the NW Lau mantle, unrelated to Samoa, or (3) a previously unidentified volcanic hotspot to the west of NWLSC. Our results indicate that some lavas from the NW Lau Basin have geochemical signatures similar to Samoa, but many have high $^3\text{He}/^4\text{He}$ with trace element and isotopic signatures more similar to MORB, requiring greater complexity to explain the origin of elevated $^3\text{He}/^4\text{He}$ ratios in lavas throughout the region.

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Figure 1.1 **A)** Regional map of the southwest Pacific, focusing on the Fiji and Samoa region. The Lau Back-arc Basin is opening behind the Tonga-Kermadec arc at a rate of 60-160 mm/yr, increasing northwards to the plate boundary while the Pacific Plate subducts at a rate of 160-240 mm/yr [Bevis et al., 1995]. **B)** Detailed map of the northern Lau Basin, showing samples from Rochambeau Rifts (RR; circles), Northwest Lau Spreading Center (NWLSC; diamonds), Peggy Ridge/Lau Extensional Transform Zone (PR/LETZ; triangles), and the Central Lau Spreading Center (CLSC; squares). The Eastern Lau Spreading Center (ELSC), Mangatolu Triple Junction (MTJ), and Niuafo'ou island are identified for reference. The shaded symbols are samples from this study, the open squares are Melson et al. [2002], the open circles and triangles are from Tian et al. [2011], and the crossed symbols are from Poreda and Craig [1992]. The dashed lines outline the regions shown on panels C-F. Basemaps in panels A-B were created using GeoMapApp [<http://www.geomapapp.org>; Ryan et al., 2009]. **C-F)** Swath bathymetry maps and sample locations for the four main regions of this study: RR, NWLSC, PR/LETZ, and CLSC. High-resolution bathymetry was collected in 2008 by R/V Southern Surveyor using an EM300 multibeam bathymetry system.

Figure 1.2: **A)** Plot of CO₂ vs. H₂O, showing samples from Rochambeau Rifts (RR; circles), Northwest Lau Spreading Center (NWLSC; diamonds), Peggy Ridge/Lau Extensional Transform Zone (PR/LETZ; triangles), and the Central Lau Spreading Center (CLSC; squares). Degassing paths, shown by the dashed gray (closed system) and dashed black (open system) lines, are calculated using Volatile Calc [Newman & Lowenstern, 2002] with the following constraints: 49 wt.% SiO₂, 1.4 wt.% H₂O, 240 ppm CO₂, 1000°C, and for closed system degassing 0.5 wt.% exsolved volatiles. **B)** Plot of hydrostatic pressure at collection depth vs. pressure of volatile saturation (see panel A) for glasses from the NW Lau basin. A 1:1 line is plotted with an uncertainty in collection pressure of 50 bars, to account for the possibility that lava flowed downhill from the initial eruption site.

Figure 1.3: Plots of MgO vs. major elements and ratios in glasses from the NW Lau basin, showing samples from Rochambeau Rifts (RR; circles), Northwest Lau Spreading Center (NWLSC; diamonds), Peggy Ridge/Lau Extensional Transform Zone (PR/LETZ; triangles), and the Central Lau Spreading Center (CLSC; squares). Shaded symbols contain <0.3 wt.% H₂O_{8.0} and open symbols contain >0.3 wt.% H₂O_{8.0}. Liquid lines of descent are shown on panels B-D, modeled using Petrolog3 [Danyushevsky & Plechov, 2011] for two compositionally different theoretical parental melts with different primary H₂O contents (Table 1.S3). The black solid line is for the wet parent magma and the gray dashed line is for the dry parent magma (panels B-D). **A)** Plot of MgO vs. H₂O. Thin lines show predicted variations of H₂O during fractional crystallization for variable initial H₂O contents, used to constrain H₂O_{8.0} (Taylor and Martinez, 2003). NW Lau samples are divided into two categories, those with <0.3 wt.% H₂O_{8.0} (shaded symbols) and those with >0.3 wt.% H₂O_{8.0} (open symbols) **B)** Plot of MgO vs. Al₂O₃. Points of plag-in and cpx-in are identified on the solid black line. **C)** Plot of MgO vs. CaO. **D)** Plot of MgO vs. CaO/Al₂O₃.

Figure 1.4: Primitive mantle-normalized trace element diagrams for glasses from the NW Lau basin. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. **A)** Select Rochambeau Rifts glasses are shown by the blue lines, and a field for the rejuvenated-stage Samoan lavas [Jackson et al., 2010] is textured with carat symbols. The heavy black line shows the composition of a 6% fractional melt of the Ta'u Samoan mantle source of Jackson et al. [2007a] using bulk D's from Kelley et al. [2006]. This composition also is shown by the 6% tick mark along the dashed gray line in Figure 8b that tracks variable degree melts of the Ta'u source. **B)** Select NWLSC glasses are shown by the orange lines. The most Nb-enriched NWLSC glass (samples NLD-44-01, NLD-44-02) is highlighted as a heavy line. Lavas from the N160 segment of the North Fiji Basin are encompassed by the field textured with crosses. The heavy black line is the same 6% fractional melt of the Ta'u as in 4a. **C)** Select glasses from PR/LETZ (gray-purple lines) and glasses from CLSC (red lines).

Figure 1.5: Radiogenic isotopes and trace element plots for NW Lau Basin samples. **A)** $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $^3\text{He}/^4\text{He}$, showing samples from RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). The $^3\text{He}/^4\text{He}$ data for the samples from this study is from Lupton et al., 2009. The shaded samples are from this study, the open and black circles, open triangles, and shaded hexagons are from Tian et al. [2011] and Hahm et al. [2012], the crossed symbols are from Poreda and Craig [1992], and the filled crosses are from the North Fiji Basin and open hexagons are from Niuafo'ou [Pearce et al., 2007]. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. An average composition for Vailulu'u is indicated by the white star within the Samoan field. Shaded fields for Manus Basin [Shaw et al., 2004; Shaw et al., 2012; Sinton et al., 2003], Iceland [Condomines et al., 1983; Poreda et al., 1992], Loihi [Craig and Lupton, 1976; Rison and Craig, 1983; Kurz et al., 1983], depleted mantle [Poreda and Craig, 1992], and Primitive Helium Mantle [PHEM; Farley et al., 1992] are shown for reference. The thin line is the average MORB $^3\text{He}/^4\text{He}$ ratio of 8. **B)** Plot of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\text{La}/\text{Sm}_\text{N}$. The field for MORB [Tables 1.S5; compiled from PetDB; <http://www.petdb.org>], is shown by the solid gray shaded region for reference. **C)** Plot of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $^{143}\text{Nd}/^{144}\text{Nd}$. The solid black line shows mixing between a depleted CLSC-like end member and an enriched Samoan-like end member (e.g., Vailulu'u). **D)** Plot of $^{206}\text{Pb}/^{204}\text{Pb}$ vs. $^{208}\text{Pb}/^{204}\text{Pb}$. The solid black line shows mixing between a depleted CLSC-like end member and an enriched Samoan-like end member (e.g., Vailulu'u). The thick solid black line is the Northern Hemisphere Reference Line [Hart, 1984]. Black squares represent the fields for the enriched mantle end-member EMII [e.g., Workman et al., 2004], primitive helium mantle [PHEM; Farley et al., 1992], and global hotspot mantle component ["FOZO"; Hart et al., 1992].

Figure 1.6: Trace element characteristics of NW Lau basin glasses as function of spatial distribution and He isotopic composition. Symbol notation is the same as in Figure 1.5. The dashed mixing line is between an average CLSC source and Ta'u source [Jackson et al., 2007a]. **A)** Plot of La/Sm_N (chondrite normalized) vs. latitude ($^{\circ}\text{S}$). **B)** Plot of Ba/La vs. latitude ($^{\circ}\text{S}$). **C)** Plot of $^3\text{He}/^4\text{He}$ (R/R_a) vs. latitude ($^{\circ}\text{S}$). **D)** Plot of La/Sm_N vs. $^3\text{He}/^4\text{He}$ (R/R_a); $R = ^3\text{He}/^4\text{He}$ and $R_a = R_{\text{air}} = 1.39 \times 10^{-6}$.

Figure 1.7: A) Plot of H₂O/Ce vs. Ba/La, showing samples from RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). Symbol notation is the same as in previous figures. The open squares are ELSC samples from Bezos et al. [2009], and the asterisks are Tonga Arc glasses from Cooper et al. [2010]. The field for MORB, encompassing East Pacific Rise MORB glasses [Table 1.S8; compiled from PetDB; <http://www.petdb.org>], is shown by the solid gray shaded region for reference. The arrow illustrates the trend of subduction influence, shown by select CLSC and ELSC samples, of increasing Ba/La with increasing H₂O/Ce. **B)** Plot of Ce/Pb vs. Nb/Nb*. Nb* is the projected concentration of Nb based on Th and La abundances, where Nb/Nb* is calculated as $Nb_N / (Th_N \times La_N)^{1/2}$. The arrow illustrates the trend of subduction influence, shown by select CLSC, ELSC, and Tonga Arc samples, of decreasing Nb/Nb* with decreasing Ce/Pb.

Figure 1.8: A) Plot of Sm/La vs. Th/La, showing samples from RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). Symbol notation is the same as in previous figures. The black lines indicate mixing trends between an enriched, possibly Samoa-like source and two different depleted MORB-like end members. B) Plot of Nb/Zr vs. Rb/Zr. The gray dashed line is a fractional melting model tracking variable degree melts of the Ta'u source [Jackson et al., 2007a; bulk D's from Kelley et al., 2006; see Figure 1.4 caption for details]. C) Plot La/Sm vs. Cu/Zn for NW Lau basalts > 6.0 wt.% MgO. The small symbols for MORB are from Jenner and O'Neill, 2012.

Figure 1.9: **A)** Plot of latitude (°S) vs. pressure for NW Lau basalts, showing samples RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). **B)** Plot of latitude (°S) vs. C_{H_2O} for NW Lau basalts. **C)** Plot of temperature vs. pressure for NW Lau basalts, showing the same symbols as Figure 1.9a. The dry solidus is from Hirschmann [2000], the two wet solidi are for C_{H_2O} of 0.05 wt.% and 0.1 wt.% [Kelley et al., 2010]. The solid black line is the adiabat for a mantle potential temperature of ~1400°C. The two dashed lines are melt paths (slope = 2°C/kbar) for the two wet solidi, generated as the adiabat crosses each solidi [Asimow et al., 2004], generating low amounts of F due to melting and the continuing dehydration of the surrounding mantle which reduces water-influenced melt productivity. The three thin lines are melt paths (slope = 7°C/kbar) above the dry solidus, a more productive melt regime, and the thin dashed line is the projected path of the adiabat [Asimow and Langmuir, 2003]. The outlined region shows the inset of the pressure-temperature diagram. Error bars are error associated with using the thermobarometer [Lee et al., 2009].

Figure 1.10: Three regional cartoons illustrating possible hypotheses for the origin of enriched mantle beneath the RR and NWLSC. **A)** The first scenario invokes a contribution from an isotopically recognizable component of Samoan mantle and a separate, noble-gas-only component that causes enrichment in He isotopes without a proportional contribution from Samoan trace elements. **B)** The second scenario invokes inherent mantle heterogeneity in the NW Lau mantle, unrelated to (or linked to, as in the case of RB) Samoa. **C)** A third scenario, in which the N. Lau basin is infiltrated by a small quantity of Samoan mantle and is also impinged upon by a previously-unidentified regional hotspot located to the west of the spreading centers and rift zone.

Supplementary Information to “Tracing mantle sources and Samoan influence in the northwestern Lau back-arc basin”

S.1. Samples and Methods

S1.1 Sample Collection

Voyage SS07/2008 of the R/V Southern Surveyor used an EM300 multibeam system to obtain new high resolution 30 kHz multibeam bathymetric data for the northwestern Lau Basin. Previous studies have viewed the Northwest Lau Spreading Center (NWLSC) as a northeast trending spreading center that connects the Peggy Ridge (PR) with the Tonga Trench and Paleo-Vitiaz trench [Hawkins, 1995]. High resolution bathymetry shows that the NWLSC region is not a single spreading center, instead consisting of one organized spreading center (NWLSC) and an area of diffuse rifting north of the NWLSC, now called Rochambeau Rifts (RR), that extends to the Vitiaz lineament. RR has no organized spreading center but instead comprises a number of small rifts and shield volcanoes (Figure 1.1c). The NWLSC is a volcanically active, organized spreading center that trends NE-SW, connecting the PR with RR (Figure 1.1b and 1.2b).

The basaltic glass samples reported here are new samples from the Northern Lau Basin that were collected from 63 bottom dredges during voyage SS07/2008. Sample locations and rock descriptions including phenocryst information are given in Table 1.S1. Figure 1.1 shows the regional location and tectonic activity for the Northern Lau Basin, while Figure 1.1 shows a summary of the new high resolution 30 kHz multibeam bathymetric data acquired on the voyage and the subsequent sample locations from which this study's glass samples were chosen.

S1.2 Sample Preparation

A total of 62 glass samples from SS07/2008 dredges were selected for geochemical analysis. Fresh glass was chiseled from pillow rims and glass chips were hand-picked for geochemical analysis using a binocular microscope to ensure that only the freshest, crystal-poor glass was used for analysis. The glass data reported in this study are from the same dredges, though not the exact pillows, as those analyzed for $^3\text{He}/^4\text{He}$ by Lupton et al. [2009] and trace elements by Jenner et al. [2012]. The glass samples reported in these previous studies originated largely from aggregate glass collected by pipe dredge. In one instance, intra-dredge heterogeneity of glass was identified in the pipe dredge, but all other dredges were comparatively homogeneous (see supplementary section S4). Twelve additional samples from the CLSC were obtained from the Smithsonian Institution's seafloor glass collection and analyzed for volatiles and trace elements.

S1.3 Electron Microprobe Analysis (EMPA)

Glass chips were mounted in 1 inch round epoxy mounts for electron microprobe analysis (EMPA). Major element concentrations (Table 1.S2) were measured on the Brown University CAMECA SX-100 electron microprobe using a 15 kV accelerating voltage, 10 nA beam current and 10 μm defocused beam following the methods of Devine et al. [1995]. Calibration was checked against basaltic glass references VG-2 and A99B compositions every 10 glass chips and a series of 5 spots

were analyzed and averaged for each glass chip. Accuracy was typically $\leq 2\%$ RSD [Jarosewich, 2002; Melson et al., 2002].

S1.4 Secondary Ionization Mass Spectrometry (SIMS)

Separate glass chips from the same pillows were mounted in indium for analysis of dissolved volatiles (H_2O , CO_2 , S, Cl, F) by secondary ionization mass spectrometry (SIMS) at the Carnegie Institution of Washington. Volatile analysis (Table 1.S2) was done in triplicate using the CAMECA IMS 6f ion microprobe with a 5-10 nA Cs^+ primary beam following procedures outlined by Hauri [2002] and Hauri et al. [2002], using $^{16}\text{O}^1\text{H}$ as the mass for determination of H_2O . Combined reproducibility and accuracy are typically $\leq 5\%$ RSD for all the volatile elements.

S1.5 Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

Trace elements (Li, Be, K_2O , Sc, TiO_2 , V, Cr, Co, Ni, Cu, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U) were determined by both laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) (Table 1.S2) and solution ICP-MS (Table 1.S5) at the Graduate School of Oceanography, University of Rhode Island. The same chips that were analyzed for major elements by EMP were also analyzed for trace elements by LA-ICP-MS using a New Wave UP 213nm Nd:YAG deep penetration laser coupled with a Thermo XSeriesII quadrupole ICP-MS. Analyses were run using an 80 μm spot size, 10 Hz repeat rate, and 80-90% energy output. Nine natural glass standards from United States Geological Survey [BIR-1g, BHVO-2g, BCR-2g; Kelley et al., 2003;

<http://georem.mpch-mainz.gwdg.de/>] and Max Planck Institute [Jochum et al., 2006; GOR132-G, StHls-G, ATHO-G, T1-G, ML3B-G, KL2-G; Table 1.S4] were used to produce calibration curves that were linear to $r^2 > 0.99$ for all elements reported. Analysis of glass chips were done in triplicate with an average reproducibility of 4% RSD for all elements.

Additional chips of fresh glass were chosen for bulk dissolution and analysis by solution ICP-MS (Li, Be, K₂O, Sc, TiO₂, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U; Table 1.S5). Chips were sonicated and rinsed in Milli-Q purified H₂O before being dissolved whole by HNO₃:HF acid attack following methods of Kelley et al. [2003]. Raw ICP-MS data were corrected for instrumental drift using an external drift correcting solution analyzed between every 4 samples. Four standards [BIR, BHVO-1, JB-3, W-2; Kelley et al., 2003; <http://georem.mpch-mainz.gwdg.de/>] and one in-house standard [EN026 10D-3; Kelley et al., In Prep; Table 1.S4] were used to produce calibration curves that were linear to $R > 0.999$. Samples were analyzed in duplicate, with an overall reproducibility of $\leq 2\%$ RSD. Solution ICP-MS and LA-ICP-MS analyses were compared for all elements analyzed to determine the relative accuracy of the two methods and to test for the effect of dissolution of micro-phenocrysts on the bulk glass analysis (see supplementary section S2). Based on this comparison, we prefer the LA-ICP-MS data for glasses because the spatial resolution of the laser avoids micro-crystals within the glass that significantly affect certain trace element concentrations in bulk samples (e.g., Ni; see supplementary section S2).

S1.6 Multicollector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS)

Samples were chosen for isotopic analysis to encompass the range of trace element ratios observed in the glass chips. Fresh glass chips were sonicated in Milli-Q purified H₂O and leached in cold 2N HNO₃ for 30 minutes prior to crushing in a steel mortar. Digestion, column chemistry, and mass spectrometry used standard methods that, for UCSC, are described in Ryder et al. [2006] and Tollstrup et al. [2010]. Results have been normalized to NBS 987 = 0.710250 for ⁸⁷Sr/⁸⁶Sr [Todd et al., 2011], JNdi-1 = 0.512115 (La Jolla = 0.511858) for ¹⁴³Nd/¹⁴⁴Nd [Tanaka et al., 2000], JMC 465 = 0.282160 for ¹⁷⁶Hf/¹⁷⁷Hf [Chauvel and Blichert-Toft, 2001], and NBS 981 = 16.941 for ²⁰⁶Pb/²⁰⁴Pb, 15.496 for ²⁰⁷Pb/²⁰⁴Pb, and 38.722 for ²⁰⁸Pb/²⁰⁴Pb [Abouchami et al., 2000]. External reproducibility (2σ) is ± 0.000010 (Sr) and 0.000010 (Nd and Hf) [Todd et al., 2011]. Accuracy can be assessed by normalized results for BHVO2 during 2009: 0.703474 (Sr); 0.512988 (Nd); 0.283092 (Hf); 18.639 (²⁰⁶Pb/²⁰⁴Pb), 15.535 (²⁰⁷Pb/²⁰⁴Pb), and 38.722 (²⁰⁸Pb/²⁰⁴Pb).

S.2 Comparison of LA-ICP-MS and solution ICP-MS data

Glasses from the Northwestern Lau basin were analyzed by both solution and laser ICP-MS techniques to assess the accuracy of the laser calibrations and trace element data relative to the more conventional solution-based analysis. Figure 1.S1 shows comparisons of trace element concentrations determined by LA-ICP-MS and solution ICP-MS, which shows excellent agreement (±≤5%) between the two methods for a variety of trace elements (e.g., Rb, Nb, Ba, La, U; Figure S1a-e). Three samples from the NW Lau basin are andesites (NLD-40-02, NLD-41-02, NLD-41-03). When

the andesites were removed from the comparison, agreement between the two methods improved slightly for many elements. We hypothesize that the improvement is a result of using a basalt-based calibration for solution-ICP-MS, which may not have properly bracketed the higher concentrations of many trace elements in the andesite unknowns.

Figure 1.S1f illustrates on particularly important pitfall of analyzing bulk glass by solution ICP-MS. Micro-phenocrysts within the glass chips cannot be avoided in a bulk dissolution, resulting in the incorporation of excess olivine in the bulk sample. The net result is that solution-based concentrations for certain elements that are enriched in olivine (e.g., Ni, Cr, Co) come out much too high, and for these elements the LA-ICP-MS data are particularly preferable. This comparison demonstrates that an important advantage of LA-ICP-MS over solution ICP-MS is the ability to avoid bulk crystals during analysis. However, in other instances (e.g., Li, Cs and Zr), the data appear to be systematically biased between LA-ICP-MS and solution ICP-MS analyses. The bias in Li and Cs could be an effect of very tiny amounts of alteration on bulk glass chips, since concentrations are low in glass and Li and Cs are highly sensitive to hydrothermal alteration in basalt [e.g., Kelley et al., 2003]. The bias in Zr cannot be explained this way because Zr is largely unaffected by hydrothermal alteration processes and no included phase could significantly bias Zr concentrations in bulk vs. glass composition. Instead, we believe the offset for Zr is an analytical bias in the LA-ICP-MS calibration, relative to the solution calibration. We thus increase the LA-ICP-MS concentrations for Zr by 7% to ensure close agreement between the two methods.

S.3 Comparison of LA-ICP-MS and electron microprobe data

Minor elements (K_2O , TiO_2 , MnO , P_2O_5) are not always routinely analyzed by LA-ICP-MS, but are most commonly measured by electron microprobe (EMP). Figure S2 shows comparison of minor element concentrations measured by LA-ICP-MS at URI/GSO with those determined by EMP. It is important to note that, for this comparison, we assume that there is no inter-laboratory bias in CaO , the element to which the LA-ICP-MS raw data were normalized for data reduction. The LA-ICP-MS concentrations for K_2O are within 1% of EMP concentrations (Figure 1.S2a), suggesting that LA-ICP-MS may be a viable method to more precisely resolve low-level K_2O in glasses, relative to EMP. Comparison of TiO_2 , P_2O_5 , and MnO concentrations show systematic biases (Figure 1.S2b-d) that likely reflect inter-laboratory

S.4 Analysis of heterogeneity within dredge NLD-44

Heterogeneity in dredge NLD-44 was identified while conducting LA-ICP-MS analyses of multiple chips from the pipe dredge, from which He isotope samples were taken [see Lupton et al., 2009]. Glass chips were chosen from four pillows and 20 chips were selected from the pipe dredge. As shown in Figure 1.S3, the samples fall into two clearly distinct geochemical groups: LREE enriched and slightly LREE depleted. All glass chips from the pillow basalts, which provided the source material for radiogenic isotope analysis of this sample, and represent the geochemical type that is reported for the major and trace element composition of the glass in this paper, were found to be LREE enriched, while the glass chips from the pipe dredge, which

provided the source material for He isotope analysis from this sample [Lupton et al., 2009], fell into both geochemical groups.

S.5 Correction process for fractional crystallization of clinopyroxene and plagioclase

The LLDs on Figure 1.3 model the effects of clinopyroxene and plagioclase fractionation on the major element composition of northwestern Lau basin lavas. Accurate constraints on the effect of increasing H₂O content on clinopyroxene and plagioclase saturation are needed to correct the samples for the effects of fractional crystallization, and ultimately back to primary melts at equilibrium with mantle olivine (Fo₉₀). As clinopyroxene and plagioclase crystallize from the magma, the major element fractionation slopes change such that simple olivine addition in most cases would incorrectly reconstruct the major element compositions of primary melts. The effects of olivine, plagioclase and clinopyroxene fractional crystallization on melt composition were modeled by LLDs run in Petrolog3 [Danyushevsky and Pelchov, 2011]. Five LLDs were modeled for similar parental major element compositions with H₂O contents varying between 0.21 – 1.25 wt.%. The onset of both plagioclase fractionation (plag-in) and clinopyroxene fractionation (cpx-in) were determined by the change in slopes of the LLDs (e.g., kinks in the LLD's on Figure 1.3). The point of plag-in was determined by the change from a trend of increasing Al₂O₃ with decreasing MgO to decreasing Al₂O₃ with decreasing MgO (Figure 1.3b) and a trend of constant CaO/Al₂O₃ with decreasing MgO to a trend of increasing CaO/Al₂O₃ with decreasing MgO (Figure 1.3d), as plagioclase contains both CaO and Al₂O₃, but has a

relatively low $\text{CaO}/\text{Al}_2\text{O}_3$ ratio. The point of cpx-in was determined by the change from a trend of increasing $\text{CaO}/\text{Al}_2\text{O}_3$ with decreasing MgO to a trend of decreasing $\text{CaO}/\text{Al}_2\text{O}_3$ with decreasing MgO (Figure 1.3d), as clinopyroxene will fractionate CaO from the melt. The MgO value at which the mineral saturates is referred to as $\text{MgO}_{\text{mineral-in}}$, and these models provide constraints on the point of each of mineral-in as a linear function of initial melt H_2O content, expressed as $\text{H}_2\text{O}_{(8.0)}$ (Figure 1.S4). Given the $\text{H}_2\text{O}_{(8.0)}$ of each glass, the individual $\text{MgO}_{\text{plag-in}}$ and $\text{MgO}_{\text{cpx-in}}$ can be determined for each individual sample. Correction of basalt compositions to primary melts is achieved by tracing each sample along empirically determined fractionation slopes (Table 1.S6) to the point of $\text{MgO}_{\text{mineral-in}}$ for both clinopyroxene and plagioclase. Once each sample is corrected to the point of plag-in, equilibrium olivine is added in 0.001% increments until each melt is in equilibrium with Fo_{90} olivine.

S.6 Melting Inversion Process and Ti/Y Source Composition Model

The water content of the NW Lau mantle sources was calculated using the melting inversion process from Kelley et al. [2006], which uses the batch melting equation and the Ti/Y source composition model. Provided here is a brief summary of the methodology behind using $\text{TiO}_{2(\text{Fo}90)}$ concentration as a proxy for melt fraction (F), while further details can be found in Kelley et al., 2006. TiO_2 is used as a single-element proxy for F because of the conservative nature of TiO_2 during melting. Kelley et al. [2006] found that TiO_2 decreases in the melt with increasing F and evidence from Mariana Trough lavas confirmed that low TiO_2 concentrations correlated with high H_2O contents. The batch melting equation was solved to yield F:

$$F = \frac{(C_{\text{Ti}}^0/C_{\text{Ti}}^l - D_{\text{Ti}})}{(1 - D_{\text{Ti}})} \quad (\text{S1})$$

where C_{Ti}^0 is the concentration of TiO_2 in the mantle source, C_{Ti}^l is the concentration of TiO_2 in the melt in equilibrium with Fo_{90} , and D_{Ti} is the bulk distribution coefficient for Ti during mantle melting [Kelley et al., 2006]. To obtain the concentration of H_2O in the mantle source, we re-solved the batch melting equation to yield:

$$C_{\text{H}_2\text{O}}^0 = C_{\text{H}_2\text{O}}^l [F(1 - D_{\text{H}_2\text{O}}) + D_{\text{H}_2\text{O}}] \quad (\text{S2})$$

where $C_{\text{H}_2\text{O}}^0$ is the concentration of H_2O in the mantle source, $C_{\text{H}_2\text{O}}^l$ is the concentration of H_2O in the melt in equilibrium with Fo_{90} , F is the output of equation S1, and $D_{\text{H}_2\text{O}}$ is the bulk distribution coefficient for H_2O during mantle melting [Stolper and Newman, 1994; Kelley et al., 2006].

C_{Ti}^0 must be well constrained to obtain a reasonable estimate of melt fraction for the Lau Basin basalts. The C_{Ti}^0 is constrained in Kelley et al. [2006] through melt removal-based source model, which is limited to mantle regions that are similar or more depleted than DMM composition. In a region such as the NW Lau Basin, a more enriched mantle source than DMM, another approach must be taken to constrain C_{Ti}^0 . Kelley et al. [2006] used a Ti/Y model to constrain the C_{Ti}^0 of an enriched mantle source, which is based on TiO_2/Y systematics during melting. TiO_2 and Y have similar mantle/melt D s, which results in little variation in the TiO_2/Y ratio during melting at mid-ocean ridges. The following equation is used to yield a maximum value for C_{Ti}^0 :

$$C_{\text{Ti}}^0 = \left[\frac{(\text{TiO}_2/\text{Y})_{\text{sample}}}{(\text{TiO}_2/\text{Y})_{\text{MORB}}} \right] \times C_{\text{Ti}}^{\text{DMM}} \quad (\text{S3})$$

where $(\text{TiO}_2/\text{Y})_{\text{sample}}$ is the TiO_2/Y ratio of the glass, $(\text{TiO}_2/\text{Y})_{\text{MORB}}$ is 0.04, and $C_{\text{Ti}}^{\text{DMM}}$ is 0.133 [Kelley et al., 2006].

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Table 1.S1: Sample Summary for Northern Lau Basin

Sample	Latitude	Longitude	Depth	Range	Depth Mid	Region	Sample Information
	S	W	m	m	m		
NLD-06-01-01	-14.70	-176.06	2527	2453	2490	RR	Aphyric, glassy basalt flow tops
NLD-07-01-01	-14.75	-176.01	2461	2451	2456	RR	Aphyric, glassy pillow basalts
NLD-08-01-01	-14.69	-175.97	2522	2691	2606.5	RR	Plagioclase-phyric glassy rims; Aphyric pillow basalt interiors
NLD-09-02-01	-14.68	-175.95	2730	2747	2738.5	RR	Plagioclase-phyric glassy basalt rims
NLD-10-01-01	-14.73	-176.00	2676	2564	2620	RR	Olivine, plagioclase glassy basalt rims
NLD-11-01-01	-14.70	-175.98	2660	2730	2695	RR	Plagioclase, olivine glassy pillow basalts
NLD-13-01-01	-14.83	-175.97	2081	2096	2088.5	RR	Plagioclase, olivine glassy pillow basalts
NLD-14-01-01	-14.84	-176.00	2096	2215	2155.5	RR	Plagioclase, olivine glassy pillow basalts
NLD-15-01-01	-14.85	-176.05	2028	2010	2019	RR	Olivine glassy pillow basalts
NLD-16-01-01	-14.78	-176.04	2313	2325	2319	RR	Aphyric, glassy pillow basalts
NLD-17-01-01	-14.79	-176.05	2385	2381	2383	RR	Plagioclase, olivine glassy pillow basalts
NLD-18-01-01	-14.82	-176.07	2295	2310	2302.5	RR	Aphyric, glassy, weathered pillow basalts
NLD-18-02-01	-14.82	-176.07	2295	2310	2302.5	RR	Plagioclase-phyric glassy basalt rims
NLD-19-01-01	-14.82	-176.08	2153	2162	2157.5	RR	Aphyric, glassy, weathered pillow basalts
NLD-20-01-01	-14.94	-176.19	2096	2112	2104	RR	Olivine, plagioclase glassy basalt rims
NLD-21-01-01	-14.96	-176.27	1837	1966	1901.5	RR	Hydrothermally altered pillow basalts

Samples from the Northwest Lau Basin, collected on the R/V Southern Surveyor 07/2008 NoLauVE cruise.

Regions include Rochambeau Rifts (RR), Northwest Lau Spreading Center (NWLSC), Peggy Ridge (PR), Lau Extensional Transform Zone (LETZ), Central Lau Spreading Center (CLSC).

Table 1.S1: *cont.* Sample Summary for Northern Lau Basin

Sample	Latitude	Longitude	Depth	Range	Depth Mid	Region	Sample Information
	S	W	m	m	m		
NLD-22-01-01	-15.04	-176.17	2030	2187	2108.5	RR	Altered, plagioclase and olivine phyric pillow basalts
NLD-22-02-01	-15.04	-176.17	2030	2187	2108.5	RR	Aphyric, glassy pillow basalts
NLD-23-01-01	-15.15	-176.59	582	562	572	RR	Aphyric, glassy pillow basalts
NLD-24-01-01	-15.11	-176.41	1834	1838	1836	RR	Plagioclase-phyric glassy basalt flow tops
NLD-24-02-01	-15.11	-176.41	1834	1838	1836	RR	Olivine glassy pillow basalts
NLD-24-03-01	-15.11	-176.41	1834	1838	1836	RR	Glass fragments from volcanic sediment
NLD-25-01-01	-15.09	-176.29	2038	2076	2057	RR	Glass fragments from volcanic sediment
NLD-27-01-01	-15.07	-176.15	2021	2026	2023.5	RR	Plagioclase-phyric glassy pillow basalts
NLD-28-01-01	-15.12	-176.14	2350	2184	2267	RR	Altered pillow basalts
NLD-30-01-01	-15.06	-176.23	1708	1878	1793	RR	Aphyric, glassy basalt rims
NLD-31-01-01	-15.12	-176.27	1279	1290	1284.5	RR	Aphyric, glassy pillow basalts
NLD-32-01-01	-15.33	-176.28	1509	1499	1504	RR	Aphyric, glassy pillow basalts
NLD-35-01-01	-15.46	-175.70	1147	1152	1149.5	Dugong Volcano	Plagioclase, olivine glassy basalt rims
NLD-37-01-01	-15.47	-176.47	1811	1821	1816	RR	Plagioclase-phyric glassy basalt flow tops
NLD-38-01-01	-15.73	-177.20	1995	1997	1996	NWLSC	Aphyric, glassy pillow basalts
NLD-40-01-01	-15.59	-177.10	2200	2128	2164	NWLSC	Plagioclase, olivine glassy pillow basalts
NLD-40-02-01	-15.59	-177.10	2200	2128	2164	NWLSC	Aphyric, glassy pillow basalts
NLD-41-01-01	-15.68	-177.16	1971	2011	1991	NWLSC	Aphyric, glassy pillow basalts
NLD-41-02-01	-15.68	-177.16	1971	2011	1991	NWLSC	Aphyric, glassy pillow basalts

Table 1.S1: *cont.* Sample Summary for Northern Lau Basin

Sample	Latitude	Longitude	Depth	Range	Depth Mid	Region	Sample Information
	S	W	m	m	m		
NLD-41-03-01	-15.68	-177.16	1971	2011	1991	NWLSC	Aphyric, glassy quenched basalt rims
NLD-42-01-01	-15.80	-177.27	2108	2105	2106.5	NWLSC	Aphyric, glassy pillow basalts
NLD-43-01-01	-15.80	-177.28	1986	2056	2021	NWLSC	Aphyric, glassy pillow basalts
NLD-43-02-01	-15.80	-177.28	1986	2056	2021	NWLSC	Altered pillow basalts
NLD-44-01-01	-15.96	-177.48	2033	2048	2040.5	NWLSC	Aphyric, glassy basalt fragments
NLD-44-02-01	-15.96	-177.48	2033	2048	2040.5	NWLSC	Hydrothermally altered pillow basalts
NLD-45-01-01	-15.91	-177.42	2165	2168	2166.5	NWLSC	Aphyric, glassy pillow basalts
NLD-46-01-01	-15.88	-177.40	1995	2026	2010.5	NWLSC	Aphyric, glassy pillow basalts
NLD-47-01-01	-15.89	-177.37	2140	2107	2123.5	NWLSC	Aphyric, glassy pillow basalts
NLD-48-01-01	-15.79	-177.26	2139	2121	2130	NWLSC	Plagioclase, glassy basalt flow tops
NLD-49-01-01	-15.84	-177.32	2027	2029	2028	NWLSC	Aphyric, glassy pillow basalts
NLD-50-01-01	-15.98	-177.52	2059	2068	2063.5	NWLSC	Aphyric, glassy pillow basalts
NLD-51-01-01	-16.04	-177.58	2129	2181	2155	NWLSC	Olivine, glassy pillow basalts
NLD-55-01-01	-17.42	-176.37	2090	2130	2110	LETZ	Plagioclase, olivine glassy pillow basalts
NLD-56-01-01	-16.86	-176.95	1800	1860	1830	PR	Weathered, aphyric glassy pillow basalts
NLD-57-01-01	-17.23	-176.72	2241	2194	2217.5	LETZ	Plagioclase, glassy pillow basalts
NLD-58-01-01	-18.49	-176.39	2377	2245	2311	CLSC	Weathered, aphyric glassy pillow basalts
NLD-59-01-01	-18.40	-176.34	2284	2289	2286.5	CLSC	Aphyric, glassy pillow basalts
NLD-60-01-01	-18.29	-176.33	2142	2207	2174.5	CLSC	Aphyric, glassy pillow basalts
NLD-61-01-01	-18.21	-176.38	2188	2150	2169	CLSC	Aphyric, glassy pillow basalts

Table 1.S1: *cont.* Sample Summary for Northern Lau Basin

Sample	Latitude	Longitude	Depth	Range	Depth Mid	Region	Sample Information
	S	W	m	m	m		
NLD-62-01-01	-18.35	-176.50	2523	2491	2507	CLSC	Porphyritic pillow basalts
NLD-63-01-01	-18.26	-176.45	2716	2460	2588	CLSC	Olivine-phyric glassy basalt flow tops
NLD-64-01-01	-18.12	-176.35	2022	2146	2084	CLSC	Olivine microphyric glassy basalt flow tops
NLD-65-01-01	-18.03	-176.32	2176	2282	2229	CLSC	Plagioclase, glassy basalt flow tops
NLD-66-01-01	-17.94	-176.36	2343	2463	2403	CLSC	Plagioclase-phyric glassy pillow basalts

Table 1.S2: Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-06-01-01	NLD-07-01-01	NLD-08-01-01	NLD-09-02-01	NLD-10-01-01	NLD-11-01-01
SiO ₂ ¹	wt.%	49.97	48.16	49.94	49.79	48.28	49.94
TiO ₂	wt.%	1.82	1.40	1.56	1.52	1.51	1.56
Al ₂ O ₃	wt.%	15.10	16.24	15.67	15.68	16.47	15.76
FeO*	wt.%	10.58	10.16	9.57	9.61	10.00	9.54
MnO	wt.%	0.23	0.16	0.19	0.17	0.18	0.18
MgO	wt.%	6.62	8.44	7.20	7.22	7.98	7.21
CaO	wt.%	11.12	11.85	11.96	12.21	12.07	12.09
Na ₂ O	wt.%	2.72	2.49	2.65	2.56	2.54	2.59
K ₂ O	wt.%	0.39	0.38	0.38	0.38	0.47	0.41
P ₂ O ₅	wt.%	0.23	0.12	0.19	0.18	0.18	0.18
Total	wt.%	98.76	99.40	99.30	99.33	99.67	99.47
H ₂ O ²	wt.%	0.72	0.41	0.81	0.71	0.49	0.75
CO ₂	ppm	148	150	110	123	158	113
F	ppm	319	206	285	263	258	281
S	ppm	1164	1196	1075	1060	1202	1063
Cl	ppm	272	132	323	299	175	324
Li ³	ppm	6.56	4.71	5.30	5.29	4.66	5.42
Be	ppm	0.957	0.665	0.715	0.530	0.493	0.647
K ₂ O	wt.%	0.416	0.385	0.381	0.363	0.462	0.403
Sc	ppm	37.9	29.6	43.4	39.8	29.5	38.3
TiO ₂	wt.%	1.78	1.31	1.48	1.45	1.47	1.50
V	ppm	330	232	266	269	237	277
Cr	ppm	215	285	241	261	255	249
Co	ppm	39.6	47.4	36.1	36.9	44.2	38.2
Ni	ppm	66.3	141	67.5	64.9	117	68.1
Cu	ppm	79.8	93.8	93.5	97.1	89.1	97.4
Zn	ppm	97.1	88.2	75.2	74.9	85.8	81.8
Rb	ppm	12.3	10.2	10.5	10.0	13.3	11.3
Sr	ppm	167	206	185	184	240	190
Y	ppm	32.0	16.1	32.3	26.9	17.3	27.1
Zr	ppm	135	71.0	131	109	85.4	112

Nb	ppm	11.1	9.04	9.84	9.24	12.1	10.4
Cs	ppm	0.154	0.0978	0.114	0.115	0.144	0.126
Ba	ppm	96.3	71.1	93.2	88.0	94.4	99.3
La	ppm	11.0	6.06	9.92	8.61	7.89	9.47
Ce	ppm	25.4	14.3	19.7	18.8	18.3	21.1
Pr	ppm	3.41	1.95	2.87	2.64	2.48	2.88
Nd	ppm	15.4	8.99	13.7	12.3	11.0	13.1
Sm	ppm	4.25	2.51	3.94	3.57	2.92	3.63
Eu	ppm	1.42	0.900	1.29	1.21	1.04	1.30
Gd	ppm	5.11	2.99	5.21	4.38	3.31	4.34
Tb	ppm	0.902	0.493	0.858	0.733	0.523	0.775
Dy	ppm	5.79	3.04	5.45	4.65	3.26	4.78
Ho	ppm	1.16	0.589	1.16	0.982	0.609	1.00
Er	ppm	3.42	1.59	3.43	2.73	1.77	2.77
Tm	ppm	0.485	0.224	0.483	0.411	0.244	0.405
Yb	ppm	3.30	1.51	3.05	2.62	1.52	2.71
Lu	ppm	0.492	0.220	0.480	0.406	0.231	0.422
Hf	ppm	2.91	1.68	2.93	2.53	1.95	2.56
Ta	ppm	0.617	0.551	0.618	0.566	0.713	0.620
Pb	ppm	1.31	0.732	1.02	0.96	0.81	1.14
Th	ppm	1.48	0.685	1.37	1.14	0.834	1.26
U	ppm	0.377	0.170	0.274	0.274	0.220	0.309
⁴ ⁸⁷ Sr/ ⁸⁶ Sr			0.704529				
¹⁴³ Nd/ ¹⁴⁴ Nd			0.512866				
¹⁷⁶ Hf/ ¹⁷⁷ Hf			0.283003				
²⁰⁶ Pb/ ²⁰⁴ Pb			18.611				
²⁰⁷ Pb/ ²⁰⁴ Pb			15.513				
²⁰⁸ Pb/ ²⁰⁴ Pb			38.549				
H ₂ O _(8.0)	wt. %	0.540	0.461	0.701	0.614	0.507	0.651

¹Major elements were determined by electron microprobe (EMP) at Brown University (NLD samples) and at the Smithsonian Institution (VG samples; Melson et al., 2002).

*Total Fe reported as FeO. ²Volatiles were determined by SIMS at Carnegie

Institution of Washington. ³Trace elements were determined by laser ablation ICP-MS

at Graduate School of Oceanography, University of Rhode Island. ⁴Isotope

concentrations determined at University of California - Santa Cruz.

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-13-01-01	NLD-14-01-01	NLD-15-01-01	NLD-16-01-01	NLD-17-01-01	NLD-18-01-01
SiO ₂ ¹	wt.%	48.40	49.29	49.01	48.83	49.82	50.92
TiO ₂	wt.%	1.42	1.60	1.61	1.61	1.44	2.06
Al ₂ O ₃	wt.%	16.92	15.99	16.34	16.25	15.61	15.10
FeO*	wt.%	9.65	10.04	9.76	9.77	9.51	10.92
MnO	wt.%	0.16	0.19	0.17	0.18	0.20	0.21
MgO	wt.%	8.60	7.65	8.45	8.54	7.71	5.55
CaO	wt.%	12.38	11.67	11.85	11.86	12.81	10.38
Na ₂ O	wt.%	2.48	2.62	2.46	2.48	2.40	3.08
K ₂ O	wt.%	0.09	0.24	0.31	0.29	0.26	0.55
P ₂ O ₅	wt.%	0.14	0.14	0.18	0.16	0.15	0.27
Total	wt.%	100.23	99.43	100.14	99.97	99.90	99.04
H ₂ O ²	wt.%	0.25	0.48	0.38	0.37	0.63	1.23
CO ₂	ppm	112	155	109	109	87	43
F	ppm	139	217	218	211	217	403
S	ppm	1005	1065	1022	1000	1054	1245
Cl	ppm	71	228	146	142	283	785
Li ³	ppm	4.05	5.36	4.38	4.56	5.76	7.57
Be	ppm	0.478	0.492	0.639	0.559	0.544	0.747
K ₂ O	wt.%	0.092	0.234	0.290	0.314	0.296	0.566
Sc	ppm	42.9	41.8	39.7	33.2	37.9	34.1
TiO ₂	wt.%	1.31	1.50	1.55	1.56	1.40	2.00
V	ppm	249	266	258	277	334	341
Cr	ppm	241	248	292	314	328	116
Co	ppm	43.1	38.5	40.8	44.3	47.0	34.2
Ni	ppm	119	99.3	151	166	104.6	45.7
Cu	ppm	135	86.8	100	109	149	72.1
Zn	ppm	68.2	78.3	73.9	84.1	90.2	101
Rb	ppm	1.97	6.66	5.49	5.84	7.30	16.4
Sr	ppm	171	162	197	196	180	210
Y	ppm	28.0	33.1	27.2	21.2	21.9	33.5
Zr	ppm	95.7	123	112	89.5	85.0	143

Nb	ppm	2.34	6.22	6.10	6.22	5.24	11.0
Cs	ppm	0.00909	0.0754	0.0518	0.0481	0.0729	0.160
Ba	ppm	18.2	53.2	48.9	51.7	53.3	126
La	ppm	3.29	7.12	6.49	5.81	5.68	10.8
Ce	ppm	8.94	15.6	14.6	15.4	16.2	25.4
Pr	ppm	1.55	2.39	2.38	2.30	2.26	3.65
Nd	ppm	8.85	12.1	12.2	10.9	10.8	16.8
Sm	ppm	3.00	3.82	3.56	3.09	3.05	4.47
Eu	ppm	1.11	1.27	1.21	1.17	1.16	1.52
Gd	ppm	4.18	5.23	4.74	3.77	3.71	5.47
Tb	ppm	0.744	0.894	0.769	0.623	0.630	0.936
Dy	ppm	4.86	5.56	5.15	3.97	4.04	6.07
Ho	ppm	0.985	1.19	1.10	0.839	0.878	1.34
Er	ppm	2.87	3.39	3.01	2.35	2.43	3.72
Tm	ppm	0.416	0.529	0.447	0.348	0.342	0.555
Yb	ppm	2.64	3.22	2.69	2.21	2.41	3.57
Lu	ppm	0.426	0.517	0.429	0.349	0.375	0.557
Hf	ppm	2.24	2.79	2.96	2.29	2.13	3.49
Ta	ppm	0.163	0.408	0.486	0.393	0.307	0.704
Pb	ppm	0.419	0.83	0.684	0.771	0.876	1.49
Th	ppm	0.243	0.921	0.511	0.429	0.532	0.978
U	ppm	0.0542	0.204	0.152	0.171	0.211	0.336
⁴ ⁸⁷ Sr/ ⁸⁶ Sr		0.703283					
¹⁴³ Nd/ ¹⁴⁴ Nd		0.513062					
¹⁷⁶ Hf/ ¹⁷⁷ Hf		0.283168					
²⁰⁶ Pb/ ²⁰⁴ Pb		18.411					
²⁰⁷ Pb/ ²⁰⁴ Pb		15.512					
²⁰⁸ Pb/ ²⁰⁴ Pb		38.225					
H ₂ O _(8.0)	wt. %	0.293	0.461	0.433	0.428	0.616	0.682

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope

concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-18-02-01	NLD-19-01-01	NLD-20-01-01	NLD-21-01-01	NLD-22-01-01	NLD-22-02-01
SiO ₂ ¹	wt.%	48.61	50.05	49.00	49.63	47.62	49.12
TiO ₂	wt.%	1.75	2.00	1.51	2.13	1.40	1.14
Al ₂ O ₃	wt.%	16.29	15.21	15.86	14.18	17.36	16.61
FeO*	wt.%	10.40	10.82	10.59	12.73	8.99	8.55
MnO	wt.%	0.19	0.20	0.18	0.23	0.17	0.16
MgO	wt.%	7.36	6.85	9.10	5.99	8.41	9.11
CaO	wt.%	12.01	11.08	11.27	10.95	12.91	13.09
Na ₂ O	wt.%	2.85	2.91	2.40	3.17	2.22	2.09
K ₂ O	wt.%	0.27	0.31	0.15	0.27	0.49	0.09
P ₂ O ₅	wt.%	0.16	0.20	0.09	0.18	0.14	0.09
Total	wt.%	99.90	99.63	100.15	99.47	99.72	100.03
H ₂ O ²	wt.%	0.35	0.62	0.40	0.55	0.65	0.21
CO ₂	ppm	125	176	105	82	151	126
F	ppm	217	307	175	281	258	154
S	ppm	1237	1280	1162	1622	953	828
Cl	ppm	506	343	165	382	224	18
Li ³	ppm	4.35	5.63	4.98	5.63	4.52	4.16
Be	ppm	0.654	0.594	0.481	0.565	0.699	0.267
K ₂ O	wt.%	0.292	0.322	0.156	0.278	0.515	0.0955
Sc	ppm	43.2	40.4	28.0	42.6	35.6	38.6
TiO ₂	wt.%	1.70	1.92	1.45	2.06	1.35	1.08
V	ppm	295	346	222	400	225	228
Cr	ppm	227	188	354	29.3	216	337
Co	ppm	43.8	38.2	48.7	43.8	40.4	39.7
Ni	ppm	78.0	80.2	176	36.4	111	113
Cu	ppm	131	77.5	93.3	96.9	113	110
Zn	ppm	83.9	87.1	89.9	105	68.3	59.8
Rb	ppm	6.91	7.75	3.27	6.17	15.2	2.00

Sr	ppm	211	167	175	174	194	110
Y	ppm	29.4	34.3	17.3	33.7	20.9	22.9
Zr	ppm	119	130	78.8	122	94.1	71.7
Nb	ppm	5.18	7.81	4.66	4.28	8.68	1.42
Cs	ppm	0.0609	0.0870	0.0309	0.0538	0.130	0.0172
Ba	ppm	49.7	68.9	27.6	48.8	97.9	15.5
La	ppm	5.35	8.87	5.28	5.40	6.65	2.56
Ce	ppm	14.1	20.6	13.3	15.8	15.2	7.42
Pr	ppm	2.38	3.10	2.00	2.62	2.33	1.37
Nd	ppm	12.4	15.0	9.86	13.5	11.2	7.47
Sm	ppm	3.85	4.39	2.81	4.16	2.99	2.49
Eu	ppm	1.36	1.46	0.99	1.51	1.05	0.899
Gd	ppm	4.78	5.46	3.28	5.39	3.56	3.33
Tb	ppm	0.854	0.951	0.530	0.914	0.650	0.599
Dy	ppm	5.47	6.15	3.30	6.16	3.88	3.99
Ho	ppm	1.18	1.30	0.717	1.32	0.828	0.915
Er	ppm	3.20	3.76	1.84	3.76	2.21	2.48
Tm	ppm	0.502	0.550	0.261	0.572	0.346	0.379
Yb	ppm	3.06	3.57	1.65	3.65	2.35	2.38
Lu	ppm	0.479	0.537	0.237	0.560	0.349	0.373
Hf	ppm	2.93	3.11	2.00	3.05	2.35	1.83
Ta	ppm	0.366	0.497	0.316	0.293	0.633	0.109
Pb	ppm	0.727	0.97	0.599	0.841	0.813	0.457
Th	ppm	0.331	0.758	0.357	0.267	0.548	0.125
U	ppm	0.112	0.233	0.127	0.101	0.183	0.0419
⁴ ⁸⁷ Sr/ ⁸⁶ Sr				0.704583			
¹⁴³ Nd/ ¹⁴⁴ Nd				0.512767			
¹⁷⁶ Hf/ ¹⁷⁷ Hf				0.282932			
²⁰⁶ Pb/ ²⁰⁴ Pb				19.098			
²⁰⁷ Pb/ ²⁰⁴ Pb				15.615			
²⁰⁸ Pb/ ²⁰⁴ Pb				39.252			
H ₂ O _(8.0)	wt. %	0.316	0.493	0.521	0.351	0.732	0.268

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-23-01-01	NLD-24-01-01	NLD-24-02-01	NLD-24-03-01	NLD-25-01-01	NLD-27-01-01
SiO ₂ ¹	wt.%	49.46	48.69	48.46	48.75	48.56	48.75
TiO ₂	wt.%	1.82	1.75	1.41	1.76	1.46	0.75
Al ₂ O ₃	wt.%	15.17	15.94	16.51	15.50	16.76	18.38
FeO*	wt.%	11.07	11.03	10.37	11.05	9.10	8.06
MnO	wt.%	0.22	0.19	0.20	0.21	0.17	0.16
MgO	wt.%	7.05	7.41	8.33	7.32	8.21	9.80
CaO	wt.%	12.05	11.86	12.27	12.03	12.59	12.73
Na ₂ O	wt.%	2.97	2.70	2.61	3.02	2.42	1.95
K ₂ O	wt.%	0.21	0.20	0.16	0.18	0.26	0.06
P ₂ O ₅	wt.%	0.15	0.14	0.13	0.13	0.14	0.07
Total	wt.%	100.16	99.91	100.44	99.95	99.67	100.71
H ₂ O ²	wt.%	0.45	0.37	0.35	0.43	0.59	0.26
CO ₂	ppm	20	110	98	79	117	135
F	ppm	212	202	158	213	247	91
S	ppm	1155	1348	1132	1360	1064	728
Cl	ppm	473	502	348	467	160	44
Li ³	ppm	4.86	5.47	4.66	5.05	3.94	3.78
Be	ppm	0.450	0.368	0.224	0.528	0.539	0.218
K ₂ O	wt.%	0.202	0.191	0.161	0.188	0.259	0.0652
Sc	ppm	52.4	39.7	39.4	45.5	42.9	27.9
TiO ₂	wt.%	1.77	1.69	1.39	1.71	1.38	0.694
V	ppm	300	307	301	308	233	174
Cr	ppm	230	245	260	228	243	278
Co	ppm	41.2	48.1	50.1	43.4	41.1	45.7
Ni	ppm	54.6	73.3	96.6	60.9	103	199
Cu	ppm	122	142	170	166	137	95.2
Zn	ppm	88.5	98.0	93.3	92.9	72.2	60.7
Rb	ppm	3.42	3.20	3.02	3.15	5.52	1.67
Sr	ppm	199	203	174	198	217	92.4
Y	ppm	36.5	25.2	22.9	29.3	25.1	14.6
Zr	ppm	140	104.8	80.5	116	108	38.0

Nb	ppm	3.76	3.21	2.64	3.40	5.85	1.14
Cs	ppm	0.0468	0.0365	0.0325	0.0466	0.0569	0.0207
Ba	ppm	36.5	28.8	27.6	30.4	51.9	12.2
La	ppm	5.31	4.15	3.41	4.58	5.77	1.56
Ce	ppm	13.7	13.7	11.0	13.7	14.0	4.73
Pr	ppm	2.34	2.18	1.72	2.26	2.28	0.834
Nd	ppm	12.8	10.8	8.57	11.5	11.6	4.34
Sm	ppm	4.18	3.44	2.72	3.75	3.29	1.47
Eu	ppm	1.44	1.29	1.10	1.37	1.15	0.603
Gd	ppm	6.04	4.18	3.66	4.83	4.15	2.11
Tb	ppm	1.02	0.735	0.628	0.822	0.674	0.380
Dy	ppm	6.68	4.72	4.23	5.43	4.53	2.55
Ho	ppm	1.44	1.00	0.928	1.16	0.962	0.581
Er	ppm	4.08	2.78	2.52	3.24	2.71	1.62
Tm	ppm	0.603	0.408	0.384	0.472	0.398	0.255
Yb	ppm	3.43	2.61	2.30	2.85	2.42	1.57
Lu	ppm	0.560	0.381	0.379	0.460	0.380	0.236
Hf	ppm	3.59	2.57	2.08	2.82	2.80	1.06
Ta	ppm	0.290	0.222	0.159	0.225	0.452	0.0756
Pb	ppm	0.715	0.717	0.643	0.699	0.674	0.340
Th	ppm	0.395	0.232	0.211	0.262	0.534	0.103
U	ppm	0.104	0.0864	0.0729	0.098	0.125	0.03
⁴ ⁸⁷ Sr/ ⁸⁶ Sr					0.703143		
¹⁴³ Nd/ ¹⁴⁴ Nd					0.513064		
¹⁷⁶ Hf/ ¹⁷⁷ Hf					0.283190		
²⁰⁶ Pb/ ²⁰⁴ Pb					18.100		
²⁰⁷ Pb/ ²⁰⁴ Pb					15.486		
²⁰⁸ Pb/ ²⁰⁴ Pb					37.866		
H ₂ O _(8.0)	wt. %	0.375	0.339	0.389	0.379	0.637	0.383

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope

concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD- 28-01- 01	NLD- 30-01- 01	NLD- 31-01- 01	NLD- 32-01- 01	NLD- 35-01- 01	NLD- 37-01- 01
SiO ₂ ¹	wt.%	51.30	50.09	48.70	49.93	50.98	51.52
TiO ₂	wt.%	1.87	1.44	1.29	2.03	1.76	1.79
Al ₂ O ₃	wt.%	14.43	15.67	17.35	14.49	14.84	15.15
FeO*	wt.%	11.99	10.84	8.94	12.08	10.88	11.10
MnO	wt.%	0.22	0.16	0.15	0.19	0.21	0.22
MgO	wt.%	5.85	7.93	8.51	5.65	6.56	5.85
CaO	wt.%	11.14	10.75	12.37	10.86	11.18	9.98
Na ₂ O	wt.%	2.97	2.75	2.41	3.08	3.04	3.05
K ₂ O	wt.%	0.27	0.25	0.21	0.46	0.25	0.57
P ₂ O ₅	wt.%	0.14	0.10	0.12	0.20	0.12	0.19
Total	wt.%	100.19	99.98	100.05	98.96	99.82	99.43
H ₂ O ²	wt.%	0.50	0.35	0.46	0.78	0.43	0.77
CO ₂	ppm	69	94	90	217	44	56
F	ppm	262	175	178	356	249	420
S	ppm	1487	1228	928	1522	1280	1220
Cl	ppm	384	150	140	564	370	1208
Li ³	ppm	7.73	4.96	4.33	6.66	5.41	8.23
Be	ppm	0.449	0.268	0.244	0.578	0.726	1.32
K ₂ O	wt.%	0.271	0.273	0.206	0.467	0.232	0.507
Sc	ppm	44.1	27.7	37.1	44.1	51.9	35.8
TiO ₂	wt.%	1.77	1.43	1.25	1.98	1.71	1.73
V	ppm	303	233	209	324	256	243
Cr	ppm	129	305	243	40.6	222	149
Co	ppm	38.3	46.0	41.8	40.9	35.1	35.5
Ni	ppm	35.6	145	119	26.2	39.0	43.5
Cu	ppm	74.0	86.0	126	96.8	61.5	72.7
Zn	ppm	105	106	70.1	107	76.9	94.5
Rb	ppm	6.57	6.57	4.36	12.0	4.35	12.5

Sr	ppm	131	165	218	186	158	146
Y	ppm	37.5	19.0	21.9	37.9	44.5	48.0
Zr	ppm	119	66.1	96.6	151	143	216
Nb	ppm	4.42	5.39	4.46	8.83	5.30	10.0
Cs	ppm	0.0706	0.0677	0.0487	0.117	0.0480	0.126
Ba	ppm	44.8	42.3	39.5	92.3	48.0	74.9
La	ppm	4.97	3.86	4.62	8.77	6.31	10.3
Ce	ppm	14.0	10.4	11.7	20.3	14.3	25.6
Pr	ppm	2.31	1.57	1.92	3.14	2.50	3.96
Nd	ppm	12.1	7.68	9.89	15.6	13.7	19.5
Sm	ppm	4.05	2.53	2.95	4.65	4.48	5.55
Eu	ppm	1.43	1.00	1.07	1.55	1.50	1.63
Gd	ppm	5.80	3.36	3.79	6.26	6.81	7.27
Tb	ppm	1.03	0.579	0.626	1.05	1.23	1.27
Dy	ppm	6.72	3.65	3.93	6.69	7.69	8.20
Ho	ppm	1.48	0.746	0.873	1.50	1.65	1.71
Er	ppm	4.20	2.02	2.27	4.06	4.53	4.80
Tm	ppm	0.642	0.279	0.340	0.598	0.700	0.767
Yb	ppm	3.84	1.73	2.02	3.70	4.20	4.86
Lu	ppm	0.607	0.260	0.336	0.592	0.663	0.720
Hf	ppm	3.04	1.75	2.33	3.70	3.82	5.50
Ta	ppm	0.319	0.361	0.331	0.632	0.432	0.721
Pb	ppm	0.870	0.547	0.536	1.00	0.794	1.21
Th	ppm	0.385	0.312	0.401	0.864	0.584	1.08
U	ppm	0.107	0.109	0.103	0.224	0.128	0.294
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.304	0.353	0.530	0.447	0.317	0.469

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-38-01-01	NLD-40-01-01	NLD-40-02-01	NLD-41-01-01	NLD-41-02-01	NLD-41-03-01
SiO ₂ ¹	wt.%	49.09	49.63	63.92	50.05	61.41	61.71
TiO ₂	wt.%	1.54	1.12	0.90	1.37	1.27	1.21
Al ₂ O ₃	wt.%	15.52	15.52	12.89	15.47	13.96	14.09
FeO*	wt.%	10.58	10.13	9.88	9.82	9.15	8.94
MnO	wt.%	0.19	0.19	0.22	0.20	0.22	0.18
MgO	wt.%	8.21	8.39	1.28	7.06	2.19	2.55
CaO	wt.%	12.28	12.87	4.54	12.40	5.59	5.46
Na ₂ O	wt.%	2.45	2.16	3.66	2.20	4.22	4.15
K ₂ O	wt.%	0.16	0.08	0.75	0.32	0.80	0.86
P ₂ O ₅	wt.%	0.13	0.09	0.24	0.14	0.26	0.27
Total	wt.%	100.13	100.17	98.29	99.02	99.06	99.42
H ₂ O ²	wt.%	0.46	0.23	1.34	1.08	1.28	1.24
CO ₂	ppm	115	107	2	75	3	3
F	ppm	189	112	975	211	703	706
S	ppm	1136	896	382	1023	506	415
Cl	ppm	447	384	7869	837	4338	4366
Li ³	ppm	4.80	4.16	22.6	4.41	15.5	15.8
Be	ppm	0.629	0.277	3.00	0.528	2.39	2.30
K ₂ O	wt.%	0.157	0.0957	0.720	0.296	0.788	0.814
Sc	ppm	39.0	38.9	19.7	37.9	21.7	22.2
TiO ₂	wt.%	1.50	1.05	0.865	1.33	1.24	1.22
V	ppm	337	308	25.9	322	125	108
Cr	ppm	274	296	4.16	103	13.9	14.3
Co	ppm	43.1	43.1	9.62	37.1	18.3	16.7
Ni	ppm	103.0	96.5	1.75	59.2	10.6	9.91
Cu	ppm	124	154	26.9	94.9	40.6	40.7
Zn	ppm	80.9	73.6	162	72.3	116	120
Rb	ppm	3.51	2.48	21.7	8.42	24.1	24.8
Sr	ppm	88.5	60.9	76.4	157	85.0	88.5
Y	ppm	31.8	24.6	185	28.1	121	128
Zr	ppm	79.2	43.3	650	77.4	425	452

Nb	ppm	3.41	2.13	23.7	5.37	20.8	21.8
Cs	ppm	0.0414	0.0185	0.250	0.0937	0.277	0.272
Ba	ppm	30.6	22.7	151	59.8	173	177
La	ppm	3.32	1.98	22.2	4.77	17.5	18.0
Ce	ppm	9.95	5.79	57.3	12.5	47.0	48.1
Pr	ppm	1.67	0.963	9.43	1.96	7.28	7.55
Nd	ppm	9.31	5.55	50.0	10.0	37.4	38.6
Sm	ppm	3.27	2.17	16.4	3.05	11.8	12.1
Eu	ppm	1.19	0.853	4.00	1.10	2.83	2.91
Gd	ppm	4.63	3.29	24.5	4.17	16.5	17.0
Tb	ppm	0.835	0.613	4.44	0.755	2.91	3.13
Dy	ppm	5.41	4.11	29.2	4.74	19.3	20.7
Ho	ppm	1.16	0.886	6.46	0.995	4.26	4.50
Er	ppm	3.20	2.52	18.9	2.79	12.2	13.0
Tm	ppm	0.526	0.382	3.01	0.437	1.93	2.06
Yb	ppm	3.27	2.51	19.0	2.83	12.5	13.3
Lu	ppm	0.490	0.369	2.98	0.424	1.93	2.06
Hf	ppm	2.26	1.40	17.7	2.07	11.4	12.2
Ta	ppm	0.213	0.127	1.52	0.319	1.28	1.39
Pb	ppm	0.448	0.285	2.59	0.633	1.90	1.99
Th	ppm	0.295	0.172	2.80	0.490	2.31	2.43
U	ppm	0.0839	0.0507	0.716	0.132	0.622	0.640
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.493	0.263	0.061	0.900	0.146	0.184

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-42-01-01	NLD-43-01-01	NLD-43-02-01	NLD-44-01-01	NLD-44-02-01	NLD-45-01-01
SiO ₂ ¹	wt.%	49.75	50.26	50.39	50.57	50.47	50.12
TiO ₂	wt.%	1.05	1.64	1.63	1.62	1.57	1.98
Al ₂ O ₃	wt.%	15.52	14.18	13.94	14.72	14.91	13.23
FeO*	wt.%	9.77	11.94	12.40	10.81	10.74	14.28
MnO	wt.%	0.18	0.21	0.22	0.20	0.21	0.27
MgO	wt.%	8.15	6.88	6.57	6.38	6.47	5.98
CaO	wt.%	13.21	11.91	11.66	11.69	11.83	10.83
Na ₂ O	wt.%	2.07	2.59	2.77	2.54	2.47	2.69
K ₂ O	wt.%	0.04	0.14	0.12	0.52	0.51	0.14
P ₂ O ₅	wt.%	0.07	0.14	0.13	0.26	0.24	0.19
Total	wt.%	99.81	99.88	99.83	99.32	99.42	99.71
H ₂ O ²	wt.%	0.11	0.37	0.30	0.71	0.66	0.36
CO ₂	ppm	154	174	160	67	97	93
F	ppm	78	163	181	440	423	226
S	ppm	798	1251	1332	1155	1136	1629
Cl	ppm	258	520	1502	1014	906	1123
Li ³	ppm	3.74	5.03	5.18	6.00	6.51	8.49
Be	ppm	0.239	0.406	0.718	0.803	0.785	0.544
K ₂ O	wt.%	0.0337	0.123	0.116	0.536	0.571	0.143
Sc	ppm	43.5	46.0	52.8	40.1	39.3	42.7
TiO ₂	wt.%	0.971	1.53	1.57	1.57	1.54	1.94
V	ppm	277	356	351	360	382	500
Cr	ppm	291	90.6	84.3	69.4	81.9	57.6
Co	ppm	40.1	39.8	40.7	39.8	42.9	49.8
Ni	ppm	82.8	53.2	44.8	49.4	55.9	47.4
Cu	ppm	145	142	149	125	136	177
Zn	ppm	62.7	82.4	87.3	93.7	98.8	129
Rb	ppm	0.687	2.81	2.60	16.9	17.5	3.59
Sr	ppm	54.3	79.3	79.0	150	149	70.1
Y	ppm	27.0	39.1	47.6	29.2	28.5	43.1
Zr	ppm	42.1	86.5	98.8	87.7	84.7	87.9

Nb	ppm	1.03	3.14	3.79	23.9	23.1	5.22
Cs	ppm	0.00902	0.0316	0.0242	0.157	0.157	0.0348
Ba	ppm	6.82	26.0	29.3	170	167	33.4
La	ppm	1.20	3.28	4.00	13.9	13.4	4.34
Ce	ppm	3.70	8.91	9.60	29.7	30.4	12.7
Pr	ppm	0.779	1.61	1.82	3.59	3.50	2.11
Nd	ppm	5.09	9.37	11.0	15.6	15.1	11.4
Sm	ppm	2.21	3.50	4.16	3.87	3.75	4.12
Eu	ppm	0.874	1.22	1.38	1.32	1.29	1.49
Gd	ppm	3.61	5.35	6.71	4.72	4.56	6.22
Tb	ppm	0.661	0.942	1.16	0.784	0.762	1.08
Dy	ppm	4.51	6.46	8.10	5.12	5.02	7.35
Ho	ppm	0.990	1.42	1.78	1.11	1.07	1.63
Er	ppm	2.74	3.98	5.15	3.12	3.03	4.72
Tm	ppm	0.430	0.610	0.796	0.480	0.473	0.734
Yb	ppm	2.64	3.91	5.09	3.25	3.24	4.88
Lu	ppm	0.398	0.600	0.820	0.493	0.478	0.754
Hf	ppm	1.51	2.53	3.16	2.42	2.46	2.80
Ta	ppm	0.0682	0.214	0.296	1.36	1.34	0.310
Pb	ppm	0.155	0.394	0.392	1.19	1.29	0.561
Th	ppm	0.0929	0.293	0.370	1.76	1.72	0.373
U	ppm	0.0260	0.0712	0.0942	0.539	0.562	0.133
⁴ ⁸⁷ Sr/ ⁸⁶ Sr		0.703393			0.703515		
¹⁴³ Nd/ ¹⁴⁴ Nd		0.513102			0.513100		
¹⁷⁶ Hf/ ¹⁷⁷ Hf		0.283225			0.283196		
²⁰⁶ Pb/ ²⁰⁴ Pb		18.506			18.635		
²⁰⁷ Pb/ ²⁰⁴ Pb		15.548			15.558		
²⁰⁸ Pb/ ²⁰⁴ Pb		38.417			38.512		
H ₂ O _(8.0)	wt. %	0.113	0.295	0.223	0.502	0.476	0.227

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-46-01-01	NLD-47-01-01	NLD-48-01-01	NLD-49-01-01	NLD-50-01-01	NLD-51-01-01
SiO ₂ ¹	wt.%	49.98	49.83	49.53	50.20	49.26	48.96
TiO ₂	wt.%	1.68	1.56	1.11	1.42	1.14	1.10
Al ₂ O ₃	wt.%	13.46	13.81	15.52	14.05	16.05	16.22
FeO*	wt.%	12.76	12.44	9.73	12.03	9.17	8.83
MnO	wt.%	0.23	0.25	0.20	0.23	0.17	0.16
MgO	wt.%	6.27	6.50	8.36	7.04	8.70	8.80
CaO	wt.%	11.45	11.89	13.31	12.07	13.52	13.66
Na ₂ O	wt.%	2.63	2.58	2.15	2.54	2.25	2.13
K ₂ O	wt.%	0.11	0.14	0.04	0.09	0.09	0.10
P ₂ O ₅	wt.%	0.14	0.12	0.08	0.10	0.11	0.10
Total	wt.%	98.72	99.13	100.05	99.78	100.46	100.06
H ₂ O ²	wt.%	0.26	0.33	0.15	0.25	0.20	0.22
CO ₂	ppm	203	169	101	208	182	172
F	ppm	195	184	95	140	137	147
S	ppm	1431	1262	874	1250	907	861
Cl	ppm	1594	537	311	604	236	122
Li ³	ppm	5.88	5.53	4.38	5.63	4.31	3.56
Be	ppm	0.444	0.404	0.291	0.401	0.309	0.250
K ₂ O	wt.%	0.118	0.140	0.0453	0.0874	0.0956	0.109
Sc	ppm	42.2	46.3	41.5	43.4	39.3	42.2
TiO ₂	wt.%	1.61	1.47	1.05	1.34	1.09	1.03
V	ppm	421	362	302	371	281	251
Cr	ppm	79.6	40.6	286	102	353	340
Co	ppm	46.9	42.6	43.6	45.3	44.8	42.1
Ni	ppm	51.4	45.5	98.2	59.5	122	115
Cu	ppm	187	161	150	180	157	144
Zn	ppm	106	87.1	69.7	92.8	69.9	63.3
Rb	ppm	2.85	3.71	0.968	2.02	2.25	2.83
Sr	ppm	71.4	79.5	62.3	68.9	123	131
Y	ppm	36.8	36.1	24.3	30.6	21.5	23.0
Zr	ppm	76.0	74.1	41.4	56.5	58.6	65.1

Nb	ppm	4.87	4.82	1.23	2.43	3.40	4.19
Cs	ppm	0.0208	0.0394	0.0108	0.0242	0.0293	0.0268
Ba	ppm	29.9	39.1	8.68	18.8	25.6	30.8
La	ppm	3.90	4.20	1.38	2.38	3.11	3.73
Ce	ppm	11.2	9.97	4.69	7.31	9.24	9.57
Pr	ppm	1.84	1.71	0.912	1.30	1.42	1.50
Nd	ppm	10.1	9.64	5.72	7.44	7.51	7.74
Sm	ppm	3.53	3.41	2.32	2.86	2.43	2.57
Eu	ppm	1.29	1.19	0.889	1.08	0.920	0.959
Gd	ppm	5.27	5.12	3.41	4.30	3.29	3.43
Tb	ppm	0.945	0.906	0.624	0.745	0.549	0.589
Dy	ppm	6.21	6.21	4.18	5.11	3.81	4.00
Ho	ppm	1.40	1.34	0.910	1.14	0.812	0.880
Er	ppm	4.00	3.86	2.63	3.32	2.32	2.66
Tm	ppm	0.631	0.612	0.401	0.510	0.375	0.357
Yb	ppm	4.17	3.98	2.67	3.48	2.32	2.58
Lu	ppm	0.633	0.604	0.402	0.518	0.354	0.359
Hf	ppm	2.43	2.39	1.44	1.82	1.63	1.79
Ta	ppm	0.283	0.317	0.0773	0.153	0.199	0.268
Pb	ppm	0.433	0.401	0.223	0.352	0.427	0.435
Th	ppm	0.371	0.415	0.0894	0.179	0.235	0.296
U	ppm	0.128	0.106	0.0295	0.0649	0.0814	0.0913
⁴ ⁸⁷ Sr/ ⁸⁶ Sr					0.703523		0.703122
¹⁴³ Nd/ ¹⁴⁴ Nd					0.513018		0.513029
¹⁷⁶ Hf/ ¹⁷⁷ Hf					0.283172		0.283165
²⁰⁶ Pb/ ²⁰⁴ Pb					18.627		18.324
²⁰⁷ Pb/ ²⁰⁴ Pb					15.559		15.502
²⁰⁸ Pb/ ²⁰⁴ Pb					38.566		38.071
H ₂ O _(8.0)	wt. %	0.180	0.237	0.168	0.212	0.242	0.273

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-55-01-01	NLD-56-01-01	NLD-57-01-01	NLD-58-01-01	NLD-59-01-01	NLD-60-01-01
SiO ₂ ¹	wt.%	48.35	50.06	50.94	50.62	50.48	50.72
TiO ₂	wt.%	1.41	0.89	1.11	1.01	1.24	1.38
Al ₂ O ₃	wt.%	16.19	15.15	14.38	15.10	15.03	15.64
FeO*	wt.%	9.87	9.59	11.44	9.90	10.26	10.91
MnO	wt.%	0.18	0.20	0.21	0.20	0.21	0.18
MgO	wt.%	8.82	8.21	7.17	8.03	7.73	6.43
CaO	wt.%	12.06	13.63	12.36	13.01	12.70	11.54
Na ₂ O	wt.%	2.78	2.22	2.46	2.30	2.55	2.77
K ₂ O	wt.%	0.03	0.04	0.05	0.04	0.07	0.13
P ₂ O ₅	wt.%	0.09	0.06	0.07	0.06	0.09	0.12
Total	wt.%	99.78	100.06	100.17	100.27	100.36	99.84
H ₂ O ²	wt.%	0.12	0.10	0.21	0.15	0.28	0.54
CO ₂	ppm	89	101	172	184	176	81
F	ppm	99	69	97	85	115	148
S	ppm	929	995	1153	1029	1090	1167
Cl	ppm	15	28	63	433	284	677
Li ³	ppm	5.25	4.36	5.82	5.07	5.47	5.59
Be	ppm	0.183	0.251	0.270	0.239	0.247	0.424
K ₂ O	wt.%	0.0336	0.0299	0.0390	0.0563	0.0759	0.123
Sc	ppm	39.1	52.3	44.2	41.7	43.7	37.5
TiO ₂	wt.%	1.33	0.828	1.07	1.00	1.17	1.32
V	ppm	288	250	333	315	338	313
Cr	ppm	285	337	61.3	296	365	180
Co	ppm	41.2	40.6	49.6	49.4	49.1	41.7
Ni	ppm	160	72.2	59.1	102.6	90.9	60.6
Cu	ppm	152	127	130	120	137	91.3
Zn	ppm	72.0	71.5	103	93.0	97.0	101
Rb	ppm	0.76	0.500	0.533	0.862	1.38	2.25
Sr	ppm	59.1	62.6	63.7	74.7	91.0	91.7
Y	ppm	34.2	26.8	26.6	22.5	24.6	30.9
Zr	ppm	49.9	45.3	51.6	48.3	59.5	78.5

Nb	ppm	0.649	0.719	0.706	1.02	1.32	1.59
Cs	ppm	0.00578	0.00566	0.00577	0.0115	0.0133	0.0260
Ba	ppm	6.51	5.05	4.86	8.24	11.6	13.8
La	ppm	1.07	1.25	1.44	1.46	1.83	2.38
Ce	ppm	3.97	3.63	5.18	5.42	6.82	8.04
Pr	ppm	0.957	0.738	0.965	0.942	1.15	1.43
Nd	ppm	6.89	4.66	5.68	5.20	6.35	8.00
Sm	ppm	3.20	1.99	2.27	2.03	2.39	2.94
Eu	ppm	1.19	0.76	0.897	0.834	0.957	1.10
Gd	ppm	5.09	3.66	3.61	3.18	3.69	4.48
Tb	ppm	0.892	0.684	0.692	0.589	0.660	0.813
Dy	ppm	5.98	4.52	4.63	3.79	4.42	5.49
Ho	ppm	1.29	1.02	1.02	0.849	0.977	1.21
Er	ppm	3.57	2.96	2.99	2.45	2.78	3.43
Tm	ppm	0.550	0.451	0.443	0.380	0.430	0.538
Yb	ppm	3.54	2.88	2.97	2.52	2.85	3.42
Lu	ppm	0.540	0.456	0.449	0.380	0.442	0.505
Hf	ppm	1.98	1.28	1.41	1.26	1.54	1.97
Ta	ppm	0.0453	0.0538	0.0443	0.0696	0.0827	0.108
Pb	ppm	0.205	0.236	0.378	0.297	0.417	0.496
Th	ppm	0.0557	0.0938	0.0741	0.0859	0.103	0.143
U	ppm	0.0159	0.0182	0.0249	0.0298	0.0354	0.0607
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.151	0.105	0.178	0.159	0.275	0.383

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-61-01-01	NLD-62-01-01	NLD-63-01-01	NLD-64-01-01	NLD-65-01-01	NLD-66-01-01
SiO ₂ ¹	wt.%	50.49	50.16	48.77	50.72	50.70	50.57
TiO ₂	wt.%	0.71	0.90	0.78	0.85	0.84	1.16
Al ₂ O ₃	wt.%	15.04	15.44	17.33	15.20	14.84	15.11
FeO*	wt.%	9.38	9.08	8.36	9.84	10.01	10.52
MnO	wt.%	0.18	0.18	0.14	0.21	0.19	0.19
MgO	wt.%	8.64	8.74	10.36	8.22	7.98	7.85
CaO	wt.%	14.02	13.96	12.85	13.08	13.20	12.37
Na ₂ O	wt.%	1.92	2.12	1.98	2.15	2.11	2.21
K ₂ O	wt.%	0.03	0.04	0.01	0.04	0.04	0.07
P ₂ O ₅	wt.%	0.06	0.06	0.05	0.07	0.04	0.08
Total	wt.%	100.46	100.67	100.64	100.37	99.94	100.13
H ₂ O ²	wt.%	0.09	0.08	0.06	0.14	0.14	0.23
CO ₂	ppm	127	132	151	166	240	179
F	ppm	47	67	52	69	68	103
S	ppm	823	996	802	923	937	1066
Cl	ppm	63	9	11	142	134	93
Li ³	ppm	3.57	4.44	3.76	4.47	4.11	5.25
Be	ppm	0.216	0.117	0.098	0.193	0.244	0.194
K ₂ O	wt.%	0.0235	0.0332	0.0200	0.0404	0.0370	0.0654
Sc	ppm	48.0	42.0	30.8	43.5	50.7	46.4
TiO ₂	wt.%	0.657	0.821	0.718	0.806	0.801	1.08
V	ppm	250	252	206	288	262	298
Cr	ppm	319	443	398	260	182	315
Co	ppm	41.5	45.8	48.5	48.1	42.6	41.6
Ni	ppm	84.1	92.0	204	94.0	75.6	91.2
Cu	ppm	137	131	125	150	137	104
Zn	ppm	67.3	75.4	72.8	84.4	75.7	86.9
Rb	ppm	0.310	0.425	0.222	0.662	0.621	1.06
Sr	ppm	55.1	62.4	69.2	64.4	63.1	77.1
Y	ppm	19.5	19.1	15.6	19.7	25.1	30.5
Zr	ppm	30.4	35.3	29.9	38.3	46.5	66.6

Nb	ppm	0.494	0.603	0.395	0.698	0.756	1.31
Cs	ppm	0.00717	0.0149	0.000341	0.0112	0.0107	0.0129
Ba	ppm	3.83	4.41	2.81	5.99	6.09	10.7
La	ppm	0.829	1.05	0.706	1.12	1.30	2.01
Ce	ppm	2.65	3.69	2.90	4.21	3.84	5.91
Pr	ppm	0.531	0.690	0.554	0.760	0.746	1.11
Nd	ppm	3.34	4.13	3.36	4.18	4.50	6.49
Sm	ppm	1.45	1.72	1.39	1.67	1.85	2.49
Eu	ppm	0.597	0.717	0.637	0.707	0.728	0.953
Gd	ppm	2.54	2.79	2.28	2.64	3.24	4.08
Tb	ppm	0.482	0.509	0.426	0.514	0.618	0.792
Dy	ppm	3.27	3.47	2.62	3.35	4.08	4.99
Ho	ppm	0.755	0.754	0.610	0.784	0.981	1.17
Er	ppm	2.18	2.15	1.76	2.25	2.84	3.35
Tm	ppm	0.332	0.328	0.268	0.346	0.427	0.517
Yb	ppm	2.24	2.06	1.68	2.28	2.81	3.33
Lu	ppm	0.332	0.326	0.245	0.347	0.443	0.511
Hf	ppm	0.863	1.08	0.857	0.979	1.30	1.72
Ta	ppm	0.0321	0.0401	0.0208	0.0485	0.0538	0.0930
Pb	ppm	0.155	0.197	0.181	0.254	0.215	0.336
Th	ppm	0.0437	0.0556	0.0259	0.0588	0.0742	0.135
U	ppm	0.0148	0.0189	0.0117	0.0180	0.0162	0.0334
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.106	0.095	0.100	0.148	0.143	0.233

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		VG 9789	VG 9785	VG 9778	VG 9786	VG 9779	VG 9764
SiO ₂ ¹	wt.%	49.40	50.13	50.69	50.97	50.93	50.67
TiO ₂	wt.%	0.81	1.26	0.83	1.66	1.64	1.70
Al ₂ O ₃	wt.%	16.04	14.99	15.96	13.51	13.94	13.75
FeO*	wt.%	8.96	10.75	9.28	12.95	12.70	12.90
MnO	wt.%						
MgO	wt.%	7.14	7.33	6.99	6.17	6.75	6.53
CaO	wt.%	13.35	12.56	12.69	10.84	11.24	11.10
Na ₂ O	wt.%	2.14	2.62	2.38	2.75	2.62	2.62
K ₂ O	wt.%	0.15	0.07	0.10	0.11	0.08	0.08
P ₂ O ₅	wt.%	0.12	0.11	0.10	0.14	0.15	0.12
Total	wt.%	98.11	99.82	99.02	99.10	100.05	99.47
H ₂ O ²	wt.%	1.20	0.26	1.08	0.31	0.27	0.27
CO ₂	ppm	2	115	5	159	296	170
F	ppm	129	111	81	158	135	150
S	ppm	251	1127	496	1361	1326	1418
Cl	ppm	719	369	373	535	323	645
Li ³	ppm	4.47	5.18	4.93	7.17	7.56	8.00
Be	ppm	0.204	0.206	0.212	0.432	0.341	0.344
K ₂ O	wt.%	0.138	0.0499	0.0895	0.0814	0.0682	0.0701
Sc	ppm	34.3	45.1	35.9	41.5	41.3	40.2
TiO ₂	wt.%	0.787	1.26	0.819	1.67	1.57	1.57
V	ppm	269	286	273	367	389	379
Cr	ppm	129	277	205	42.3	107	114
Co	ppm	48.8	39.6	39.9	42.9	47.1	44.2
Ni	ppm	123	66.7	68.8	38.2	56.9	56.8
Cu	ppm	129	106	116	86.5	97.5	92.5
Zn	ppm	69.5	64.6	80.4	102	102	88.4
Rb	ppm	2.91	0.715	1.08	1.29	1.06	0.967
Sr	ppm	240	89.6	188	84.9	78.3	74.4
Y	ppm	17.0	30.8	17.9	44.2	36.4	36.6
Zr	ppm	38.8	67.2	32.9	104	78.7	80.6

Nb	ppm	2.58	1.12	0.631	1.97	1.46	1.42
Cs	ppm	0.0230	0.00877	0.00383	0.0151	0.0113	0.0124
Ba	ppm	23.8	8.38	12.2	12.8	10.0	9.24
La	ppm	3.53	1.92	1.72	3.20	2.37	2.32
Ce	ppm	10.2	6.34	5.66	10.5	8.61	7.99
Pr	ppm	1.43	1.25	0.909	1.95	1.55	1.54
Nd	ppm	6.74	7.30	4.71	10.8	8.78	8.94
Sm	ppm	1.92	2.81	1.67	4.05	3.35	3.44
Eu	ppm	0.756	1.08	0.705	1.43	1.26	1.27
Gd	ppm	2.58	4.47	2.60	6.21	5.10	5.24
Tb	ppm	0.453	0.801	0.481	1.13	0.947	0.964
Dy	ppm	3.02	5.43	3.15	7.58	6.28	6.40
Ho	ppm	0.642	1.20	0.682	1.63	1.35	1.40
Er	ppm	1.85	3.38	1.97	4.76	3.90	4.00
Tm	ppm	0.277	0.543	0.296	0.761	0.617	0.646
Yb	ppm	1.83	3.30	2.00	4.63	3.91	3.96
Lu	ppm	0.280	0.516	0.288	0.744	0.590	0.594
Hf	ppm	1.09	1.97	0.971	2.97	2.26	2.35
Ta	ppm	0.135	0.0805	0.0370	0.137	0.0944	0.0941
Pb	ppm	0.573	0.327	0.349	0.487	0.421	0.421
Th	ppm	0.227	0.0879	0.0783	0.155	0.104	0.103
U	ppm	0.0773	0.0254	0.0328	0.0528	0.0416	0.0411
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.989	0.220	0.858	0.201	0.200	0.193

Table 1.S2: *cont.* Major element, volatile, trace element, and Sr-Nd-Hf-Pb isotope concentrations for basaltic glass samples from the Northern Lau Basin

Sample		VG 9751	VG 9768	VG 9758	VG 9760	VG 9750	VG 9775
SiO ₂ ¹	wt.%	50.16	58.34	50.52	50.95	49.39	60.77
TiO ₂	wt.%	2.20	1.51	2.14	2.62	0.88	1.26
Al ₂ O ₃	wt.%	12.49	12.73	12.68	11.92	15.05	12.63
FeO*	wt.%	16.30	11.56	15.73	17.57	10.85	11.68
MnO	wt.%						
MgO	wt.%	5.15	2.48	5.29	4.40	6.99	1.29
CaO	wt.%	9.51	6.41	9.51	8.86	13.42	5.42
Na ₂ O	wt.%	2.72	4.23	3.01	3.08	2.06	4.20
K ₂ O	wt.%	0.09	0.43	0.10	0.12	0.09	0.50
P ₂ O ₅	wt.%	0.17	0.25	0.17	0.18	0.14	0.26
Total	wt.%	98.79	97.94	99.15	99.70	98.87	98.01
H ₂ O ²	wt.%	0.35	1.45	0.43	0.52	1.13	1.33
CO ₂	ppm	85	17	123	148	3	10
F	ppm	251	829	227	284	110	759
S	ppm	2065	760	1899	2319	195	658
Cl	ppm	637	10043	690	1441	894	4869
Li ³	ppm	12.4	19.2	7.83	11.6	4.60	25.6
Be	ppm	0.446	1.19	0.525	0.501	0.156	1.51
K ₂ O	wt.%	0.101	0.374	0.104	0.113	0.0788	0.420
Sc	ppm	40.3	28.3	34.3	44.3	42.4	23.9
TiO ₂	wt.%	2.13	1.54	2.14	2.59	0.820	1.26
V	ppm	470	175	429	507	263	42.5
Cr	ppm	24.8	5.55	4.42	3.79	77.0	1.38
Co	ppm	50.2	24.8	41.8	48.3	37.1	14.4
Ni	ppm	29.9	9.13	18.0	17.2	48.1	1.88
Cu	ppm	87.5	42.9	74.2	81.8	123	24.3
Zn	ppm	126	120	142	147	74.0	138
Rb	ppm	1.52	6.62	1.66	1.86	0.803	8.15
Sr	ppm	72.1	83.5	66.2	77.9	303	81.6
Y	ppm	51.5	142	55.1	65.0	20.9	181
Zr	ppm	115	554	135	157	39.6	671

Nb	ppm	2.11	6.85	2.50	2.77	0.732	7.90
Cs	ppm	0.0179	0.0716	0.0195	0.0226	0.00214	0.0864
Ba	ppm	12.8	42.5	14.6	15.7	9.01	51.6
La	ppm	3.24	14.8	4.39	4.43	2.39	16.6
Ce	ppm	11.0	43.9	14.2	13.9	6.40	45.6
Pr	ppm	2.11	7.47	2.58	2.62	1.19	8.51
Nd	ppm	12.3	40.0	13.6	15.9	6.32	48.4
Sm	ppm	4.75	13.1	5.15	5.94	1.98	16.8
Eu	ppm	1.67	3.01	1.74	1.99	0.762	3.87
Gd	ppm	7.33	18.7	7.62	9.56	3.07	25.9
Tb	ppm	1.35	3.34	1.38	1.75	0.554	4.64
Dy	ppm	8.96	22.3	9.17	11.6	3.74	30.8
Ho	ppm	1.92	4.95	2.02	2.51	0.808	6.71
Er	ppm	5.62	14.9	5.93	7.12	2.27	19.6
Tm	ppm	0.908	2.34	0.969	1.09	0.351	3.09
Yb	ppm	5.69	14.8	5.54	7.18	2.25	19.1
Lu	ppm	0.857	2.35	0.913	1.09	0.335	3.03
Hf	ppm	3.33	13.7	3.74	4.36	1.16	17.6
Ta	ppm	0.142	0.438	0.171	0.188	0.0557	0.604
Pb	ppm	0.604	1.65	0.720	0.651	0.460	2.21
Th	ppm	0.151	1.06	0.227	0.232	0.0885	1.25
U	ppm	0.0588	0.404	0.0678	0.0752	0.0305	0.338
⁴ ⁸⁷ Sr/ ⁸⁶ Sr							
¹⁴³ Nd/ ¹⁴⁴ Nd							
¹⁷⁶ Hf/ ¹⁷⁷ Hf							
²⁰⁶ Pb/ ²⁰⁴ Pb							
²⁰⁷ Pb/ ²⁰⁴ Pb							
²⁰⁸ Pb/ ²⁰⁴ Pb							
H ₂ O _(8.0)	wt. %	0.164	0.198	0.211	0.188	0.896	0.060

Table 1.S3: Parental melt compositions for liquid lines of descent modeled using

Petrolog3 (Danyushevsky and Pelchov, 2011)

	"Dry"	"Wet"
SiO ₂	48.27	48.27
TiO ₂	1.22	1.22
Al ₂ O ₃	16.88	18.20
FeO*	7.99	7.99
Fe ₂ O ₃	1.42	1.42
FeO	6.71	6.71
MnO	0.16	0.16
MgO	9.94	9.94
CaO	13.00	11.50
Na ₂ O	1.93	2.34
K ₂ O	0.05	0.05
P ₂ O ₅	0.07	0.07
H ₂ O	0.21	0.75

Theoretical parental melt compositions for appropriate liquid lines of descent (LLD)

as created by Petrolog3 (Danyushevsky and Plechov, 2011). Petrolog3 conditions: P =

2 kbar; Initial oxidation state: closed system for oxygen; Mineral-melt models:

Olivine, Plagioclase, and Clinopyroxene – Danyushevsky, 2001. Iron oxidation state

was 16% Fe³⁺/ΣFe.

Table 1.S4: Standard values for in-house solution standard, EN026 10D-3 and LA-

ICP-MS standards

Standard		EN026 10D-3 ¹	GOR1 32-G ²	StHls- G	ATHO -G	T1-G	ML3B- G	KL2-G
SiO ₂ ^a	wt%	51.38 ^a	45.5	63.7	75.6	58.6	51.4	50.3
Al ₂ O ₃	wt%	15.42	11	17.8	12.2	17.1	13.6	13.3
Fe ₂ O ₃	wt%	2.38						
FeO	wt%	8.06						
FeO*	wt%	9.88	10.1	4.37	3.27	6.44	10.9	10.7
MgO	wt%	8.03	22.4	1.97	0.103	3.75	6.59	7.34
CaO	wt%	11.15	8.45	5.28	1.7	7.1	10.5	10.9
Na ₂ O	wt%	2.06	0.83	4.44	3.75	3.13	2.4	2.35
K ₂ O	wt%	0.3	0.0308	1.29	2.64	1.96	0.385	0.48
TiO ₂	wt%	1.37	0.306	0.703	0.255	0.755	2.13	2.56
MnO	wt%	0.19	0.154	0.076	0.106	0.127	0.17	0.165
P ₂ O ₅	wt%	0.16	0.036	0.164	0.025	0.168	0.23	0.232
H ₂ O	wt%	0.35						
CO ₂	wt%	0.2						
Li	ppm		10.60	19.36	29.72	24.26	4.67	5.78
Be	ppm		0.08	1.2	3.2	2	0.62	0.88
B	ppm		17.2	11.8	5.7	4.1	2.5	2.73
Sc	ppm	38 ^b	36.5	11.5	7.0	26.9	31.6	31.8
V	ppm	300	214	90.3	3.91	190	268	309
Cr	ppm	289	2528	16.9	6.1	20.9	177	294
Co	ppm	41	92.7	13.2	2.13	18.9	41.2	41.2
Ni	ppm	106	1187	23.7	13	10.6	107	112
Cu	ppm	85	205	41.5	18.6	18.8	112	87.9
Zn	ppm	83	76.8	67	141	74	108	110
Ga	ppm	16	10.4	20.9	25.3	19.4	19.6	20
Rb	ppm	7.586	2.1	30.7	65.3	79.7	5.8	8.7
Sr	ppm	128 ^c	15.3	482	94.1	284	312	356
Y	ppm	29.4	12.9	11.4	94.5	23.9	23.9	25.4
Zr	ppm	83.5	9.9	118	512	144	122	152
Nb	ppm	8.8	0.073	6.94	62.4	8.87	8.61	15
Cs	ppm	0.1	7.45	1.75	1.08	2.69	0.14	0.115
Ba	ppm	91.4	0.815	298	5.47	388	80.1	123

La	ppm	6.42	0.0842	12	55.6	70.4	8.99	13.1
Ce	ppm	15.9	0.393	26.1	121	127	23.1	32.4
Pr	ppm	2.36	0.094	3.2	14.6	12.4	3.47	4.7
Nd	ppm	11.32 ^c	0.689	13	60.9	41.4	16.7	21.6
Sm	ppm	3.41 ^c	0.508	2.78	14.2	6.57	4.75	5.54
Eu	ppm	1.18	0.255	0.953	2.76	1.21	1.67	1.92
Gd	ppm	4.09	1.19	2.59	15.3	5.31	5.26	5.92
Tb	ppm	0.757	0.269	0.371	2.55	0.785	0.85	0.93
Dy	ppm	4.98	2.15	2.15	16.2	4.5	4.84	5.22
Ho	ppm	1.096	0.517	0.44	3.53	0.9	0.94	0.985
Er	ppm	3.16	1.56	1.18	10.3	2.49	2.44	2.54
Tm	ppm		0.244	0.175	1.6	0.38	0.35	0.355
Yb	ppm	2.97	1.55	1.09	10.25	2.38	2.03	2.1
Lu	ppm	0.449	0.237	0.168	1.6	0.368	0.298	0.31
Hf	ppm	1.97	0.357	3.07	13.7	3.88	3.22	3.93
Ta	ppm	0.539	0.031	0.42	3.9	0.464	0.555	0.961
Pb	ppm	0.68 ^c	19.5	10.3	5.67	11.6	1.38	2.07
Th	ppm	0.65 ^c	0.009	2.28	7.4	31.3	0.548	1.02
U	ppm	0.172 ^c	0.048	1.01	2.37	1.71	0.442	0.548
Ir	ppb	0.017 ^c						
Ru	ppb	0.047 ^c						
Pd	ppb	0.85 ^c						
Pt	ppb	1.8 ^c	13	1	8	6	8.8	16
Re	ppb	1.3 ^c	0.0009	0.0009	0.0005	0.0018	0.0007	0.0007
Cd	ppb	110 ^c	0.08	0.1	0.5	0.2	0.1	0.09
Ag	ppb	26 ^c	0.04	0.02	0.3	0.1	0.03	0.15
¹⁷⁶ Hf/ ¹⁷⁷ Hf		0.283327 ^d						
¹⁴³ Nd/ ¹⁴⁴ Nd		0.513006 ^d						
⁸⁷ Sr/ ⁸⁶ Sr		0.703185 ^d						
²⁰⁶ Pb/ ²⁰⁴ Pb		18.294 ^e						
²⁰⁷ Pb/ ²⁰⁴ Pb		15.454 ^e						
²⁰⁸ Pb/ ²⁰⁴ Pb		38.031 ^e						

¹Unpublished data from J-G Schilling [Kelley et al., In Prep], ^aMajor elements analysis by XRF, Trace element analysis by ^bICP-MS and ^cID-ICP-MS, Radiogenic isotope analysis by ^dMC-ICP-MS and ^eTIMS. ²LA-ICP-MS standard values used at Graduate School of Oceanography, University of Rhode Island, modified from published values by Jochum et al., 2006

Table 1.S5: Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-06-01-01	NLD-07-01-01	NLD-08-01-01	NLD-09-02-01	NLD-10-01-01	NLD-11-01-01	NLD-13-01-01	NLD-14-01-01	NLD-15-01-01	NLD-16-01-01
Li	ppm	6.75	4.93	5.69	5.42	5.10	5.95	4.44	5.97	4.90	4.64
Be	ppm	0.886	0.577	0.708	0.648	0.687	0.729	0.439	0.670	0.676	0.597
K ₂ O	wt.%	0.397	0.368	0.366	0.341	0.445	0.388	0.092	0.238	0.278	0.252
Sc	ppm	38.0	30.3	37.1	36.7	30.1	38.7	38.0	38.8	34.0	30.5
TiO ₂	wt.%	1.72	1.33	1.39	1.34	1.45	1.45	1.27	1.51	1.49	1.34
V	ppm	309	235	263	256	245	273	253	284	265	240
Cr	ppm	195	297	230	302	280	236	263	257	393	437
Co	ppm	42.4	50.1	40.1	42.7	48.1	41.6	48.7	43.0	50.3	59.8
Ni	ppm	86.9	176	92.2	118	162	92.1	182	122	246	427
Cu	ppm	84.2	103	101	104	98.0	108	146	100	107	96.1
Zn	ppm	97.7	87.5	76.1	74.3	98.5	85.9	79.8	82.3	78.2	104
Ga	ppm	15.7	16.7	15.4	15.1	16.1	15.6	16.7	17.7	16.2	14.5
Rb	ppm	12.1	10.0	10.2	9.34	12.2	10.9	1.89	6.80	5.82	5.31
Sr	ppm	175	212	192	192	225	196	172	168	196	177
Y	ppm	36.0	17.2	27.8	26.3	18.9	28.8	25.0	30.3	25.4	22.2
Zr	ppm	145	75.2	106	99.6	89.8	112	80.1	109	103	93.8
Nb	ppm	10.6	9.13	9.22	8.61	11.0	9.91	2.19	6.13	6.42	5.78
Cs	ppm	0.132	0.101	0.109	0.0976	0.119	0.115	0.0185	0.0785	0.0534	0.0522
Ba	ppm	99.6	73.2	95.4	90.3	90.9	103	18.6	56.9	54.0	47.3
La	ppm	11.6	6.38	8.88	8.22	7.82	9.44	2.98	6.80	5.80	5.27
Ce	ppm	26.9	14.0	19.3	17.8	17.1	20.4	8.59	15.7	15.3	13.6

Pr	ppm	3.54	2.08	2.76	2.59	2.49	2.93	1.55	2.44	2.36	2.13
Nd	ppm	16.3	9.54	12.8	12.1	11.4	13.5	8.32	11.9	11.4	10.3
Sm	ppm	4.45	2.64	3.55	3.34	3.07	3.73	2.78	3.58	3.24	2.94
Eu	ppm	1.45	0.937	1.20	1.15	1.05	1.27	1.05	1.25	1.16	1.05
Gd	ppm	5.67	3.31	4.53	4.29	3.68	4.73	3.83	4.75	4.08	0.647
Tb	ppm	0.937	0.527	0.739	0.697	0.588	0.775	0.650	0.799	0.719	3.71
Dy	ppm	6.19	3.33	4.79	4.55	3.65	4.99	4.31	5.25	4.34	3.91
Ho	ppm	1.35	0.699	1.03	0.977	0.754	1.07	0.923	1.13	0.920	0.824
Er	ppm	3.64	1.79	2.80	2.63	1.98	2.91	2.51	3.10	2.51	2.26
Tm	ppm	0.559	0.263	0.417	0.393	0.289	0.441	0.382	0.473	0.381	0.344
Yb	ppm	3.61	1.66	2.70	2.55	1.82	2.81	2.43	3.00	2.32	2.11
Lu	ppm	0.554	0.246	0.409	0.384	0.274	0.431	0.372	0.458	0.351	0.320
Hf	ppm	3.51	1.96	2.64	2.46	2.24	2.77	2.03	2.75	2.53	2.34
Ta	ppm	0.649	0.601	0.563	0.526	0.724	0.614	0.154	0.396	0.428	0.392
Pb	ppm	1.81	0.732	1.14	1.20	1.02	1.51	0.517	0.885	0.963	0.795
Th	ppm	1.46	0.644	1.05	0.961	0.804	1.12	0.192	0.816	0.533	0.519
U	ppm	0.366	0.166	0.271	0.244	0.210	0.286	0.052	0.201	0.154	0.142

Trace elements were determined by solution ICP-MS at Graduate School of Oceanography, University of Rhode Island.

Table 1.S5: *cont.* Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-17- 01-01	NLD-18- 01-01	NLD-18- 02-01	NLD-19- 01-01	NLD-20- 01-01	NLD-21- 01-01	NLD-22- 01-01	NLD-22- 02-01	NLD-23- 01-01	NLD-24- 01-01
Li	ppm	5.35	8.12	4.75	6.65	5.53	6.29	4.48	4.53	5.34	5.03
Be	ppm	0.651	1.03	0.667	0.916	0.564	0.781	0.647	0.417	0.784	0.718
K ₂ O	wt.%	0.239	0.538	0.255	0.308	0.143	0.241	0.468	0.0956	0.220	0.177
Sc	ppm	42.8	37.2	38.9	42.3	26.1	47.7	29.8	34.3	47.4	43.8
TiO ₂	wt.%	1.32	1.87	1.50	1.93	1.39	1.88	1.26	1.01	1.74	1.60
V	ppm	286	332	276	361	222	384	220	225	328	307
Cr	ppm	274	162	270	184	412	57.7	232	323	232	303
Co	ppm	44.2	37.9	51.2	42.4	57.3	45.4	47.8	45.5	43.3	48.4
Ni	ppm	108	61.8	182	82.6	279	43.5	165	150	57.8	108
Cu	ppm	131	74.8	127	84.8	107	107	116	120	129	146
Zn	ppm	71.1	97.3	78.9	102	92.3	92.6	66.7	62.9	84.1	81.5
Ga	ppm	15.9	17.2	16.9	18.0	17.5	19.0	14.0	14.8	18.5	17.7
Rb	ppm	6.33	16.2	6.70	8.55	3.42	5.81	15.5	2.22	4.30	3.16
Sr	ppm	189	228	212	180	176	183	206	117	211	210
Y	ppm	27.2	37.3	27.7	37.5	17.8	35.8	18.9	20.7	32.9	30.4
Zr	ppm	103	161	111	144	85.6	129	90.1	70.3	123	118
Nb	ppm	5.37	11.2	4.87	8.39	4.79	4.11	8.64	1.43	4.30	3.34
Cs	ppm	0.0618	0.150	0.0589	0.0912	0.0360	0.0534	0.132	0.0210	0.0451	0.0328
Ba	ppm	55.4	130	51.7	77.4	29.1	47.8	101	16.2	42.4	27.0
La	ppm	5.89	10.5	4.65	8.65	5.01	4.92	6.02	2.27	4.97	4.16
Ce	ppm	15.0	27.7	13.3	22.0	13.4	14.9	15.4	7.31	14.6	13.1

Pr	ppm	2.33	3.71	2.25	3.32	2.09	2.55	2.27	1.33	2.44	2.23
Nd	ppm	11.3	17.1	11.1	15.7	9.87	12.9	10.5	6.99	12.3	11.3
Sm	ppm	3.29	4.63	3.36	4.50	2.78	4.07	2.82	2.26	3.83	3.49
Eu	ppm	1.16	1.52	1.22	1.54	0.975	1.48	0.974	0.852	1.41	1.28
Gd	ppm	4.23	5.82	4.36	5.82	3.38	5.46	3.39	3.12	5.00	4.55
Tb	ppm	0.750	1.03	0.769	1.03	0.591	0.979	0.586	0.573	0.893	0.814
Dy	ppm	4.63	6.37	4.75	6.41	3.45	6.16	3.52	3.63	5.55	5.04
Ho	ppm	0.994	1.37	1.02	1.38	0.706	1.34	0.740	0.788	1.17	1.07
Er	ppm	2.76	3.83	2.77	3.83	1.87	3.72	2.04	2.21	3.25	2.96
Tm	ppm	0.423	0.595	0.428	0.598	0.279	0.584	0.311	0.344	0.492	0.451
Yb	ppm	2.62	3.70	2.63	3.69	1.66	3.60	1.92	2.11	3.00	2.78
Lu	ppm	0.398	0.566	0.399	0.562	0.244	0.549	0.293	0.323	0.455	0.421
Hf	ppm	2.53	3.80	2.65	3.45	2.10	3.14	2.16	1.87	3.06	2.87
Ta	ppm	0.341	0.735	0.342	0.543	0.323	0.287	0.597	0.110	0.286	0.238
Pb	ppm	1.08	1.49	0.977	1.54	0.737	0.794	1.19	0.531	0.665	0.453
Th	ppm	0.652	1.20	0.345	0.941	0.428	0.298	0.571	0.211	0.355	0.243
U	ppm	0.181	0.307	0.105	0.248	0.119	0.0880	0.169	0.0474	0.177	0.0803

Table 1.S5: *cont.* Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-24- 02-01	NLD-24- 03-01	NLD-25- 01-01	NLD-27- 01-01	NLD-28- 01-01	NLD-30- 01-01	NLD-31- 01-01	NLD-32- 01-01	NLD-35- 01-01	NLD-37- 01-01
Li	ppm	4.40	5.27	4.79	4.06	7.55	4.60	4.44	7.29	6.76	9.88
Be	ppm	0.520	0.705	0.644	0.280	0.690	0.485	0.616	0.967	0.710	1.31
K ₂ O	wt.%	0.130	0.169	0.263	0.0641	0.270	0.221	0.211	0.459	0.237	0.544
Sc	ppm	40.6	45.7	42.5	28.1	47.8	25.7	36.3	44.3	45.5	34.7
TiO ₂	wt.%	1.23	1.58	1.44	0.713	1.65	1.22	1.26	2.00	1.60	1.66
V	ppm	264	305	273	185	317	211	229	361	283	262
Cr	ppm	256	249	273	320	243	665	260	40.0	234	158
Co	ppm	48.6	46.0	44.3	47.2	43.0	64.7	45.6	43.4	41.8	42.3
Ni	ppm	136	86.6	109	239	59.6	503	142	30.6	59.3	82.2
Cu	ppm	141	153	148	91.2	84.2	75.4	136	104	68.5	104
Zn	ppm	71.1	79.3	80.7	71.9	99.4	95.8	67.4	109	104	101
Ga	ppm	16.7	17.9	16.7	13.7	17.9	16.1	16.3	19.3	18.1	20.0
Rb	ppm	2.59	2.98	6.17	1.70	6.77	5.76	4.80	12.9	5.16	14.4
Sr	ppm	182	213	226	99.9	142	145	223	189	172	157
Y	ppm	25.9	31.2	25.6	16.0	38.5	18.4	21.6	36.9	35.0	45.4
Zr	ppm	84.7	117	106	37.3	117	63.5	94.9	143	121	218
Nb	ppm	2.53	3.40	6.59	1.23	4.37	4.96	4.82	9.86	5.35	10.1
Cs	ppm	0.0314	0.0332	0.0597	0.0232	0.0686	0.0583	0.0469	0.120	0.0549	0.127
Ba	ppm	24.4	31.4	56.9	11.6	45.6	36.3	40.5	101	49.5	76.1
La	ppm	3.20	4.25	5.66	1.59	4.73	3.37	4.43	8.45	5.41	9.82
Ce	ppm	9.66	13.2	15.5	4.81	13.4	8.87	12.3	22.0	15.0	28.6

Pr	ppm	1.67	2.23	2.50	0.86	2.33	1.42	2.04	3.34	2.49	4.12
Nd	ppm	8.50	11.3	12.0	4.54	11.7	7.05	9.95	15.9	12.5	19.2
Sm	ppm	2.71	3.50	3.29	1.55	3.83	2.27	2.90	4.47	4.00	5.47
Eu	ppm	1.03	1.29	1.17	0.610	1.32	0.864	1.07	1.56	1.39	1.59
Gd	ppm	3.68	4.60	3.99	2.24	5.29	0.56	3.55	5.66	5.32	6.80
Tb	ppm	0.665	0.821	0.704	0.419	1.00	3.05	0.631	1.00	0.957	1.22
Dy	ppm	4.24	5.16	4.24	2.73	6.30	3.38	3.83	6.17	6.03	7.68
Ho	ppm	0.905	1.10	0.888	0.597	1.37	0.690	0.793	1.31	1.28	1.65
Er	ppm	2.55	3.05	2.48	1.70	3.85	1.89	2.19	3.65	3.56	4.65
Tm	ppm	0.394	0.466	0.376	0.265	0.608	0.278	0.331	0.560	0.546	0.728
Yb	ppm	2.46	2.88	2.30	1.65	3.68	1.66	2.02	3.43	3.39	4.54
Lu	ppm	0.375	0.435	0.347	0.253	0.572	0.248	0.307	0.519	0.519	0.693
Hf	ppm	2.12	2.81	2.62	1.14	2.93	1.71	2.26	3.52	2.97	5.16
Ta	ppm	0.167	0.229	0.420	0.0845	0.309	0.337	0.309	0.615	0.359	0.675
Pb	ppm	0.384	0.598	0.546	0.162	1.01	0.260	0.368	0.816	0.736	1.11
Th	ppm	0.215	0.269	0.530	0.115	0.373	0.284	0.390	0.777	0.470	1.03
U	ppm	0.0711	0.0935	0.129	0.0326	0.117	0.0918	0.106	0.229	0.142	0.303

Table 1.S5: *cont.* Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-38-01-01	NLD-40-01-01	NLD-40-02-01	NLD-41-01-01	NLD-41-02-01	NLD-41-03-01	NLD-42-01-01	NLD-43-01-01	NLD-43-02-01	NLD-44-01-01
Li	ppm	5.62	5.31	31.8	5.72	19.7	20.4	5.01	6.68	6.85	6.72
Be	ppm	0.476	0.282	2.63	0.564	2.09	2.16	0.215	0.491	0.545	0.772
K ₂ O	wt.%	0.143	0.0887	0.797	0.292	0.816	0.835	0.0339	0.129	0.144	0.526
Sc	ppm	42.4	44.4	20.2	42.0	24.0	23.2	45.8	49.1	47.8	45.2
TiO ₂	wt.%	1.43	1.04	0.891	1.34	1.23	1.19	1.00	1.58	1.56	1.53
V	ppm	336	311	29.2	339	133	113	316	411	396	364
Cr	ppm	260	292	3.69	97.4	19.5	15.9	313	98.2	89.9	58.9
Co	ppm	44.6	47.6	10.7	40.7	18.8	17.3	46.6	46.4	45.8	43.7
Ni	ppm	122	142	3.05	67.7	14.6	12.3	103	63.1	52.3	69.8
Cu	ppm	120	150	32.4	104	49.7	46.1	161	164	163	125
Zn	ppm	81.1	73.8	188	83.2	123	125	71.9	94.3	98.8	88.9
Ga	ppm	16.6	15.2	27.8	16.1	24.6	25.0	14.9	17.6	18.2	17.5
Rb	ppm	3.65	2.65	26.1	9.13	26.9	27.6	0.79	3.32	3.85	17.6
Sr	ppm	93.3	63.8	84.1	162	92.3	93.6	57.3	84.9	82.7	158
Y	ppm	33.4	27.3	180	29.8	123	128	26.7	38.4	43.5	33.6
Zr	ppm	86.2	46.6	644	86.3	441	457	38.5	89.7	106	110
Nb	ppm	3.36	2.14	24.5	5.62	20.6	21.4	1.05	3.33	4.46	24.5
Cs	ppm	0.0391	0.0265	0.266	0.0954	0.269	0.275	0.0083	0.0354	0.0431	0.153
Ba	ppm	28.0	20.8	166	59.8	179	185	5.72	26.0	33.3	165
La	ppm	3.24	1.93	23.2	4.86	17.7	18.2	1.11	3.21	3.96	14.1
Ce	ppm	9.45	5.49	65.7	12.6	50.0	51.6	3.77	9.57	11.5	31.0

Pr	ppm	1.72	1.03	10.6	2.08	7.86	8.13	0.821	1.78	2.07	3.79
Nd	ppm	9.28	5.78	53.1	10.4	38.8	40.1	5.08	9.76	11.1	16.0
Sm	ppm	3.28	2.29	16.7	3.24	11.9	12.3	2.21	3.55	4.01	4.05
Eu	ppm	1.17	0.867	4.40	1.12	3.01	3.13	0.854	1.28	1.38	1.33
Gd	ppm	4.67	3.50	23.1	4.31	16.0	16.6	3.45	5.23	5.86	5.06
Tb	ppm	0.864	0.671	4.30	0.781	2.97	3.08	0.663	0.975	1.10	0.897
Dy	ppm	5.62	4.42	28.1	4.96	19.1	19.8	4.32	6.36	7.11	5.56
Ho	ppm	1.22	0.982	6.21	1.08	4.23	4.39	0.954	1.41	1.58	1.22
Er	ppm	3.46	2.80	18.1	3.06	12.3	12.7	2.71	4.01	4.50	3.47
Tm	ppm	0.539	0.439	2.90	0.476	1.98	2.04	0.423	0.629	0.708	0.540
Yb	ppm	3.36	2.74	18.3	2.94	12.5	13.0	2.61	3.89	4.42	3.37
Lu	ppm	0.515	0.424	2.84	0.455	1.95	2.01	0.404	0.606	0.681	0.522
Hf	ppm	2.39	1.56	17.2	2.34	11.7	12.1	1.45	2.58	3.01	2.79
Ta	ppm	0.223	0.139	1.46	0.340	1.26	1.31	0.0723	0.261	0.283	1.39
Pb	ppm	0.264	0.129	2.80	0.526	1.95	2.00	0.0228	0.285	0.339	1.01
Th	ppm	0.286	0.186	2.65	0.511	2.26	2.33	0.0860	0.282	0.403	2.02
U	ppm	0.0870	0.0529	0.739	0.146	0.600	0.624	0.0283	0.0857	0.124	0.507

Table 1.S5: *cont.* Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-44- 02-01	NLD-45- 01-01	NLD-46- 01-01	NLD-47- 01-01	NLD-48- 01-01	NLD-49- 01-01	NLD-50- 01-01	NLD-51- 01-01	NLD-55- 01-01	NLD-56- 01-01
Li	ppm	6.60	8.65	6.76	6.70	5.18	6.16	4.67	4.40	5.90	5.06
Be	ppm	0.775	0.554	0.479	0.423	0.249	0.355	0.419	0.401	0.204	0.202
K ₂ O	wt.%	0.512	0.133	0.112	0.138	0.0462	0.0764	0.0880	0.102	0.0324	0.0320
Sc	ppm	45.2	45.3	46.6	47.0	44.8	49.0	43.0	38.8	33.2	46.3
TiO ₂	wt.%	1.50	1.91	1.64	1.43	1.08	1.36	1.07	0.979	1.20	0.812
V	ppm	359	477	423	380	310	375	271	243	279	267
Cr	ppm	75.7	56.0	79.6	55.9	304	171	350	360	594	446
Co	ppm	43.2	48.4	48.0	49.1	46.6	47.9	45.8	45.6	56.7	46.0
Ni	ppm	70.6	47.5	53.7	66.5	113	70.0	135	166	431	98.2
Cu	ppm	127	168	190	183	157	185	152	141	152	145
Zn	ppm	87.1	146	105	105	74.6	91.7	66.7	61.6	77.0	68.8
Ga	ppm	17.3	19.3	18.1	17.6	15.6	17.2	15.1	14.6	15.4	14.9
Rb	ppm	16.9	3.57	3.00	4.03	1.03	1.88	2.28	2.75	0.772	0.575
Sr	ppm	155	75.2	76.2	86.7	65.9	73.4	131	139	55.9	67.0
Y	ppm	32.8	49.8	43.8	35.2	28.1	34.1	25.4	21.2	31.4	23.4
Zr	ppm	107	109	97.4	78.4	49.7	68.2	74.3	68.2	47.1	33.4
Nb	ppm	23.6	5.15	5.01	4.79	1.25	2.43	3.38	3.88	0.579	0.743
Cs	ppm	0.148	0.0352	0.0294	0.0420	0.0119	0.0210	0.0202	0.0237	0.00894	0.00719
Ba	ppm	159	31.9	28.9	38.8	8.50	16.8	23.7	28.3	5.88	5.02
La	ppm	13.6	4.23	3.98	3.78	1.34	2.29	3.10	3.37	0.936	1.08
Ce	ppm	30.1	12.3	11.2	10.1	4.54	7.02	8.73	8.97	3.61	3.62

Pr	ppm	3.69	2.17	1.97	1.73	0.957	1.34	1.49	1.46	0.903	0.725
Nd	ppm	15.5	12.0	10.6	9.18	5.80	7.61	7.67	7.30	6.17	4.21
Sm	ppm	3.96	4.42	3.88	3.26	2.38	2.91	2.57	2.34	2.81	1.79
Eu	ppm	1.30	1.53	1.34	1.17	0.903	1.09	0.944	0.868	1.08	0.727
Gd	ppm	4.94	6.48	5.74	4.74	3.63	4.45	3.53	3.17	0.81	2.94
Tb	ppm	0.888	1.22	1.07	0.882	0.683	0.837	0.656	0.580	4.32	0.572
Dy	ppm	5.50	8.08	7.12	5.80	4.53	5.59	4.23	3.71	5.25	3.86
Ho	ppm	1.19	1.78	1.59	1.28	1.00	1.24	0.922	0.806	1.14	0.870
Er	ppm	3.40	5.16	4.57	3.68	2.84	3.55	2.64	2.30	3.19	2.49
Tm	ppm	0.528	0.803	0.713	0.570	0.442	0.551	0.404	0.353	0.491	0.390
Yb	ppm	3.31	5.11	4.50	3.58	2.76	3.48	2.54	2.21	3.04	2.44
Lu	ppm	0.511	0.788	0.699	0.554	0.423	0.538	0.391	0.340	0.467	0.375
Hf	ppm	2.72	3.23	2.86	2.32	1.63	2.08	1.89	1.71	1.85	1.17
Ta	ppm	1.35	0.334	0.321	0.302	0.09	0.161	0.219	0.245	0.0461	0.0552
Pb	ppm	0.959	0.548	0.416	0.438	0.235	0.327	0.385	0.400	0.211	0.230
Th	ppm	1.96	0.439	0.434	0.413	0.104	0.205	0.292	0.328	0.0534	0.0663
U	ppm	0.495	0.125	0.127	0.111	0.0331	0.0611	0.0756	0.0854	0.0161	0.0200

Table 1.S5: *cont.* Trace element concentrations for basaltic glass samples from the Northern Lau Basin

Sample		NLD-57- 01-01	NLD-58- 01-01	NLD-59- 01-01	NLD-60- 01-01	NLD-61- 01-01	NLD-62- 01-01	NLD-63- 01-01	NLD-64- 01-01	NLD-65- 01-01	NLD-66- 01-01
Li	ppm	6.60	4.88	5.29	6.71	4.59	4.23	4.00	5.22	5.36	6.22
Be	ppm	0.306	0.273	0.375	0.452	0.159	0.172	0.166	0.238	0.224	0.316
K ₂ O	wt.%	0.0381	0.0482	0.0631	0.125	0.0252	0.0298	0.0173	0.0370	0.0392	0.0668
Sc	ppm	47.0	45.1	49.9	40.1	48.5	37.9	30.9	51.6	49.6	44.6
TiO ₂	wt.%	1.09	0.960	1.18	1.34	0.683	0.720	0.693	0.834	0.838	1.09
V	ppm	329	277	295	321	273	213	191	284	294	315
Cr	ppm	61.6	255	319	183	357	388	481	249	196	330
Co	ppm	49.8	46.0	45.0	43.1	46.8	46.2	54.4	47.7	47.6	46.2
Ni	ppm	61.9	113	84.9	64.0	103	156	359	96.4	86.5	112.5
Cu	ppm	136	111	123	98.2	153	123	117	151	159	114
Zn	ppm	97.7	71.6	75.0	95.4	66.8	60.7	60.0	72.3	74.1	84.1
Ga	ppm	17.0	15.4	16.1	17.5	14.4	14.0	13.1	15.1	15.2	16.1
Rb	ppm	0.548	0.801	1.22	2.50	0.389	0.421	0.219	0.655	0.715	1.21
Sr	ppm	68.2	78.3	100	98.5	58.3	68.5	68.8	69.7	66.4	81.8
Y	ppm	31.5	26.1	31.6	36.5	19.4	18.8	17.2	23.9	24.1	30.8
Zr	ppm	56.5	45.7	66.8	86.7	25.7	29.5	27.7	38.7	39.3	61.2
Nb	ppm	0.755	1.03	1.40	1.68	0.526	0.579	0.385	0.765	0.806	1.38
Cs	ppm	0.00696	0.0104	0.0138	0.0332	0.00419	0.00525	0.00217	0.00703	0.00764	0.0135
Ba	ppm	4.78	7.37	10.9	13.9	3.80	3.77	2.45	5.66	6.20	10.3
La	ppm	1.44	1.42	1.88	2.43	0.791	0.874	0.687	1.19	1.18	1.83
Ce	ppm	5.13	4.75	6.89	8.08	2.71	3.05	2.60	4.02	4.05	5.91

Pr	ppm	1.03	0.930	1.23	1.54	0.550	0.612	0.552	0.786	0.776	1.12
Nd	ppm	5.96	5.32	6.97	8.49	3.27	3.68	3.41	4.45	4.42	6.20
Sm	ppm	2.44	2.12	2.68	3.21	1.41	1.56	1.48	1.80	1.80	2.40
Eu	ppm	0.933	0.867	1.08	1.24	0.624	0.679	0.648	0.762	0.761	0.950
Gd	ppm	3.84	3.32	4.07	4.79	2.38	2.52	0.449	2.98	2.98	3.78
Tb	ppm	0.744	0.639	0.774	0.903	0.468	0.482	2.36	0.576	0.582	0.727
Dy	ppm	5.02	4.22	5.09	5.94	3.21	3.20	2.97	3.93	3.95	4.85
Ho	ppm	1.13	0.942	1.12	1.31	0.724	0.703	0.650	0.882	0.887	1.09
Er	ppm	3.27	2.69	3.18	3.71	2.08	1.99	1.83	2.55	2.57	3.12
Tm	ppm	0.514	0.420	0.497	0.581	0.330	0.309	0.286	0.406	0.409	0.493
Yb	ppm	3.24	2.64	3.10	3.65	2.09	1.93	1.77	2.56	2.57	3.10
Lu	ppm	0.502	0.408	0.482	0.562	0.325	0.295	0.271	0.399	0.400	0.483
Hf	ppm	1.68	1.47	1.86	2.47	0.907	1.04	0.989	1.23	1.25	1.71
Ta	ppm	0.0581	0.0766	0.103	0.127	0.0403	0.0433	0.0312	0.0592	0.0617	0.0999
Pb	ppm	0.363	0.264	0.402	0.572	0.184	0.171	0.137	0.248	0.292	0.362
Th	ppm	0.0727	0.0804	0.102	0.209	0.0418	0.0462	0.0285	0.0589	0.0615	0.109
U	ppm	0.0217	0.0259	0.0308	0.0622	0.0137	0.0148	0.0096	0.0175	0.0183	0.0332

Table 1.S6: Slopes for correction compositions back to Fo90 accounting for
plagioclase and clinopyroxene crystallization

	Plagioclase	Clinopyroxene
SiO ₂	-0.595	0.415
TiO ₂	-0.316	-0.567
Al ₂ O ₃	1.568	0.614
FeO*	-0.746	-1.200
MnO	-0.027	-0.035
MgO	-0.205	1.143
CaO	-0.135	-0.264
Na ₂ O	-0.013	-0.028
K ₂ O	-0.018	-0.039
P ₂ O ₅	-0.125	-0.247
H ₂ O	-0.595	0.415

Table 1.S7: Corrected Fo90 compositions for NW Lau Basin basalts

Sample		NLD-06-01-01	NLD-07-01-01	NLD-08-01-01	NLD-09-02-01	NLD-10-01-01	NLD-11-01-01
SiO ₂	wt. %	48.12	47.00	48.31	48.19	46.90	48.27
TiO ₂	wt. %	1.45	1.37	1.39	1.33	1.43	1.38
Al ₂ O ₃	wt. %	16.01	15.62	15.98	16.17	16.08	16.17
Fe ₂ O ₃	wt. %	1.52	1.63	1.49	1.49	1.59	1.48
FeO	wt. %	7.35	8.27	7.14	7.08	7.91	7.06
MnO	wt. %	0.19	0.15	0.17	0.15	0.17	0.15
CaO	wt. %	11.08	12.48	10.78	10.69	11.92	10.66
Na ₂ O	wt. %	11.15	10.38	11.29	11.67	10.79	11.50
K ₂ O	wt. %	2.48	2.54	2.61	2.50	2.55	2.54
H ₂ O	wt. %	0.48	0.37	0.67	0.56	0.42	0.61
Sample		NLD-13-01-01	NLD-14-01-01	NLD-15-01-01	NLD-16-01-01	NLD-17-01-01	NLD-18-01-01
SiO ₂	wt. %	47.03	47.73	47.57	47.50	48.17	48.22
TiO ₂	wt. %	1.42	1.44	1.60	1.60	1.35	1.48
Al ₂ O ₃	wt. %	16.42	16.10	15.86	15.82	15.52	16.60
Fe ₂ O ₃	wt. %	1.56	1.55	1.57	1.57	1.52	1.46
FeO	wt. %	7.82	7.62	7.86	7.88	7.37	6.87
MnO	wt. %	0.15	0.17	0.16	0.17	0.18	0.16
CaO	wt. %	11.79	11.49	11.86	11.88	11.13	10.36
Na ₂ O	wt. %	10.92	10.87	10.47	10.51	11.67	11.12
K ₂ O	wt. %	2.59	2.58	2.54	2.57	2.42	2.66
H ₂ O	wt. %	0.24	0.37	0.35	0.34	0.54	0.86

Table 1.S7: *cont.* Corrected Fo90 compositions for NW Lau Basin basalts

Sample		NLD-18-02-01	NLD-19-01-01	NLD-20-01-01	NLD-21-01-01	NLD-22-01-01	NLD-22-02-01
SiO ₂	wt. %	46.72	47.82	47.43	46.74	46.54	48.19
TiO ₂	wt. %	1.48	1.64	1.47	1.47	1.43	1.20
Al ₂ O ₃	wt. %	16.81	15.68	15.20	14.95	17.32	17.17
Fe ₂ O ₃	wt. %	1.53	1.56	1.64	1.64	1.49	1.43
FeO	wt. %	7.46	7.64	8.52	8.40	7.21	6.77
MnO	wt. %	0.16	0.16	0.16	0.17	0.16	0.16
CaO	wt. %	11.26	11.52	12.85	12.67	10.89	10.21
Na ₂ O	wt. %	11.59	10.78	9.83	11.11	11.72	12.32
K ₂ O	wt. %	2.71	2.68	2.45	2.61	2.36	2.30
H ₂ O	wt. %	0.19	0.40	0.37	0.21	0.61	0.20
Sample		NLD-23-01-01	NLD-24-01-01	NLD-24-02-01	NLD-24-03-01	NLD-25-01-01	NLD-27-01-01
SiO ₂	wt. %	47.10	46.66	46.74	46.64	47.40	47.66
TiO ₂	wt. %	1.45	1.46	1.35	1.46	1.50	0.81
Al ₂ O ₃	wt. %	15.50	15.97	15.67	15.54	16.27	19.49
Fe ₂ O ₃	wt. %	1.57	1.60	1.62	1.60	1.53	1.34
FeO	wt. %	7.84	8.08	8.31	8.07	7.49	6.26
MnO	wt. %	0.18	0.16	0.18	0.17	0.16	0.16
CaO	wt. %	11.83	12.19	12.52	12.16	11.30	9.50
Na ₂ O	wt. %	11.52	11.09	10.62	11.24	11.07	12.29
K ₂ O	wt. %	2.71	2.50	2.61	2.81	2.56	2.20
H ₂ O	wt. %	0.24	0.21	0.31	0.26	0.57	0.26

Table 1.S7: *cont.* Corrected Fo90 compositions for NW Lau Basin basalts

Sample		NLD-28-01-01	NLD-30-01-01	NLD-31-01-01	NLD-32-01-01	NLD-35-01-01	NLD-37-01-01
SiO ₂	wt. %	48.09	48.12	47.43	47.22	48.50	48.81
TiO ₂	wt. %	1.21	1.27	1.31	1.36	1.30	1.21
Al ₂ O ₃	wt. %	15.79	15.19	17.34	15.83	16.02	16.71
Fe ₂ O ₃	wt. %	1.53	1.63	1.49	1.56	1.49	1.47
FeO	wt. %	7.52	8.37	7.13	7.70	7.20	7.01
MnO	wt. %	0.16	0.13	0.15	0.14	0.17	0.17
CaO	wt. %	11.33	12.63	10.78	11.61	10.88	10.56
Na ₂ O	wt. %	11.76	9.64	11.26	11.51	11.50	10.80
K ₂ O	wt. %	2.43	2.65	2.57	2.55	2.73	2.63
H ₂ O	wt. %	0.14	0.25	0.44	0.40	0.16	0.43
Sample		NLD-38-01-01	NLD-40-01-01	NLD-41-01-01	NLD-42-01-01	NLD-43-01-01	NLD-43-02-01
SiO ₂	wt. %	47.34	48.04	48.34	48.35	47.72	47.64
TiO ₂	wt. %	1.46	1.06	1.21	0.92	1.20	1.09
Al ₂ O ₃	wt. %	14.55	15.14	15.35	16.04	14.49	14.56
Fe ₂ O ₃	wt. %	1.66	1.59	1.54	1.50	1.63	1.64
FeO	wt. %	8.54	8.02	7.52	7.34	8.38	8.41
MnO	wt. %	0.16	0.17	0.17	0.17	0.16	0.17
CaO	wt. %	12.88	12.10	11.35	11.07	12.64	12.67
Na ₂ O	wt. %	10.49	11.47	11.34	12.56	11.42	11.50
K ₂ O	wt. %	2.43	2.18	2.12	2.06	2.23	2.31
H ₂ O	wt. %	0.40	0.19	0.92	0.02	0.14	0.02

Table 1.S7: *cont.* Corrected Fo90 compositions for NW Lau Basin basalts

Sample		NLD-44-01-01	NLD-44-02-01	NLD-45-01-01	NLD-46-01-01	NLD-47-01-01	NLD-48-01-01
SiO ₂	wt. %	48.36	48.28	46.81	47.58	47.42	48.11
TiO ₂	wt. %	1.18	1.14	1.23	1.06	1.02	1.04
Al ₂ O ₃	wt. %	15.80	15.98	13.55	14.48	14.55	15.64
Fe ₂ O ₃	wt. %	1.51	1.50	1.76	1.65	1.65	1.53
FeO	wt. %	7.28	7.25	9.51	8.51	8.46	7.54
MnO	wt. %	0.16	0.17	0.19	0.18	0.20	0.19
CaO	wt. %	10.99	10.95	14.35	12.82	12.74	11.38
Na ₂ O	wt. %	11.86	11.97	10.65	11.70	11.81	12.28
K ₂ O	wt. %	2.22	2.16	1.99	2.11	2.12	2.19
H ₂ O	wt. %	0.44	0.40	0.01	0.00	0.04	0.10
Sample		NLD-49-01-01	NLD-50-01-01	NLD-51-01-01	NLD-55-01-01	NLD-56-01-01	NLD-57-01-01
SiO ₂	wt. %	47.76	47.94	47.96	47.21	48.61	48.47
TiO ₂	wt. %	0.99	1.17	1.18	1.42	0.77	0.72
Al ₂ O ₃	wt. %	14.37	15.85	16.07	15.76	15.67	14.89
Fe ₂ O ₃	wt. %	1.64	1.52	1.50	1.60	1.49	1.59
FeO	wt. %	8.49	7.41	7.26	8.03	7.21	8.02
MnO	wt. %	0.19	0.16	0.15	0.17	0.18	0.17
CaO	wt. %	12.81	11.17	10.97	12.10	10.88	12.09
Na ₂ O	wt. %	11.55	12.14	12.27	10.67	12.95	11.96
K ₂ O	wt. %	2.18	2.39	2.33	2.90	2.23	2.16
H ₂ O	wt. %	0.04	0.20	0.24	0.12	0.02	0.00

Table 1.S7: *cont.* Corrected Fo90 compositions for NW Lau Basin basalts

Sample		NLD-58-01-01	NLD-59-01-01	NLD-60-01-01	NLD-61-01-01	NLD-62-01-01	NLD-63-01-01
SiO ₂	wt. %	48.85	48.44	48.15	49.06	48.75	47.86
TiO ₂	wt. %	0.84	1.03	0.91	0.68	0.90	0.84
Al ₂ O ₃	wt. %	15.49	15.27	16.78	15.15	15.58	18.51
Fe ₂ O ₃	wt. %	1.51	1.54	1.49	1.50	1.48	1.35
FeO	wt. %	7.38	7.58	7.20	7.37	7.17	6.54
MnO	wt. %	0.17	0.18	0.14	0.17	0.17	0.14
CaO	wt. %	11.15	11.44	10.84	11.11	10.81	9.95
Na ₂ O	wt. %	12.30	11.91	11.81	12.88	12.83	12.49
K ₂ O	wt. %	2.26	2.46	2.43	2.00	2.24	2.25
H ₂ O	wt. %	0.06	0.16	0.26	0.06	0.06	0.06
Sample		NLD-64-01-01	NLD-65-01-01	NLD-66-01-01			
SiO ₂	wt. %	49.00	49.06	48.62			
TiO ₂	wt. %	0.73	0.66	0.96			
Al ₂ O ₃	wt. %	15.43	15.33	15.20			
Fe ₂ O ₃	wt. %	1.52	1.52	1.57			
FeO	wt. %	7.47	7.43	7.87			
MnO	wt. %	0.19	0.17	0.17			
CaO	wt. %	11.27	11.20	11.88			
Na ₂ O	wt. %	12.19	12.56	11.50			
K ₂ O	wt. %	2.14	2.05	2.10			
H ₂ O	wt. %	0.06	0.03	0.12			

Table 1.S8: PetDB references for East Pacific Rise glasses

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Figure 1.S1: Plot of solution inductively coupled plasma mass spectrometry (ICP-MS) vs. laser ablation ICP-MS (LA-ICP-MS) trace element concentrations for NW Lau basin basalts. **A-E)** Trace element concentrations for Rb, Nb, Ba, La, and U exhibit 1:1 agreement $\pm <5\%$ between LA-ICP-MS and solution ICP-MS. **F)** The effects of microphenocrysts during bulk dissolution for solution ICP-MS analysis are shown with in trace elements such as Ni.

Figure 1.S2: Plot of electron microprobe (EMP) vs. LA-ICP-MS data for minor elements K₂O, TiO₂, MnO, P₂O₅ for NW Lau basin basalts.

Figure 1.S3: Chondrite-normalized rare earth element (REE) diagram for multiple glass chips in dredge NLD-44, showing glass from pillow basalts (circles) and glass chips from the pipe dredge (diamonds). Dredge NLD-44 is heterogeneous with two geochemical groups: light REE-enriched and light REE-depleted.

Figure 1.S4: Plot of $\text{MgO}_{\text{mineral-in}}$ vs. average $\text{H}_2\text{O}_{8.0}$ values, showing point of plagioclase (diamonds) and clinopyroxene (squares) saturation for modeled liquid lines of descent of varying H_2O contents (0.21 – 1.25 wt.%), determined using Petrolog3 (Danyushevsky and Pelchov, 2011). The equation determined from the plagioclase trend is $\text{MgO}_{\text{plag-in}} = -0.6(\text{H}_2\text{O}_{8.0}) + 9.3789$ and the equation for clinopyroxene crystallization is $\text{MgO}_{\text{cpx-in}} = -0.2654(\text{H}_2\text{O}_{8.0}) + 7.8617$.

Figure 1.S5: Plot of radiogenic isotopic plots for NW Lau Basin samples. **A)** $^{207}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$, showing samples from RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). The shaded samples are from this study, and the filled crosses are from the North Fiji Basin open hexagons are from Niuafo'ou [Pearce et al., 2007]. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. Shaded field for Manus Basin [Shaw et al., 2004; Shaw et al., 2012; Sinton et al., 2003] is shown for reference. The field for MORB, encompassing East Pacific Rise MORB glasses [Table 1.S8; compiled from PetDB; <http://www.petdb.org>], is shown by the solid gray shaded region for reference. “Indian” and “Pacific” type mantle designations from [Pearce et al., 2007]. The solid black line is the Northern Hemisphere Reference Line [Hart, 1984]. **B)** Plot of $^{143}\text{Nd}/^{144}\text{Nd}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. **C)** Plot of $^{143}\text{Nd}/^{144}\text{Nd}$ vs. $^{176}\text{Hf}/^{177}\text{Hf}$. The field for the Vai trend of Samoan shield-stage volcanic [Salters et al., 2011] is shown by the solid shaded region for reference. **D)** Plot of $^3\text{He}/^4\text{He}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. **E)** Plot of $^3\text{He}/^4\text{He}$ vs. $^{143}\text{Nd}/^{144}\text{Nd}$. The field for the Vai trend of Samoan shield-stage volcanics [Workman et al., 2004; Workman et al., 2006; Jackson et al., 2007b, Jackson et al., 2010] is shown by the solid shaded region for reference. **F)** Plot of $^{21}\text{Ne}/^{22}\text{Ne}$ vs. $^4\text{He}/^3\text{He}$. The solid shaded RR and NWLSC samples are from Lupton et al., 2012. The open RB, CLSC, and ELSC samples are from Hahm et al., 2012. The solid triangles are Samoan data from Jackson et al., 2009. The mixing arrays and end-member sources are from Lupton et al., 2012.

Figure 1.S6: Plot of trace element source compositions A) Plot of C_{La}^0 vs. C_{Th}^0 , showing samples from RR (circles), NWLSC (diamonds), PR/LETZ (triangles), and CLSC (squares). The solid square is DMM [Workman et al., 2005] and the solid diamond is Ta'u source [Jackson et al., 2007a]. The solid circle is a theoretical source determined from the highly enriched RR samples and the solid black line is a mixing line between DMM and Ta'u. B) Plot of C_{Ba}^0 vs. C_{Nb}^0 .

MANUSCRIPT II

**THE INFLUENCE OF VOLATILES ON CRYSTALLIZATION, MANTLE
MELTING, AND TRACE ELEMENT SYSTEMATICS OF BACK-ARC BASIN
MAGMAS**

by

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Abstract

Back-arc spreading ridges are distinguished from normal mid-ocean ridges by a central geochemical component, water. The addition of water from the subducted plate to back-arc basin magma sources strongly influences mantle melting and magmatic crystallization processes. Here, we present new major element analyses of back-arc basin basalt (BABB) glasses, coupled with previously published major and trace element and volatile data from the Mariana Trough, East Scotia Ridge, Manus, Lau, and North Fiji back-arc basins. These data show that glasses record magmatic liquid lines of descent (LLD) reflecting fractional crystallization of olivine, plagioclase and clinopyroxene, in predictable sequence as a function of magmatic H₂O concentration. Using the tighter constraints on melt composition in equilibrium with the mantle, provided by the LLDs, we apply an inverse melting model to produce more accurate constraints on source composition and extent of melting. Prior forward melting models lack one of two important components, either a realistic treatment of hydrous melting or realistic adiabatic melt paths. Using the most current available constraints, we develop a hydrous, adiabatic melting model that may be applied to mantle of variable source H₂O concentrations, which accounts for melting generated both by solidus depression, as a function of H₂O content, and by adiabatic decompression. The inverse model of melt composition is well constrained by the melt curves produced by the hydrous, adiabatic melting model, which differs from prior models with a shallower and more linear relationship between mantle H₂O content and extent of melting.

1. Introduction

Back-arc basins (BAB) are similar to mid-ocean ridges in many ways, including decompression melting beneath the spreading center. At mid-ocean ridges (MOR), magmatic and mantle water contents are relatively low, and recent studies have developed a reasonable understanding of the behavior of water in these settings (Dixon et al., 1995; Dixon and Stolper, 1995; Dixon et al., 2002; Asimow and Langmuir, 2003). At back-arc basin spreading centers, however, H₂O plays a more complex role because it can be added to the mantle source by the subducting slab, which changes the melting behavior and the mantle source composition (Stolper and Newman, 1994; Taylor and Martinez, 2003). Water from the subducting plate influences magma formation and evolution in many ways, including depression of the solidus temperature (Kushiro et al., 1968; Gaetani and Grove, 1998) and the suppression of plagioclase crystallization (Sisson and Grove, 1993a; Sisson and Grove, 1993b; Danyushevsky, 2001). Both of these processes result in basalts of fundamentally different bulk composition than those from relatively anhydrous tectonic settings.

The role of volatiles within back-arc basin settings affects both the melting process and conditions under which melting takes place, allowing greater amounts of hydrous melt at greater depths and lower temperatures within the mantle. Studies investigating the role of volatiles have been limited by poor data coverage and the lack of a realistic hydrous melting model to constrain the melting process. While the Mariana Trough and East Scotia Ridge have been well studied (Stolper and Newman, 1994; Fretzdorff et al., 2002), there are three back-arc basins (Lau, Manus, N. Fiji) in the Western Pacific that are less well investigated for magmatic volatile content.

Although these three basins have been well-sampled, the central role of volatiles has never been comprehensively addressed in these regions (e.g. Hawkins, 1976; Johnson et al., 1987; Perfit et al., 1987; Eissen et al., 1991; Eissen et al., 1994; Nohara et al., 1994; Sinton et al., 2003).

Although models of adiabatic decompression melting of a relatively anhydrous mantle source have been developed for mid-ocean ridge settings (Langmuir et al., 1992; Asimow & Langmuir, 2003), these models do not account for the more hydrous mantle of back-arc basin settings. A parameterization of hydrous, adiabatic melting was developed by Katz et al. (2003), but the treatment of melt fraction (F) vs. temperature at low melt fraction does not fully capture the variation observed in data. Back-arc basin melting models were empirically investigated by Kelley et al. (2006) and showed a correlation between $dF/dC_{\text{H}_2\text{O}}^0$ (i.e., the change in melt fraction with respect to the change in mantle source H_2O concentration) and mantle potential temperature (T_p). The problem with the model in Kelley et al. (2006) is that F vs. H_2O was assumed to be a linear relationship. Back-arc basin melting models were also investigated by Langmuir et al. (2006), who, using the melting parameterization of Katz et al. (2003), calculated an equation for the concentration of H_2O in the mantle source ($C_{\text{H}_2\text{O}}^0$). Addressing the problem of F vs. T at low melt fractions (Katz et al., 2003), Langmuir et al. (2006) improved the fit of the melting model to the data at low melt fractions for isothermal/isobaric models at 10 kbar. Most recently, the hydrous back-arc melting model developed by Kelley et al. (2010) expanded the parameterization of the Langmuir et al. (2006) model to apply at multiple pressures.

Yet, these most recent isothermal/isobaric melting models cannot currently account for adiabatic ascent through the mantle.

Volatiles and incompatible trace elements (e.g., H₂O, Ti, Nb) provide constraints on mantle melting as H₂O has an effect on where and how much melt can be made in the mantle, which is reflected in the trace element signature of the basalts. Observations based on geochemical data suggest two possibilities: mixing of end-member melts or a continuous melting regime, but most models of mantle melting are restricted to isothermal/isobaric conditions and offer unrealistic tests of these competing hypotheses of back-arc magma generation. The model invoking mixing of end-member melts consists of a dry, MORB-like melt and a wet, arc-like melt that are generated in physically separate domains of the back-arc source, which are mixed beneath the spreading center (Langmuir et al., 2006), while the continuous melting regime requires a continuum from wet to dry conditions throughout the back-arc mantle sources (Kelley et al., 2006).

One approach for testing these competing hypotheses of back-arc magma generation is a forward melting model (e.g., Katz et al., 2003; Langmuir et al., 2006; Kelley et al., 2010), as described above, while another approach is an inverse melting model (e.g., Stolper and Newman, 1994; Kelley et al., 2006). An inverse melting model uses the melt composition to constrain the conditions of melting. Stolper and Newman (1994) looked at Mariana Trough basaltic glasses and used a multi-element (H₂O, TiO₂, K₂O, Na₂O and P₂O₅) inversion to constrain the melt fraction, source composition, and the composition of the H₂O-rich component. More recent work used TiO₂ as a single element proxy for melt fraction, providing constraints on the

maximum F and determining one single C_{Ti}^0 value for each back-arc basin or back-arc basin spreading segment (Kelley et al., 2006).

Using the model- and data-based LLDs to project compositions back to equilibrium with the mantle, we provide more accurate constraints on source composition and extent of melting in each back-arc basin. Well constrained values for titanium source concentrations (C_{Ti}^0) are important because C_{Ti}^0 is often used to estimate the melt fraction (F) for lavas (Kelley et al., 2006). Revisiting previous inverse melting models with more data, we will attempt to determine the shape of the melting function, which will help discern between competing models for trends in H_2O vs. F in BABBs. The well constrained estimates on melt fraction from the newly calculated C_{Ti}^0 values will be compared with a newly developed, hydrous, adiabatic melting model. We will take the advances made since the Katz et al. (2003) model for isobaric/isothermal melting, and incorporate these with an adiabatic melting model (Langmuir et al., 1992) to provide a new forward model of hydrous, adiabatic melting beneath back arcs. We will then test this new, polybaric hydrous back-arc basin melting model against the inversion of natural melt compositions to resolve the competing hypotheses of mixing vs. melting processes of back-arc basin basalt generation.

2. Methods and Data Treatment

2.1 Tectonic Setting

2.1.1 Mariana Trough

The Mariana Trough (Figure 2.1a), a crescent-shaped back-arc basin opening behind the Mariana Arc, formed from the subduction of the Pacific Plate beneath the Philippine Sea plate (Fryer, 1995). Deep Sea Drilling Project (DSDP) Leg 60 determined that spreading, at a rate of 2.15 cm/yr, in the back-arc began about 6.5 Ma (Hussong and Uyeda, 1981; Fryer, 1995). The Mariana Trough can be divided into three sections, Northern, Central, and Southern, based on spreading characteristics. The Northern Mariana Trough (NMT) is a region of rifting shown by block-faulted terrain and localized volcanism, where the areas of volcanism are located close to the arc (Fryer, 1995). The Central Mariana Trough (CMT) is the mature spreading center with volcanism restricted to the main spreading axis (Hussong and Fryer, 1983; Fryer, 1995). The Southern Mariana Trough (SMT) is a shallow region where the end of the back-arc spreading ridge intersects with the volcanic arc, forming a complex region known as the Southeast Mariana Forearc Rift (Fryer, 1995; Pearce et al., 2005).

2.1.2 East Scotia Ridge

The South American Plate is subducting beneath the Sandwich Plate at a rate of 70-85 km/Myr (Pelayo and Wiens, 1989), forming the South Sandwich Islands and Trench. Located to the west of the South Sandwich Islands, the East Scotia Ridge Back-arc Basin (Figure 2.1b) consists of nine spreading segments (E1-E9) with spreading rates of 60-70 km/Myr (Livermore et al., 1995; Fretzdorff et al., 2002). Spreading segment E1 is a trough that intersects the South Sandwich trench, spreading segments E2 and E9 are axial volcanic ridges, and segments E3-E8 are faulted median valleys similar to the Mid-Atlantic Ridge (Livermore et al., 1997; Bruguier and Livermore, 2001). Spreading along the East Scotia Ridge began ca. 11 Ma, initiating

in the north and moving southward over time, with an average basin-wide spreading rate of 65 mm/yr over the last 1.7 Ma (Barker, 1995).

2.1.3 Manus Basin

Located behind the New Britain arc in the Bismarck Sea is the complex, rapidly opening Manus Back-arc Basin (Figure 2.1c). About 10 Ma, the subduction direction changed as a result of a collision of the Ontong Java Plateau with New Ireland and the North Solomon Arc (Cooper and Taylor, 1987; Beier et al., 2010). The Solomon Sea Plate, a relatively young plate, subducts northwards beneath the New Britain Arc at a rate of 15.4 cm/yr (Lee and Ruellan, 2006; Joshima and Honza, 1987). The Manus Basin consists of one primary active spreading segment, Manus Spreading Center (MSC), but a magmatically active Extensional Transform Zone (ETZ) to the west of the MSC also produces young lavas. The Southern Rift and East Manus Rift are active rift zones located between the back-arc spreading center and the New Britain arc. Spreading along MSC and ETZ began ~3.5 Ma ago at a full spreading rate for MSC of 92 mm/yr (Taylor, 1979; Martinez and Taylor, 1996).

2.1.4 Lau Basin

The Tonga-Lau system is an oceanic subduction zone in the southwest Pacific, where the Pacific Plate subducts beneath the Indo-Australian Plate. Behind the Tonga Arc, back-arc spreading initiated at ~6 Ma in the Lau Basin (Figure 2.1d; Taylor et al. 1996), which is a V-shaped basin with several actively spreading segments that impinge upon the Tonga Arc towards the south. The rates of both plate convergence and back-arc spreading are highest at the north end of the subduction zone (Hawkins 1995), which exhibits the fastest back-arc opening on Earth, spreading at a rate of 160

mm/yr, decreasing southwards to rates of 60 mm/yr (e.g., Bevis et al., 1995; Taylor et al., 1996). At the northern end of the Tonga Arc, the plate boundary bends 90° and the Pacific Plate ceases to subduct, and this northern boundary is the Vitiaz Lineament, which is interpreted as a paleo-subduction zone that is now a transform boundary separating the Pacific and Indo-Australian Plates (Hawkins 1995). The Lau Basin consists of several actively spreading segments (Rochambeau Rifts [RR], Northwest Lau Spreading Center [NWLSC], Peggy Ridge [PR], Central Lau Spreading Center [CLSC], Intermediate Lau Spreading Center [ILSC], and Eastern Lau Spreading Center [ELSC]), that are progressively closer to the arc towards the south (ELSC).

2.1.5 North Fiji Basin

The North Fiji Basin (NFB; Figure 2.1e) is located to the west of the Lau Basin, opening behind the Vanuatu Arc. The New Hebrides subduction zone, the western boundary of the NFB, experiences subduction at a rate of 9-12 cm/yr (Maillet et al., 1989), and evolves into the Hunter Fracture Zone, a transform fault, starting at the southern end of the NFB. The NFB contains several regions of spreading, including the Central Ridge System (CR), Eastern Ridge (ER), and Fiji Fracture Zone (FFZ) (Price et al., 1990; Eissen et al., 1994). The CR consists of the N-S segment, N15 segment, and the N160 segment (Eissen et al., 1991), which are E-W trending en-echelon grabens on top of a ridge-like region of elevated topography (Eissen et al., 1994). The CR is a slow spreading ridge with a spreading rate of 2 cm/yr (Price and Kroenke, 1991; Kroenke and Eade, 1990).

2.2 Back-arc Basin Basalt Samples

Compiled here is a global back-arc basin data set of major element, trace element, and volatile measurements of 327 basaltic glass samples from the Mariana Trough (Volpe et al., 1987; Hawkins et al., 1990; Stolper and Newman, 1994; Gribble et al., 1996; Gribble et al., 1998; Pearce et al., 2005), East Scotia Ridge (Fretzdorff et al., 2002), Manus Basin (Danyushevsky et al., 1993; Kamenetsky et al., 2001; Sinton et al., 2003; Shaw et al., 2004; Shaw et al., 2012), Lau Basin (Hawkins, 1976; Aggrey et al., 1988; Jambon and Zimmermann, 1990; Danyushevsky et al., 1993; Sinton et al., 1993; Pearce et al., 1995; Kamenetsky et al., 1997; Peate et al., 2001; Melson et al., 2002; Keller et al., 2008; Bézoz et al., 2009; Escrig et al., 2009; Tian et al., 2011; Escrig et al., 2012; Lytle et al., 2012), and North Fiji Basin (Aggrey et al., 1988; Danyushevsky et al., 1993; Eissen et al., 1991; Sinton et al., 1993; Eissen et al., 1994; Nohara et al., 1994). All samples reported here are literature data, with the exception of select volatiles and trace elements from Manus Basin, Lau Basin, and NFB (M. Lytle, unpublished data; see Manuscript III) and major elements for five samples from NFB (Table 2.S1), three of which are referenced in Eissen et al., 1991, Eissen et al., 1994, and Nohara et al., 1994. Two others are from the *R/V Southern Surveyor* SS07/2008 cruise (Lytle et al., 2012).

2.3 Analytical Methods

The five glass chips from NFB that required major element analysis (see section 2.2) were mounted in 1 inch round epoxy mounts for electron microprobe analysis (EMPA). Major element concentrations (Table 2.S1) were measured on the Brown University CAMECA SX-100 electron microprobe using a 15 kV accelerating

voltage, 10 nA beam current and 10 μm defocused beam following the methods of Devine et al. (1995). Calibration was checked against basaltic glass references VG-2 and A99B compositions (Melson et al., 2002) every 10 glass chips and a series of 5 spots were analyzed and averaged for each glass chip. Precision was typically $\leq 2\%$ RSD (Jarosewich, 2002; Melson et al., 2002).

2.4 Interlaboratory Bias

Before using compiled major element data from multiple laboratories, we must consider bias introduced into the data set from analysis of major elements and volatiles in different laboratories. The major element concentrations of all samples were corrected for interlaboratory bias following the procedure discussed in Langmuir et al. (2006) because major elements were analyzed at several laboratories. Major element data (i.e., SiO_2 , TiO_2 , Al_2O_3 , FeO , MgO , Na_2O , K_2O , P_2O_5) were corrected to reference Smithsonian standard measurements (Melson et al., 2002) through a two step procedure, in which a bulk correction factor was determined (Table 2.1). There were either no common standards for the published data, or no values for the standards published, thus requiring a two step procedure using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and EMPA. The correction factor is the slope of the linear regression calculated from comparing either the LA-ICP-MS data with the Smithsonian EMPA data or the published EMPA data. The bulk correction factor is the result of multiplying the two correction factors together. During trace element analysis by LA-ICP-MS at the Graduate School of Oceanography, University of Rhode Island, experimental major element data (SiO_2 , TiO_2 , Al_2O_3 , FeO^* , MgO ,

MnO, CaO, K₂O, P₂O₅) was collected. This allowed a correction factor from the LA-ICP-MS major elements to the Smithsonian major elements to be determined using the VG glasses (Melson et al., 2002). Therefore, all non-Smithsonian major element analyses were first corrected to the LA-ICP-MS major element values and then corrected back to Smithsonian values (reported as bulk correction factors in Table 2.1). The corrected major elements are reported in Table 2.S2. Major elements from the East Scotia Ridge samples (Fretzdorff et al., 2002) were collected using the Lamont Doherty EMP glass standard JDF-D2, and as such, the correction factor applied for these samples is the same as the one for Lamont Doherty.

2.5 Effect of Degassing

Volatile loss from magma results from exsolution of dissolved gases from the magma during depressurization upon ascent from the mantle to the surface. Assessment of volatile loss from each glass is possible as major volatile species (e.g., H₂O, CO₂) have different vapor/melt solubilities. Carbon dioxide has lower solubility in silicate melt at low pressure and is expected to begin degassing before H₂O (Dixon and Stolper, 1995), and the mixed CO₂-H₂O content of a glass reflects the minimum pressure of final equilibration of vapor with melt if the latter was volatile-saturated. Figure 2.2a shows CO₂ vs. H₂O in the glasses from Mariana Trough, Manus Basin, Lau Basin, North Fiji Basin, and East Scotia Ridge, which indicate vapor saturation at pressures of 200-800 bars, and samples without measured CO₂ data were treated as having no CO₂ in the glass. Model degassing paths show that CO₂ is more sensitive to the early stages of degassing, and that H₂O loss is not significant until most CO₂ has

been removed from the melt (Dixon and Stolper, 1995; Newman and Lowenstern, 2002). Based on this analysis, most glasses have likely lost variable amounts of CO₂, but H₂O concentrations are relatively unmodified from the original magmatic values.

Figure 2.2b compares the calculated pressure at H₂O-CO₂ saturation with the hydrostatic pressure at the mean collection depth of each sample. Most samples are found to be vapor-oversaturated or saturated at the pressure of collection, which is typical of mid-ocean ridge basalts and reflects relatively fast transport and eruption of magma from mid-crustal depths (Danyushevsky et al., 1993). Samples were filtered for degassing and included in further modeling if the samples either a) appeared undersaturated if there was no CO₂ data or b) lay along or below the 1:1 line (Figure 2.2b), and therefore are considered saturated or undersaturated (n = 246).

2.6 *Effects of Crystallization*

Water suppresses plagioclase and clinopyroxene crystallization (e.g., Sisson and Grove, 1993a; Sisson and Grove, 1993b) and its effects can be seen in the major element systematics. The basalts from the five back-arc basins can be segregated into four major groups on the basis of H₂O content, which we reference here to H₂O_(8.0) (i.e., glass H₂O concentration corrected for fractional crystallization to the equivalent concentration at 8 wt.% MgO; Table 2.S3), calculated using the expression $H_2O_{(8.0)} = H_2O * MgO^{1.7} / 34.3$ (Taylor and Martinez, 2003). Figure 2.S1a-2.S5a shows the functional form of the expression for H₂O_(8.0), and the discriminating curves between the four major water groups (< 0.3 wt.% H₂O_(8.0), 0.3 – 0.75 wt.% H₂O_(8.0), 0.75 – 1.2 wt.% H₂O_(8.0), and > 1.2 – 1.7 wt.% H₂O_(8.0)) for all five back-arc basins.

Grouping the samples this way is important for further analysis because the variable and relatively high H₂O contents of back-arc basin basalts influences the crystallization sequence and the liquid line of descent (LLD). As clinopyroxene (cpx) and/or plagioclase (plag) crystallize from the magma, the major element fractionation slopes significantly change such that simple olivine addition back to Fo₉₀ in most cases would incorrectly reconstruct the major element compositions of primary melts. Therefore, accurate reconstruction of the primary melts relies on correcting the melt composition along empirically determined fractionation slopes until reaching the point where the mineral (cpx or plag) first saturated from the melt. Using Petrolog3 (Danyushevsky and Plechov, 2011), the shifts in saturation point of plagioclase (plag) and clinopyroxene (cpx) due to melt H₂O content, expressed at H₂O_(8.0), can be referenced to the MgO content of the model melts at the point of mineral saturation (Figure 2.3; Lytle et al., 2012). For each sample, the MgO content at plag-in (i.e., MgO_{plag-in}) and MgO_{cpx-in} can be determined using the equations from Lytle et al., 2012.

2.7 Reconstruction of Primary Melt Compositions

Accurate constraints on the effect of increasing H₂O content on clinopyroxene and plagioclase saturation are needed to correct the samples for the effects of fractional crystallization, and ultimately back to primary melts at equilibrium with mantle olivine (Fo₉₀). As clinopyroxene and plagioclase crystallize from the magma, the major element fractionation slopes change such that simple olivine addition in most cases would incorrectly reconstruct the major element compositions of primary

melts. The effects of olivine, plagioclase and clinopyroxene fractional crystallization on melt composition were modeled by LLDs run in Petrolog3 (Danyushevsky and Pelchov, 2011). Figures 2.S1-2.S5 show variations in Al_2O_3 , CaO , and $\text{CaO}/\text{Al}_2\text{O}_3$ ratio as MgO decreases, which track the appearances of plag and cpx on the liquidus during crystallization. The onset of both plagioclase fractionation (plag-in) and clinopyroxene fractionation (cpx-in) were determined by the change in slopes of the LLDs (e.g., kinks in the LLD's; Figures 2.S1-2.S5; see Lytle et al., 2012 for details). The two LLDs on Figures 2.S1-2.S5 provide examples of a wet magma (2.23 wt.% H_2O) and a dry magma (0.10 wt.% H_2O), which bracket the variation in the data, and show that the wetter magmas are consistent with later saturation of plag and cpx in the melt.

The MgO value at which the mineral saturates is referred as $\text{MgO}_{\text{mineral-in}}$, and these models provide constraints on the point of each of mineral-in as a linear function of initial melt H_2O content, expressed as $\text{H}_2\text{O}_{(8.0)}$ (Figure 2.3; Lytle et al., 2012). Given the $\text{H}_2\text{O}_{(8.0)}$ value, the specific $\text{MgO}_{\text{plag-in}}$ and $\text{MgO}_{\text{cpx-in}}$ can be determined for each individual sample, allowing for correction of basalt compositions to primary melts by tracing each sample along empirically determined fractionation slopes (Table 2.2) to the point of $\text{MgO}_{\text{mineral-in}}$ for both clinopyroxene and plagioclase. Once each sample is corrected to the point of plag-in, equilibrium olivine is added in 0.001% increments until each melt is in equilibrium with Fo_{90} olivine (Table 2.S3).

3. Results

Using dry BABBs (< 0.5 wt.% H_2O), we can treat these basalts like MORBs and investigate the melting relationships of BABBs with respect to well-characterized adiabatic decompression melting behaviors of MORBs (Klein and Langmuir, 1987; Langmuir et al., 1992). The behavior of Na_2O is well-known in MORBs, where the Na_2O content of the melt varies as a function of the melt fraction. Due to the incompatible nature of Na_2O during melting, low melt fractions in MORBs will have high Na_2O contents and further melting will progressively dilute the amount of Na_2O in the melt, resulting in high melt fractions correlating with low Na_2O contents (Klein and Langmuir, 1987).

Another well-characterized aspect of MORBs is the relationship between axial depth and the melt fraction. Deeper axial depths (i.e., 5000 – 6000m), resulting from decreased crustal thicknesses, which is caused by smaller extents of melting in a region with cooler mantle temperatures and therefore, have higher Na_2O contents in the melts (Klein and Langmuir, 1987). The dry BABBs follow the well-characterized relationship found in MORBs, where the increasing axial depth (more negative depths) for BABBs correlates with the increasing Na_{F090} of the melt (Figure 2.4a). Another well understood relationship in MORBs is FeO systematics, in which FeO is sensitive to the pressure and temperature of melting (Klein and Langmuir, 1987; Langmuir et al., 1992). Higher FeO contents in the lava are indicative of melting at deeper pressures and warmer temperatures, where olivine is more MgO-rich and therefore the melt becomes more enriched in FeO.

Higher pressures and warmer temperatures of melting result in higher melt fractions, therefore Na_2O and FeO are anticorrelated at global spreading centers

(Langmuir et al., 1992). Using the dry, adiabatic melting model from Langmuir et al. (1992), the MORB Na_2O and FeO values were fit with a potential temperature (T_p) model curve and resultant T_p parameterizations from Na_2O and FeO (Kelley et al., 2006). Figure 2.4b shows constraints on the mantle potential temperature for the dry BABB lavas using Fe_{Fo90} vs. Na_{Fo90} (Kelley et al., 2006), estimating the coldest basins to be the East Scotia Ridge and Mariana Trough ($T_p \sim 1315$ and 1320°C respectively) and the hottest basin to be the Manus Basin ($T_p \sim 1480^\circ\text{C}$).

Additional modeling investigates major element vs. H_2O systematics in primary melt compositions (Fo_{90}) from the Mariana Trough, East Scotia Ridge, Manus Basin, Lau Basin, and NFB (Figure 2.5). Incompatible elements (e.g., TiO_2 , Na_2O) are widely used to evaluate mantle melting processes beneath mid-ocean ridges (Klein and Langmuir, 1987; Langmuir et al., 1992) as low melt fractions will contain high concentrations of the incompatible elements, which become progressively diluted as melt fraction increases. Figure 2.5a shows a broad trend of increasing H_2O (Fo_{90}) with decreasing TiO_2 (Fo_{90}) suggesting a relationship between the H_2O content of the melt and the extent of melting, usually estimated by the TiO_2 content of the primary melt, which has been previously shown in many studies (e.g., Stolper and Newman, 1994; Gribble et al., 1996; Kelley et al., 2006; Kelley et al., 2010). Na_2O (Fo_{90}) generally decreases with increasing H_2O (Fo_{90}) (Figure 2.5b), although this trend is less well defined, because although Na is an incompatible element, Na can also be added to the mantle source region by a slab-derived fluid. Na_2O has been identified as a primary component of slab-derived fluids (e.g., Stolper and Newman, 1994; Eiler et al., 2005), making it challenging to separate out mantle and slab-derived contributions to the

Na₂O content of basalts. Therefore, the addition of Na via subduction to the back-arc mantle source will affect the relationship between H₂O_(Fo90) and Na₂O_(Fo90), decreasing the strength of correlation observed in Figure 2.5b.

The negative relationship between H₂O_(Fo90) and FeO_(Fo90) (Figure 2.5c) shows the effect of water on the MgO and FeO abundances in hydrous melts (Gaetani and Grove, 1998). The addition of H₂O to the mantle expands the olivine-liquidus boundary, inducing melting at cooler temperatures than in an anhydrous case (Kushiro et al., 1968; Gaetani and Grove, 1998). The MgO and FeO contents of the hydrous melt record the temperature, and therefore, pressure of melting. The composition of a melt produced at cooler temperatures will reflect equilibrium with a Fe-rich olivine, yielding a melt with lower FeO concentration than the anhydrous, higher temperature scenario (Roeder and Emslie, 1970). Therefore, at a similar depth of melting, a melt with higher H₂O contents is expected to have lower FeO* because it will have lower temperature, resulting in the negative relationship observed between H₂O_(Fo90) and FeO_(Fo90) in Figure 2.5c.

4. Discussion

Previous attempts at modeling back-arc melting were limited by the availability of high-quality trace element data, as a means of assessing the mantle source composition, and by a lack of realistic melting models. Here we improve on the inverse melting model by using trace element data to constrain the mantle source composition for each sample, and we improve on the forward melting models by developing a hydrous, adiabatic melting model that uses the most current constraints

on how melting proceeds at low F and allows melting to occur over a range of pressures. These two modeling approaches are then shown to be in fairly good agreement.

4.1 Constraining the source composition of the BABB lavas

The source composition of the mantle is an important factor to consider when estimating the melt fraction (F), especially when using TiO_2 as a single-element proxy for F . The inherent assumption in using TiO_2 concentration to constrain melt fraction is that Ti behaves conservatively. Specifically, because Ti is a high field strength element with low mobility in aqueous fluids (Pearce and Parkinson, 1993), the concentration of Ti in a primary mantle melt (C_{Ti}^0) should reflect the TiO_2 concentration of the mantle source and not any additions from the slab-derived fluid. Although there are questions about whether Ti behaves in a completely conservative manner or behaves in a slightly fluid mobile manner, we continue to use Ti to estimate melt fraction, as the study by Stolper and Newman (1994) observed both a negative correlation between H_2O and TiO_2 and a positive correlation between H_2O and F in Mariana Trough basalts, thus we can treat TiO_2 an acceptable proxy for F in back-arc basin basalts. However, if Ti behaves in a slightly fluid-mobile manner, then estimates for F would provide a maximum constraint on the extent of melting in BABBs. Using a C_{Ti}^0 that does not reflect the enriched nature of the mantle source will result in low estimates for melt fraction. Following the approach of Kelley et al. (2006), we will estimate the C_{Ti}^0 values on an individual sample basis, using TiO_2/Y systematics.

Kelley et al. (2006) found that TiO_2 decreases in the melt with increasing F and evidence from Mariana Trough lavas confirmed that low TiO_2 concentrations correlated with high H_2O contents, also seen in our study (Figure 2.5). The batch melting equation is solved to yield F :

$$F = \frac{(C_{\text{Ti}}^0/C_{\text{Ti}}^l - D_{\text{Ti}})}{(1 - D_{\text{Ti}})} \quad (1)$$

where C_{Ti}^0 is the concentration of TiO_2 in the mantle source, C_{Ti}^l is the concentration of TiO_2 in the melt in equilibrium with Fo_{90} , and D_{Ti} is the bulk distribution coefficient for Ti during mantle melting (Kelley et al., 2006). C_{Ti}^0 must be well constrained to obtain a reasonable estimate of melt fraction for the back-arc basin basalts. We are using a Ti/Y model to constrain the C_{Ti}^0 of an enriched mantle source, which is based on TiO_2/Y systematics during melting. Ti and Y have similar mantle/melt D s, which results in little variation in the TiO_2/Y ratio during melting at mid-ocean ridges. The following equation is used to yield a maximum value for C_{Ti}^0 :

$$C_{\text{Ti}}^0 = \left[\frac{(\text{TiO}_2/\text{Y})_{\text{sample}}}{(\text{TiO}_2/\text{Y})_{\text{MORB}}} \right] \times C_{\text{Ti}}^{\text{DMM}} \quad (2)$$

where $(\text{TiO}_2/\text{Y})_{\text{sample}}$ is the TiO_2/Y ratio of the glass, $(\text{TiO}_2/\text{Y})_{\text{MORB}}$ is 0.04, DMM is depleted MORB mantle, and $C_{\text{Ti}}^{\text{DMM}}$ is 0.133 (Kelley et al., 2006).

Constraining the source for every sample is very important due to the large variation in the mantle source composition at the back-arc basins. Other ratios that provide constraints on the source composition would use high field strength elements (HFSE), such as Nb and Zr, which like Ti, are comparatively immobile during subduction. Comparing Nb/Zr and TiO_2/Y ratios (Figure 2.6), we see large variations in enrichment in both ratios. For example, in the Lau Basin, the TiO_2/Y ratios range from 0.03 to 0.07 and the Nb/Zr ratios range of 0.01 – 0.05, showing that using an

average C_{Ti}^0 value would significantly both underestimate and overestimate the resulting melt fraction for majority of the Lau Basin samples. Although the Lau Basin is the most extreme example of the variations in the mantle source composition, within each individual back-arc basin, samples span a minimum range of 0.02 for the TiO_2/Y ratio and 0.03 for the Nb/Zr ratio (Figure 2.6). Therefore, the observed range in the source composition for all the back-arc basins emphasizes the importance of calculating a C_{Ti}^0 value for every sample.

4.2 Modeling hydrous, adiabatic melting

A hydrous, adiabatic melting model is developed following the approach and steps applied by Langmuir et al. (1992) in developing a dry, adiabatic melting model for MORB. The dry solidus was identified and then the melt curves were spaced at two constant dT/dF values of $3.5^\circ\text{C}/\%$ for $< 22\%$ melt fraction (point of cpx-out) and $6.8^\circ\text{C}/\%$ for $> 22\%$ melt fraction (Langmuir et al., 1992). The first modification is to change the dry solidus to a hydrous solidus, using the hydrous, isobaric, isothermal equation from Kelley et al. (2010).

$$C_{\text{H}_2\text{O}}^0 = [D_{\text{H}_2\text{O}}(1 - F) + F] * \left[\frac{T - (aP^2 + bP + c) - (x \ln(P) + y)F}{-60} \right]^{1.85} \quad (3)$$

where $C_{\text{H}_2\text{O}}^0$ is the source H_2O concentration, $D_{\text{H}_2\text{O}}$ is the bulk partition coefficient for H_2O , $[\partial T/\partial F]_P = x \ln(P) + y$, and the remaining coefficients are $a = -5.14047$, $b = 132.899$, $c = 1120.661$, $x = -221.34$, $y = 536.86$, and $D_{\text{H}_2\text{O}} = 0.012$. The wet solidus was calculated by solving Equation 3 for T (using, for example $C_{\text{H}_2\text{O}}^0 = 0.20$ wt.%, and $F = 0$) and the melt fraction contours are derived by increasing F .

A mantle adiabat is calculated using $dT/dP = 1^\circ\text{C/kbar}$ and the mantle potential temperature (T_p) is selected to be a reasonable estimate for the specific back-arc basin from Na-Fe systematics (Kelley et al., 2006). Calculation of the adiabatic melt path relies on the melt productivity, which is the extent of melting as a function of pressure, referred to as γ in Langmuir et al. (1992).:

$$\gamma = \frac{\frac{dT}{dP}_{adiabat} - \frac{dT}{dP}_{solidus}}{\frac{H_f}{C_p} + \frac{dT}{dF} * 100 * \left(1 - \frac{P}{88}\right)} \quad (4)$$

where $dT/dP_{adiabat}$ is the slope of the adiabat (1°C/kbar), $dT/dP_{solidus}$ is the slope of the solidus (13°C/kbar), H_f is the heat of fusion or energy required for melting, and C_p is the heat capacity ($0.238 \text{ cal/g/}^\circ\text{C}$; Katz et al., 2003). Here we use a value of -0.16%/GPa for melt productivity from Ganguly, 2005 and because the melt fraction contours are spaced more closely as pressure increases, γ must include a pressure correction term to account for the change in spacing between melt fraction contours. Langmuir et al. (1992) used a pressure correction term of $1-P/88$, where P is in kbar and 88 reflects the decrease of the melting interval by a factor of 2 over ~45 kbar and the melting contours are assumed to decrease proportionally.

Since γ is the extent of melting as a function of pressure, we will calculate F over 1 kbar pressure intervals. However, γ is a negative value and the absolute value of γ must be taken, yielding:

$$F = \text{abs}(\gamma) * 100 \quad (5)$$

and the total melt fraction is calculated using the following equation:

$$F_{total} = \sum_{P_o}^{P_f} F \quad (6)$$

where P_f is the final pressure of melting and P_o is the initial pressure of melting. The temperature, per 1 kbar pressure intervals, for the adiabatic melt path then can be calculated with the following equation:

$$T = T_{adb} - F * \frac{dT}{dF} \quad (7)$$

in which dT/dF changes with increasing F , and F is the total melt fraction at a specific pressure (Figure 2.7). Figure 2.7a shows the wet melting model with $C_{H_2O}^0 = 0.2$ wt.% and Figure 2.7b shows the dry melting model with $C_{H_2O}^0 = 0.0$ wt.%. The melting model is restricted to pressures greater than 1 GPa due to the lack of experimental peridotite melting data at pressures less than 1 GPa (Walter, 1998), in which the parameterization of melting results in strongly curved melt fraction contours that “roll over” at lower pressures and higher F , an artifact of the natural log function in the pressure term (i.e., $[\partial T/\partial F]_P$) of the equation; Equation 3). Unlike the anhydrous melting model of Langmuir et al. (1992), we do not account for cpx-out at >22% melting because for the range of $C_{H_2O}^0$ addressed in this study (0.0 – 0.2 wt.%) the sample data do not exceed 20% melting for T_p appropriate for the back-arc basins (1315°C -1480°C).

4.3 Application of models

The adiabatic, hydrous melting model developed above requires a mantle potential temperature that is appropriate for the back-arc basin in question to be selected. As seen in Figure 2.4b, T_p is constrained using the dry BABB lavas and the Na and Fe T_p parameterizations from Kelley et al. (2006). The average T_p is calculated for all five back-arc basins and for the Mariana Trough is 1320°C, the East Scotia

Ridge is 1315°C, the Manus Basin is 1480°C, the Lau Basin is 1400°C, and the North Fiji Basin is 1412°C. When T_p is examined on a sample by sample basis, the T_p may vary within an individual basin by 100-200°C. However, from the averaged estimates of T_p , we observe that the Mariana Trough and East Scotia Ridge are the coldest basins and the Manus Basin is the hottest, and the differences in T_p reflect a 165°C difference, which is within the range reported for global mid-ocean ridges (250°C; Klein and Langmuir, 1987).

The resulting melt fraction curves from the adiabatic model show a near linear shape (Figure 2.8) rather than a more curved shape observed in the isothermal/isobaric melting models (e.g., Katz et al., 2003; Langmuir et al., 2006; Kelley et al., 2010). The shape of the melt fraction curves is important to consider because linear data trends are indicative of mixing rather than melting (Langmuir et al., 2006). Another important feature of the adiabatic melt curves is the shallowing of the slope as a function of increasing T_p and pressure, which according to Langmuir et al. (2006), should not change with increasing temperature. However, the melting models Langmuir et al. (2006) used to arrive at these conclusions were isothermal/isobaric models for one specific pressure. The relationship of mixing vs. melting will be further examined using the newly developed hydrous, adiabatic melting model.

Using the inverse modeling and the constraints on T_p for each basin, we can examine the relationship between F and $C_{H_2O}^0$ in a hydrous, adiabatically upwelling mantle, as shown in Figure 2.8. To evaluate the effects of uncertainties on data trends, we used a Monte Carlo error analysis, which allows each parameter to vary simultaneously within its assigned uncertainty during the calculation of F and $C_{H_2O}^0$, on

ten select samples from the back-arc basins. The error ellipses around data points represent 90% error confidence, and the elongation of the ellipses emphasizes that errors on this diagram are highly correlated. The error ellipses are accounting for additional error ($\pm 50\%$) associated with estimating the C_{Ti}^0 using TiO_2/Y systematics (see section 4.1), rather than previous constraints on C_{Ti}^0 , which result in $\pm 10\%$ error (see Kelley et al., 2010).

The five T_p curves shown in Figure 2.8 are the T_p 's for each of the back-arc basins, and the basins are split into individual spreading segments. The curves generated in this parameterization of hydrous melting are less strongly curved than ones produced by the isothermal/isobaric hydrous melting model from Kelley et al. (2010). Comparison of the curves generated by the melting model from Kelley et al. (2010) requires constraints on the pressure and temperature of melting. Using melt thermobarometry (Lee et al., 2009), we can determine the pressures and temperatures of last melt equilibration with the mantle for each primary reconstructed melt, therefore generating melt fraction curves that reflect the PT conditions of the primary melts (Table 2.S3).

The pressures and temperatures can be used to produce melt fraction curves from the isothermal/isobaric melting model of Kelley et al., 2010. The Mariana Trough PT conditions produce a curve with $P = 0.74$ GPa and $T - T_o = -13$, in which the negative $T - T_o$ value suggests that the Mariana Trough samples experienced melting beneath the dry solidus. Positive $T - T_o$ values indicate melting above the dry solidus, which is a characteristic behavior of melting in back-arc basins (Kelley et al., 2010). The P and $T - T_o$ determined from thermobarometry (Lee et al., 2009) for the

East Scotia Ridge are 0.87 GPa and +13, for the Manus Basin are 1.04 GPa and +62, for the Lau Basin are 1.08 GPa and +41, and for the North Fiji Basin are 1.27 GPa and +43. The adiabatic melt fraction curves lack the strong curvature of the isothermal/isobaric melt fraction curves, and thus are more consistent with the approximately linear trending data arrays produced by the compositional inversion.

The adiabatic melting model is in agreement with the model points determined using the inverse melting model approach (Figure 2.8). Since the model points are constrained by the melt curves produced by the adiabatic melting model, this suggests that melting is a plausible explanation. The melting models in Figure 2.8 match the functional form of the data trends, but mixing trends would also match the data. Therefore, the assumption that a more linear melting model trend suggests mixing and not melting is not valid for an adiabatic, hydrous melt curve. Samples produced at back-arc spreading centers can result from either an integrated melting process or mixing between a shallow, hydrous, arc-like melt and a drier, MORB-like melt. Further work, such as constraining the depth of release for the slab-derived fluid, is required to further determine whether back-arc basin basalts are products of melting or mixing processes.

5. Conclusions

Well constrained LLD's show that the previous $C_{\text{TiO}_2}^0$ estimates are inaccurate and analysis on a sample by sample basis using TiO_2/Y systematics provides better constraints on estimates of melt fraction. The development of well constrained LLD's accounts for the effects of plagioclase and clinopyroxene crystallization on melting,

providing reasonable estimates of primary melt composition in equilibrium with the mantle ($F_{0.90}$). Application of the hydrous adiabatic melting model developed here, in combination with Na and Fe parameterizations of mantle potential temperature predicts that the Mariana Trough and East Scotia Ridge samples melt under the coldest conditions ($T_p = 1320^\circ\text{C}$ and 1315°C), while the Manus Basin samples experience the hottest T_p (1480°C). The adiabatic melting model curves and the data modeled by inverse melting models are in good agreement, suggesting that the range of data produced at back-arc basins are indicative of melting trends. Although the melt fraction curves produced by this parameterization of hydrous melting are more linear than curved, the data is constrained by these curves. However, samples produced at back-arc spreading centers can result from either an integrated melting process or mixing between a shallow, hydrous, arc-like melt and a drier, MORB-like melt.

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Table 2.1: Bulk correction factors for interlaboratory bias corrections to Smithsonian electron microprobe (EMP) values

Institute	Type	SiO ₂ ^a	TiO ₂	Al ₂ O ₃	FeO*	MnO ^b	MgO	CaO ^c	Na ₂ O	K ₂ O	P ₂ O ₅
University of Rhode Island	LA-ICP-MS	1.040	0.982	1.039	1.009		0.956		0.947	1.130	1.168
University of Hawaii	EMP		0.968	1.078	0.982		0.930		0.888	1.147	1.320
Brown University	EMP		0.985	1.045	0.992		0.923		0.873	1.087	1.108
IFREMER Centre at Brest	EMP		1.019	1.042	1.015		0.980		0.919	0.653	0.830
Lamont Doherty ^d	EMP	1.009	1.042	0.990	1.026		0.926	1.000	1.000		

^aSiO₂ is not measured by LA-ICP-MS, preventing correction to Smithsonian EMP values for samples that rely on the two step LA-ICP-MS and EMP correction scheme

^bMnO was not measured by Melson et al., 2002 on the Smithsonian electron microprobe

^cSamples are referenced to CaO values during LA-ICP-MS data reduction

^dLamont Doherty bulk correction factors are from Langmuir et al., 2006

Table 2.2: Slopes for correcting compositions back to Fo90 accounting for plagioclase and clinopyroxene crystallization

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	H ₂ O
Plag	-0.595	-0.0458	1.568	-0.746	-0.027	-0.205	-0.135	0.001	0.0037	-0.049
Cpx	0.415	-0.223	0.614	-1.200	-0.035	1.143	-0.264	-0.028	-0.039	-0.134

Table 2.S1: New major element data for samples from the North Fiji Basin

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%
Y90 S53.D9.1	50.32	1.30	16.20	8.34	0.16	8.12	12.25	2.64	0.40	0.21	99.93
Y90 S53.D9.3	50.28	1.32	16.30	8.36	0.14	8.06	12.27	2.59	0.40	0.23	99.96
Y90 S55.D11.3	48.97	1.17	16.88	9.02	0.16	8.99	12.53	2.56	0.10	0.10	100.48
NLD-05-01-01	50.19	1.16	15.28	9.73	0.18	8.35	12.60	2.26	0.04	0.08	99.86
NLD-05-02-01	49.41	1.10	15.69	9.36	0.18	8.46	12.76	2.39	0.05	0.08	99.48

Major elements were determined by electron microprobe (EMP) at Brown University.

*Total Fe reported as FeO.

Table 2.S2: Corrected Major Elements using bulk correction factors

Sample	SiO ₂ wt. %	TiO ₂ wt. %	Al ₂ O ₃ wt. %	FeO* wt. %	MgO wt. %	CaO wt. %	Na ₂ O wt. %	K ₂ O wt. %	P ₂ O ₅ wt. %
Manus Basin									
15-9		0.43	16.92	9.41	4.70		1.92	1.56	0.33
16-12		0.51	17.10	7.56	5.20		2.39	0.95	0.18
18-2		0.57	16.73	8.64	5.27		1.90	0.41	0.21
18-3		0.47	18.04	7.91	6.08		1.63	0.36	0.18
20-3		0.66	17.10	7.97	6.86		1.76	0.26	0.20
21-1		0.78	16.33	9.97	5.69		2.03	0.26	0.18
22-4		0.51	16.27	7.52	7.33		1.71	0.24	0.18
22-5		1.07	16.04	9.62	6.45		1.95	0.13	0.21
23-3		0.66	18.50	9.52	8.03		1.83	0.03	0.16
24-3		1.27	14.86	12.10	6.37		2.04	0.06	0.13
25-2		1.00	16.03	9.73	7.39		1.88	0.03	0.20
25-3		1.44	14.56	12.74	5.95		2.15	0.06	0.21
26-6		0.99	15.55	10.55	6.78		1.89	0.08	0.24
27-4		1.10	15.15	11.06	6.74		1.87	0.05	0.21
28-2		1.08	15.84	10.74	6.29		1.87	0.14	0.22
28-PD		0.93	17.65	7.67	4.11		2.86	0.20	0.22
29-3		0.99	16.22	10.39	7.59		1.93	0.05	0.20
29-5		0.73	17.15	7.68	6.48		1.93	0.16	0.12
30-4		1.36	15.22	12.60	4.08		2.71	0.17	0.21
30-8		1.11	15.66	10.99	4.81		2.68	0.21	0.21
31-4		1.29	14.70	12.02	6.89		2.03	0.05	0.24
31-9		1.58	15.37	11.61	5.94		2.43	0.13	0.24
32-2		0.99	15.96	10.12	7.54		2.03	0.05	0.22
33-1		0.89	15.94	10.47	6.67		1.93	0.09	0.18
33-5		1.07	15.29	11.32	6.92		1.99	0.03	0.21
35-2		0.75	17.49	6.74	4.18		2.98	0.75	0.38
35-5		0.79	17.46	6.74	4.19		2.92	0.80	0.41
36-1		1.25	14.86	12.00	6.32		1.90	0.06	0.21
36-3		0.97	15.87	9.90	7.89		1.82	0.07	0.21
36-8		1.96	14.75	14.14	5.07		2.64	0.13	0.28
37-5		1.16	15.27	11.39	6.74		2.02	0.05	0.22
38-4		1.45	13.71	13.63	6.17		2.11	0.05	0.26
38-6		1.09	15.68	11.71	5.42		2.33	0.21	0.20
39-2		1.52	13.73	13.65	6.05		2.19	0.09	0.22
39-3		1.27	13.99	12.83	6.72		2.08	0.05	0.22
40-3		1.07	15.95	10.75	5.52		2.25	0.20	0.21

Table 2.S2: *cont.* Corrected Major Elements using bulk correction factors

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	FeO* wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	P ₂ O ₅ wt.%
41-3		0.93	16.40	9.77	5.81		2.34	0.09	0.12
42-2		1.20	14.75	11.75	6.08		2.06	0.07	0.11
43-2		1.66	13.85	14.80	4.44		2.53	0.11	0.24
43-3		1.18	15.26	11.53	6.30		2.17	0.09	0.22
44-3		1.18	14.99	12.49	6.41		1.99	0.05	0.22
46-3		2.26	12.45	17.68	2.61		2.67	0.15	0.40
47-2		1.73	13.88	15.38	4.99		2.25	0.13	0.57
BC15-2		1.34	14.80	12.71	6.03		2.12	0.06	0.17
BC19-1		1.51	14.66	13.60	4.90		2.21	0.08	0.22
Lau Basin									
VG-9750	49.39	0.88	15.05	10.85	6.99	13.42	2.06	0.09	0.14
VG-9751	50.16	2.20	12.49	16.30	5.15	9.51	2.72	0.09	0.17
VG-9758	50.52	2.14	12.68	15.73	5.29	9.51	3.01	0.10	0.17
VG-9760	50.95	2.62	11.92	17.57	4.40	8.86	3.08	0.12	0.18
VG-9764	50.67	1.70	13.75	12.90	6.53	11.10	2.62	0.08	0.12
VG-9768	58.34	1.51	12.73	11.56	2.48	6.41	4.23	0.43	0.25
VG-9775	60.77	1.26	12.63	11.68	1.29	5.42	4.20	0.50	0.26
VG-9778	50.69	0.83	15.96	9.28	6.99	12.69	2.38	0.10	0.10
VG-9779	50.93	1.64	13.94	12.70	6.75	11.24	2.62	0.08	0.15
VG-9785	50.13	1.26	14.99	10.75	7.33	12.56	2.62	0.07	0.11
VG-9786	50.97	1.66	13.51	12.95	6.17	10.84	2.75	0.11	0.14
VG-9789	49.40	0.81	16.04	8.96	7.14	13.35	2.14	0.15	0.12
VG-9792	47.58	1.05	17.76	9.30	9.18	12.23	2.56	0.03	0.08
VG-9801	52.40	1.08	14.49	10.67	7.10	11.70	2.14	0.07	0.10
VG-9809	51.54	0.86	14.93	9.04	7.84	13.04	1.84	0.08	0.10
VG-9812	51.21	1.02	15.06	10.14	7.30	12.46	2.24	0.06	0.11
VG-9816	51.41	1.19	14.60	10.94	6.80	11.55	2.42	0.08	0.12
VG-9824	50.62	0.77	16.38	8.56	7.10	12.59	1.91	0.12	0.11
VG-9825	51.66	1.15	14.34	10.93	7.24	11.54	2.11	0.05	0.11
VG-9831	51.36	0.63	16.53	7.65	7.27	12.88	1.64	0.11	0.10
VG-9834	51.70	1.07	14.48	10.58	7.42	12.16	2.04	0.05	0.10
VG-9836	50.82	0.78	16.06	8.59	7.14	12.63	1.91	0.11	0.12
VG-9838	51.23	1.29	14.96	11.09	5.96	10.90	2.71	0.11	0.13
VG-9839	52.18	1.06	15.36	9.98	5.95	11.02	2.16	0.16	0.12
VG-9842	53.29	1.98	13.60	13.73	3.74	8.03	3.18	0.20	0.19
VG-9844	50.46	1.12	15.42	10.21	7.06	11.73	2.46	0.11	0.11

Table 2.S2: *cont.* Corrected Major Elements using bulk correction factors

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	FeO* wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	P ₂ O ₅ wt.%
VG-9847	50.18	0.79	15.61	8.67	8.39	13.08	2.01	0.08	0.10
NLD-06-01-01		1.79	15.78	10.50	6.11		2.37	0.43	0.25
NLD-07-01-01		1.38	16.96	10.08	7.79		2.17	0.41	0.14
NLD-08-01-01		1.54	16.36	9.49	6.65		2.32	0.41	0.21
NLD-09-02-01		1.50	16.38	9.54	6.66		2.23	0.41	0.20
NLD-10-01-01		1.49	17.20	9.92	7.37		2.22	0.51	0.19
NLD-11-01-01		1.53	16.46	9.47	6.66		2.26	0.44	0.20
NLD-13-01-01		1.40	17.67	9.57	7.94		2.17	0.10	0.15
NLD-14-01-01		1.57	16.70	9.96	7.06		2.29	0.26	0.15
NLD-15-01-01		1.59	17.07	9.68	7.80		2.14	0.34	0.20
NLD-16-01-01		1.58	16.97	9.69	7.88		2.16	0.32	0.18
NLD-17-01-01		1.42	16.31	9.44	7.11		2.10	0.28	0.16
NLD-18-01-01		2.02	15.77	10.83	5.12		2.69	0.60	0.30
NLD-18-02-01		1.72	17.02	10.32	6.79		2.49	0.30	0.18
NLD-19-01-01		1.97	15.88	10.74	6.33		2.54	0.34	0.22
NLD-20-01-01		1.48	16.57	10.50	8.40		2.09	0.17	0.10
NLD-21-01-01		2.10	14.81	12.64	5.53		2.77	0.29	0.20
NLD-22-01-01		1.38	18.13	8.92	7.76		1.94	0.54	0.15
NLD-22-02-01		1.12	17.34	8.48	8.41		1.83	0.10	0.10
NLD-23-01-01		1.79	15.85	10.98	6.50		2.59	0.23	0.17
NLD-24-01-01		1.73	16.65	10.94	6.84		2.36	0.21	0.15
NLD-24-02-01		1.39	17.24	10.29	7.68		2.28	0.17	0.15
NLD-24-03-01		1.73	16.19	10.97	6.75		2.63	0.20	0.14
NLD-25-01-01		1.43	17.50	9.03	7.58		2.11	0.28	0.15
NLD-27-01-01		0.74	19.20	8.00	9.04		1.71	0.07	0.07
NLD-28-01-01		1.85	15.07	11.90	5.40		2.59	0.30	0.16
NLD-30-01-01		1.42	16.37	10.76	7.32		2.40	0.27	0.11
NLD-31-01-01		1.27	18.12	8.87	7.85		2.11	0.23	0.13
NLD-32-01-01		2.00	15.13	11.98	5.21		2.69	0.50	0.22
NLD-35-01-01		1.73	15.50	10.79	6.06		2.65	0.27	0.13
NLD-37-01-01		1.76	15.82	11.01	5.40		2.66	0.62	0.21
NLD-38-01-01		1.51	16.21	10.50	7.57		2.14	0.17	0.14
NLD-40-01-01		1.11	16.21	10.05	7.74		1.88	0.09	0.10
NLD-40-02-01		0.89	13.46	9.81	1.18		3.20	0.82	0.26
NLD-41-01-01		1.35	16.15	9.75	6.51		1.92	0.34	0.15
NLD-41-02-01		1.25	14.58	9.08	2.02		3.68	0.86	0.29
NLD-41-03-01		1.19	14.71	8.87	2.35		3.62	0.93	0.30

Table 2.S2: *cont.* Corrected Major Elements using bulk correction factors

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	FeO* wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	P ₂ O ₅ wt.%
NLD-42-01-01		1.04	16.21	9.69	7.52		1.81	0.04	0.07
NLD-43-01-01		1.62	14.81	11.84	6.35		2.26	0.15	0.15
NLD-43-02-01		1.61	14.56	12.30	6.07		2.42	0.13	0.14
NLD-44-01-01		1.60	15.38	10.73	5.89		2.21	0.57	0.29
NLD-44-02-01		1.55	15.58	10.66	5.97		2.16	0.55	0.27
NLD-45-01-01		1.95	13.82	14.17	5.52		2.35	0.15	0.21
NLD-46-01-01		1.66	14.06	12.67	5.79		2.30	0.12	0.15
NLD-47-01-01		1.54	14.43	12.34	6.00		2.26	0.15	0.13
NLD-48-01-01		1.10	16.21	9.65	7.72		1.88	0.04	0.08
NLD-49-01-01		1.40	14.68	11.94	6.50		2.22	0.09	0.11
NLD-50-01-01		1.12	16.76	9.10	8.03		1.96	0.09	0.13
NLD-51-01-01		1.08	16.94	8.76	8.12		1.86	0.11	0.11
NLD-55-01-01		1.39	16.91	9.79	8.14		2.42	0.04	0.10
NLD-56-01-01		0.88	15.82	9.52	7.58		1.94	0.04	0.07
NLD-57-01-01		1.09	15.01	11.35	6.61		2.15	0.05	0.08
NLD-58-01-01		0.99	15.77	9.83	7.41		2.01	0.05	0.07
NLD-59-01-01		1.22	15.70	10.18	7.14		2.23	0.07	0.10
NLD-60-01-01		1.36	16.34	10.82	5.94		2.42	0.14	0.14
NLD-61-01-01		0.70	15.71	9.31	7.97		1.68	0.03	0.07
NLD-62-01-01		0.88	16.13	9.01	8.07		1.85	0.04	0.06
NLD-63-01-01		0.76	18.10	8.29	9.56		1.73	0.01	0.06
NLD-64-01-01		0.83	15.88	9.76	7.59		1.87	0.04	0.08
NLD-65-01-01		0.83	15.50	9.93	7.36		1.84	0.04	0.04
NLD-66-01-01		1.14	15.78	10.44	7.25		1.93	0.07	0.09
North Fiji Basin									
KK 16-1		1.18	17.97	9.31	7.91		2.19	0.08	0.22
KK 16-2		1.30	17.12	9.86	7.64		2.28	0.11	0.25
KK 16-3		1.22	17.89	9.48	8.03		2.24	0.09	0.22
KK 16-4		1.27	17.62	9.29	7.65		2.22	0.14	0.25
KK 16-5		1.26	17.12	9.47	7.51		2.27	0.10	0.22
KK 16-6		1.19	17.89	9.42	8.01		2.21	0.08	0.21
KK 16-7		1.21	17.97	9.35	8.31		2.19	0.08	0.21
KK 16-8		1.24	17.93	9.44	7.88		2.20	0.08	0.22
KK 16-10		1.01	16.55	8.04	7.92		2.29	0.05	0.11
KK 16-11		1.20	17.76	9.42	8.00		2.19	0.11	0.22
KK 16-12		1.22	17.78	9.61	7.80		2.35	0.10	0.25

Table 2.S2: *cont.* Corrected Major Elements using bulk correction factors

Sample	SiO ₂ wt. %	TiO ₂ wt. %	Al ₂ O ₃ wt. %	FeO* wt. %	MgO wt. %	CaO wt. %	Na ₂ O wt. %	K ₂ O wt. %	P ₂ O ₅ wt. %
KK 16-13		1.22	17.84	9.67	8.02		2.24	0.15	0.26
KK 16-14		1.25	18.15	9.42	8.29		2.32	0.06	0.21
KK 16-16		1.17	15.86	10.92	7.14		2.28	0.05	0.24
KK 16-17		1.05	16.14	10.04	7.35		2.22	0.06	0.26
SPS3 DT-1		1.62	14.94	10.25	7.54		2.46	0.07	0.08
SPS3 D1-3		1.41	15.49	10.58	7.86		2.28	0.05	0.07
SPS3 D4-2		1.56	15.22	10.37	6.92		2.44	0.20	0.24
SPS3 D4-5		1.46	15.46	10.95	7.61		2.21	0.05	0.08
K87 ST4 D2-1		1.53	15.99	10.17	7.41		3.11	0.08	0.08
K87 ST4 D2-2		1.54	15.67	10.06	7.55		3.02	0.08	0.08
K87 ST4 D2-4		1.58	15.75	9.88	7.29		3.00	0.08	0.11
K87 ST4 D2-5		1.54	15.54	10.00	7.52		3.02	0.09	0.10
K87 ST4 D2-7		1.57	15.62	10.23	7.67		2.79	0.07	0.08
K87 ST4 D2-8		1.56	15.96	10.02	7.32		3.14	0.08	0.10
K87 ST4 DTA-3		2.04	18.51	7.06	8.98		2.35	0.51	0.24
K87 ST4 DTA-4		1.86	15.15	12.00	7.32		1.65	0.11	0.10
K87 ST4 DTA-7		1.86	14.91	11.67	7.33		2.51	0.10	0.12
K87 ST4 DTB-1		1.12	16.41	9.01	9.83		1.76	0.05	0.07
K87 ST4 DTB-2		2.04	18.82	6.90	8.83		2.23	0.51	0.24
K87 ST6 D4-1		1.43	15.55	10.10	7.98		2.45	0.02	0.08
K87 ST6 D4-3		1.42	15.63	10.03	7.82		2.52	0.03	0.07
K87 ST6 D4-5		1.42	15.66	9.76	7.96		2.61	0.03	0.07
K87 ST6 DTA-1		1.37	17.04	9.16	7.83		2.74	0.28	0.17
K87 ST8 D5-5		2.12	18.27	7.19	8.67		2.31	0.61	0.27
K87 ST8 D5-6		1.85	14.90	11.47	7.33		2.29	0.09	0.11
K87 ST14 D10-1		1.51	15.71	10.42	8.01		2.35	0.05	0.08
K87 ST14 D10-2		1.51	15.85	10.45	8.12		2.34	0.05	0.08
K87 ST14 D10-6		1.76	15.56	10.79	7.22		2.51	0.13	0.12
K87 ST14 D10-10		1.75	15.71	10.47	7.45		2.57	0.12	0.12
K87 ST15 D11-2		1.89	16.32	9.93	7.68		2.63	0.11	0.12
K87 ST15 D11-8		1.85	16.18	10.16	7.82		2.66	0.08	0.12
K87 ST21 D3-6		2.06	17.19	9.37	8.02		2.87	0.29	0.24
Y90 S53.D9.1		1.32	16.89	8.46	7.96		2.43	0.26	0.17
Y90 S53.D9.3		1.35	16.99	8.48	7.90		2.38	0.26	0.19
Y90 S55.D11.3		1.19	17.60	9.16	8.81		2.35	0.06	0.08
NLD-05-01-01		1.14	15.96	9.65	7.71		1.97	0.04	0.09
NLD-05-02-01		1.08	16.38	9.29	7.81		2.09	0.05	0.09

Table 2.S3: Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
Mariana Trough														
ALV 1832-2	54.46	0.90	21.79	0.68	2.42	0.00	3.66	12.32	1.28	0.70	1.78	0.663	1086.97	0.11
ALV 1833-1	51.55	0.98	20.26	0.86	3.45	0.08	5.25	12.53	2.59	0.44	2.01	0.948	1131.64	0.46
ALV 1833-11	49.59	0.97	18.75	1.17	5.47	0.12	8.32	11.57	2.67	0.25	1.13	1.087	1219.29	0.82
ALV 1839-21	49.72	1.08	19.41	1.16	5.42	0.10	8.25	11.12	2.36	0.26	1.12	1.077	1214.94	0.77
ALV 1840-3	50.62	0.95	19.37	1.09	4.90	0.09	7.45	11.43	2.73	0.28	1.10	0.951	1193.80	0.67
ALV 1846-12	49.73	0.95	19.52	1.09	4.94	0.10	7.50	11.87	2.48	0.39	1.44	1.235	1194.52	0.74
ALV 1846-9	48.81	0.42	19.76	1.02	4.52	0.12	6.88	14.12	1.83	0.71	1.81	1.488	1181.76	0.69
GH88-1 D1009	50.38	1.13	18.69	1.16	5.33	0.00	8.10	10.92	2.80	0.37	1.13	1.061	1209.76	0.76
GH88-1 D1010	50.30	1.20	18.38	1.19	5.53	0.00	8.39	10.73	2.84	0.37	1.07	1.029	1217.95	0.80
MARA 18-2	51.31	0.80	20.63	0.88	3.56	0.09	5.42	13.02	2.55	0.42	1.32	0.914	1142.42	0.46
MARA 34-2	49.73	0.96	18.58	1.21	5.76	0.14	8.68	10.71	2.83	0.24	1.17	1.128	1226.00	0.87
MARA 34-20	50.72	0.84	19.75	1.01	4.36	0.10	6.61	12.37	2.69	0.29	1.26	0.916	1172.60	0.59
MARA 39-1	49.78	0.70	19.18	1.19	5.61	0.14	8.52	11.30	2.21	0.26	1.12	1.081	1221.57	0.76
MARA 39-3	49.66	0.90	18.53	1.19	5.59	0.13	8.49	11.79	2.59	0.21	0.91	0.861	1226.66	0.81
MARA 39-8	50.29	1.02	18.98	1.08	4.81	0.07	7.30	12.13	2.91	0.24	1.17	0.869	1192.38	0.70
MARA 41-3	49.78	1.15	17.46	1.37	6.76	0.15	10.20	9.99	2.55	0.21	0.37	0.408	1275.92	0.95
MARA 8-10	50.79	1.18	19.52	1.04	4.47	0.10	6.79	12.14	2.84	0.27	0.86	0.700	1181.34	0.61
MARA 8-2	50.77	1.23	19.20	1.10	4.92	0.11	7.46	11.24	2.91	0.27	0.79	0.704	1197.59	0.67
MARA 8-5	50.39	1.20	19.49	1.03	4.44	0.09	6.77	12.05	3.41	0.27	0.87	0.703	1183.71	0.71
MARA 9-1	50.67	1.08	19.88	1.04	4.51	0.06	6.84	12.09	2.64	0.30	0.88	0.752	1181.88	0.60
MARA 16-1	49.56	1.39	18.06	1.28	6.14	0.12	9.25	10.57	2.94	0.21	0.48	0.527	1251.99	0.94

Iron oxidation state was 16% Fe³⁺/ΣFe

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
RAMA 25-1	52.13	0.85	20.73	0.85	3.37	0.05	5.12	12.52	2.80	0.47	1.11	0.607	1134.58	0.42
RAMA 26-2	49.56	0.98	19.12	1.15	5.28	0.10	8.02	11.65	2.66	0.30	1.17	1.062	1211.51	0.80
RAMA 26-5	49.32	1.05	18.96	1.19	5.55	0.14	8.42	11.30	2.65	0.32	1.10	1.033	1222.81	0.87
S-DS18:1-6	49.62	0.74	18.68	1.11	5.11	0.10	7.75	12.68	2.07	0.30	1.85	1.486	1195.99	0.69
S-DS22:2-2	47.64	1.12	19.13	1.33	6.51	0.11	9.84	10.68	3.13	0.20	0.32	0.398	1280.43	1.27
S-DS74:2-1	50.47	0.75	19.37	1.03	4.55	0.11	6.91	12.38	2.17	0.27	2.00	1.629	1171.10	0.58
S-DS74:2-3	49.71	0.74	19.26	1.02	4.52	0.09	6.87	13.27	2.26	0.29	1.97	1.435	1175.14	0.64
S-DS74:3-1	50.39	1.06	18.80	1.15	5.31	0.11	8.07	11.32	2.45	0.29	1.05	0.970	1209.64	0.70
S-DS-79:2-2	49.29	1.04	18.82	1.21	5.66	0.12	8.61	11.25	2.87	0.26	0.87	0.848	1231.59	0.91
S-DS-80:23-2	49.21	0.85	18.60	1.17	5.53	0.15	8.40	12.20	2.22	0.23	1.43	1.331	1218.48	0.80
S-DS-80:25-3	52.32	0.75	20.24	0.82	3.23	0.00	4.91	12.41	2.38	0.56	2.37	1.077	1118.53	0.39
S-DS84:1-1	48.95	1.29	17.19	1.35	6.59	0.11	9.95	11.72	2.78	0.04	0.03	0.164	1283.61	1.02
S-DS84:2-1	49.48	1.24	17.47	1.31	6.31	0.12	9.51	11.68	2.77	0.05	0.06	0.176	1268.35	0.92
S-DS86:4-1	49.66	1.29	18.43	1.13	5.11	0.00	7.77	12.73	3.26	0.39	0.23	0.322	1221.44	0.83
S-DS88:1-2	49.66	1.30	19.01	1.10	4.96	0.10	7.54	12.00	3.02	0.27	1.05	0.838	1202.40	0.79
S-DS88:2-1	49.50	1.08	19.36	1.15	5.23	0.00	7.95	11.92	2.71	0.25	0.85	0.773	1214.59	0.80
S-DS88:3-1	48.97	1.07	19.29	1.17	5.44	0.00	8.28	11.65	2.80	0.26	1.07	0.947	1222.08	0.90
S-GTVA71:1-7	48.29	0.88	18.09	1.24	5.96	0.14	8.98	12.51	2.35	0.26	1.30	1.267	1240.43	0.96
S-GTVA73:2-2	49.73	1.08	18.56	1.18	5.58	0.00	8.50	11.29	2.45	0.30	1.32	1.189	1219.08	0.80
S-GTVA75:1-1	49.84	0.76	19.35	1.04	4.66	0.09	7.07	12.44	2.28	0.48	2.00	1.472	1177.83	0.68
T7-46:1-6	50.09	0.95	18.93	1.13	5.19	0.10	7.90	11.82	2.40	0.21	1.28	1.143	1204.10	0.70
T7-46:1-8	50.85	1.06	18.09	1.14	5.36	0.13	8.15	11.15	2.22	0.20	1.65	1.489	1200.76	0.63
T7-47:1-5	49.94	0.87	18.00	1.16	5.48	0.12	8.35	11.89	2.29	0.23	1.67	1.517	1210.43	0.74

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
T7-48:1-3	49.66	0.63	18.70	1.11	5.06	0.11	7.69	13.06	1.98	0.49	1.51	1.388	1199.48	0.68
T7-48:3-1	51.10	0.62	19.14	1.00	4.29	0.08	6.51	13.48	1.77	0.51	1.50	1.273	1166.01	0.45
T7-51:1-1	52.66	0.72	20.01	0.91	3.71	0.03	5.64	12.78	2.27	0.19	1.07	0.629	1144.11	0.31
T7-54:1-1	49.60	0.73	19.99	1.02	4.46	0.08	6.78	13.01	2.44	0.37	1.53	1.197	1178.43	0.67
T7-68:1-2	51.53	0.69	19.62	0.94	3.95	0.08	6.01	12.67	2.44	0.41	1.66	1.213	1151.64	0.47
T7-71:1-14	50.48	0.81	19.28	0.99	4.25	0.08	6.48	13.05	2.57	0.39	1.63	1.226	1167.47	0.59
T7-72:2	50.61	1.04	19.31	1.00	4.38	0.09	6.67	11.56	2.76	0.46	2.09	1.587	1165.05	0.66
T7-73:2-1	50.45	1.16	19.90	1.04	4.52	0.09	6.88	11.49	3.18	0.31	0.97	0.848	1183.36	0.70
T7-74:1-1	49.52	1.10	19.59	1.14	5.25	0.12	7.99	11.43	2.61	0.30	0.95	0.941	1212.99	0.80
T7-75:1-2	50.34	1.43	18.22	1.21	5.68	0.11	8.65	10.50	2.93	0.33	0.59	0.620	1230.97	0.82
T7-76:1-1	50.04	1.36	17.05	1.32	6.54	0.12	9.87	9.95	2.97	0.20	0.56	0.614	1263.96	0.95
T7-80:1-3	47.70	0.92	18.15	1.45	7.50	0.15	11.33	9.58	2.30	0.35	0.59	0.645	1310.78	1.32
T7-82:1-1	50.32	0.98	19.31	1.04	4.55	0.09	6.91	12.43	2.66	0.21	1.50	1.166	1178.57	0.63
WOK 10-1	50.82	0.96	18.98	1.09	4.82	0.07	7.32	12.25	2.50	0.23	0.95	0.822	1192.51	0.59
WOK 16-2	49.41	1.37	17.38	1.35	6.68	0.12	10.08	10.13	2.77	0.18	0.53	0.579	1272.60	1.01
WOK 28-3	47.95	1.07	18.76	1.36	6.74	0.17	10.18	10.44	2.84	0.09	0.39	0.459	1285.21	1.21
WOK 5-4	49.65	0.85	19.33	1.11	5.09	0.13	7.74	11.88	2.40	0.29	1.53	1.382	1199.03	0.74
East Scotia Ridge														
100DS-1	50.91	1.36	18.10	1.19	5.49	0.12	8.34	10.88	2.85	0.19	0.60	0.607	1220.99	0.71
104DS-1	50.92	1.49	18.24	1.16	5.26	0.12	7.99	11.14	3.04	0.15	0.48	0.504	1214.79	0.70
104DS-3	51.18	1.52	18.22	1.13	5.08	0.13	7.73	11.42	2.97	0.16	0.45	0.482	1207.58	0.64
106DS-1	49.21	1.57	16.79	1.41	6.99	0.17	10.54	10.43	2.67	0.10	0.13	0.192	1293.77	1.06

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
106DS-2	49.12	1.53	17.43	1.39	6.80	0.13	10.24	10.51	2.67	0.10	0.10	0.179	1286.33	1.03
106DS-3	49.22	1.59	17.56	1.37	6.65	0.13	10.03	10.57	2.70	0.09	0.08	0.160	1280.69	1.00
106DS-4	47.40	1.60	18.03	1.48	6.98	0.15	10.52	10.92	2.75	0.10	0.07	0.149	1305.07	1.31
107DS-1	48.70	1.42	18.66	1.28	6.02	0.12	9.16	10.96	3.34	0.15	0.20	0.246	1259.91	1.08
107DS-3	49.28	1.42	16.76	1.40	6.91	0.16	10.42	11.01	2.25	0.16	0.25	0.286	1288.11	0.97
107DS-4	48.94	1.41	18.66	1.27	5.93	0.13	9.00	11.01	3.31	0.15	0.19	0.243	1254.72	1.03
108DS-1	49.73	1.57	17.43	1.33	6.34	0.14	9.56	10.89	2.70	0.17	0.15	0.224	1265.01	0.90
109DS-2	49.36	1.37	17.88	1.29	6.12	0.11	9.23	11.17	3.22	0.11	0.13	0.209	1260.14	0.98
109DS-3	49.42	1.44	16.80	1.39	6.92	0.14	10.43	10.73	2.45	0.16	0.11	0.195	1290.30	0.99
110DS-2	49.70	1.67	17.49	1.29	6.13	0.12	9.26	11.44	2.51	0.24	0.15	0.262	1257.63	0.85
110DS-5	49.82	1.68	17.52	1.28	6.04	0.11	9.11	11.52	2.51	0.24	0.16	0.275	1252.99	0.83
110DS-6	50.12	1.68	17.42	1.27	6.03	0.11	9.12	11.26	2.53	0.23	0.23	0.320	1250.44	0.80
96DS-1	49.63	1.26	18.54	1.29	6.07	0.14	9.22	10.60	2.90	0.14	0.22	0.248	1254.62	0.92
96DS-3	49.86	1.39	18.03	1.27	5.98	0.11	9.09	11.00	2.82	0.15	0.31	0.376	1249.48	0.86
97DS-2	50.89	1.48	19.14	1.12	4.92	0.10	7.48	11.35	3.06	0.19	0.28	0.354	1204.46	0.66
97DS-5	50.97	1.51	19.02	1.12	4.96	0.11	7.55	11.18	3.06	0.19	0.32	0.384	1205.06	0.67
98DS-1	51.23	1.21	18.44	1.06	4.75	0.12	7.23	11.55	2.51	0.41	1.50	1.246	1181.35	0.59
99DS-1	53.84	0.91	20.91	0.70	2.55	0.07	3.85	11.88	2.23	0.95	2.12	1.321	1093.26	0.27
wx42	52.71	1.19	20.46	0.86	3.38	0.04	5.11	12.33	3.03	0.39	0.50	0.342	1137.71	0.38
wx43	53.14	0.98	20.20	0.85	3.32	0.07	5.03	12.69	2.90	0.47	0.35	0.344	1136.08	0.33
wx45	48.64	1.33	17.20	1.36	6.55	0.14	9.89	10.90	3.77	0.12	0.10	0.126	1283.83	1.24
wx48	49.23	1.33	17.40	1.34	6.44	0.15	9.71	10.95	3.18	0.11	0.15	0.185	1273.26	1.05
wx49	49.06	1.39	18.11	1.32	6.29	0.15	9.48	10.56	3.30	0.14	0.21	0.238	1266.08	1.07

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
wx50	49.20	1.40	16.98	1.38	6.75	0.15	10.18	10.76	2.87	0.13	0.21	0.273	1283.84	1.05
wx51	49.38	1.54	16.79	1.37	6.72	0.15	10.13	10.77	2.80	0.12	0.24	0.320	1281.01	1.01
wx54b	49.12	1.78	15.85	1.45	7.40	0.14	11.15	10.19	2.67	0.14	0.11	0.220	1311.45	1.14
wx57	49.37	1.37	16.73	1.36	6.69	0.14	10.09	11.06	2.93	0.13	0.13	0.228	1282.97	1.03
wx58	49.54	1.36	16.82	1.35	6.58	0.13	9.91	11.23	2.87	0.14	0.08	0.199	1278.32	0.98
wx65	50.92	0.73	19.28	1.06	4.63	0.12	7.04	12.81	2.41	0.20	0.80	0.744	1187.51	0.54
wx66	49.58	1.31	18.07	1.23	5.77	0.12	8.77	11.50	3.22	0.28	0.15	0.251	1247.25	0.93
wx67	49.84	1.51	18.42	1.17	5.37	0.09	8.18	11.48	3.23	0.48	0.21	0.318	1229.39	0.88
wx68	49.72	1.36	17.30	1.25	5.86	0.13	8.90	12.01	3.08	0.29	0.08	0.227	1252.06	0.90
wx69	49.88	1.38	18.08	1.22	5.70	0.12	8.67	11.27	3.13	0.35	0.19	0.286	1241.91	0.89
Manus Basin														
16-12	54.65	0.00	20.44	0.80	3.03		4.59	12.70	2.09	0.82	0.92	0.655	1115.43	0.17
18-2	52.81	0.09	19.30	1.00	4.26	0.04	6.46	13.19	1.49	0.31	1.06	0.753	1162.43	0.25
18-3	50.74	0.20	19.64	1.06	4.68	0.01	7.10	13.76	1.41	0.29	1.12	0.926	1184.61	0.43
20-3	50.58	0.57	17.50	1.22	5.78	0.10	8.70	12.53	1.73	0.22	1.07	1.027	1224.73	0.60
21	50.18	0.37	16.84	1.30	6.41	0.09	9.66	12.09	1.62	0.27	1.16	0.976	1248.47	0.71
21-1	50.46	0.40	17.27	1.26	6.09	0.06	9.19	12.47	1.64	0.18	0.98	0.820	1238.70	0.63
21-2	50.16	0.30	16.84	1.33	6.55	0.11	9.87	12.02	1.58	0.37	0.87	0.803	1258.58	0.74
22-4	50.85	0.50	16.43	1.26	6.04	0.12	9.12	12.50	1.82	0.21	1.15	1.153	1233.57	0.62
22-5	49.77	0.85	16.85	1.35	6.68	0.10	10.08	11.93	1.75	0.09	0.55	0.575	1271.63	0.78
23	47.31	0.61	16.55	1.53	7.99	0.15	12.04	11.85	1.87	0.02	0.08	0.130	1349.37	1.35
23-3	47.24	0.60	16.92	1.52	7.87	0.12	11.88	11.95	1.82	0.03	0.05	0.100	1345.56	1.33

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
24-3	48.40	0.91	14.65	1.59	8.64	0.10	13.02	10.92	1.64	0.02	0.12	0.255	1367.82	1.28
25-2	48.61	0.93	15.96	1.50	7.76	0.11	11.71	11.38	1.84	0.03	0.17	0.230	1328.99	1.11
25-3	48.38	0.98	14.62	1.60	8.74	0.13	13.18	10.64	1.63	0.01	0.09	0.242	1372.67	1.30
26-6	49.03	0.85	15.85	1.51	7.96	0.11	12.01	10.65	1.71	0.06	0.26	0.322	1330.93	1.08
27-4	48.76	0.87	15.24	1.54	8.16	0.12	12.31	11.28	1.60	0.02	0.09	0.206	1346.62	1.12
28-1	48.95	0.78	15.76	1.47	7.69	0.09	11.61	11.35	1.63	0.09	0.59	0.630	1314.69	1.02
28-2	48.88	0.78	16.12	1.45	7.47	0.10	11.28	11.81	1.55	0.09	0.47	0.525	1309.35	0.98
29-3	48.13	0.92	15.25	1.57	8.46	0.16	12.76	10.72	1.84	0.05	0.14	0.188	1361.27	1.33
29-5	51.27	0.56	18.38	1.12	5.04	0.09	7.68	12.71	1.87	0.12	1.15	1.013	1195.97	0.48
29A	48.16	0.92	15.19	1.57	8.48	0.16	12.79	10.69	1.84	0.05	0.14	0.193	1361.79	1.33
31-4	48.11	1.02	13.96	1.65	9.17	0.11	13.85	10.27	1.72	0.03	0.12	0.230	1392.28	1.47
31-9	48.25	1.15	15.75	1.48	7.73	0.10	11.66	11.54	1.99	0.07	0.28	0.385	1328.04	1.18
31A	48.04	1.20	15.17	1.53	8.13	0.14	12.27	11.22	1.97	0.08	0.26	0.367	1346.61	1.30
31C	50.95	0.40	15.64	1.25	6.13	0.09	9.24	13.65	1.47	0.08	1.12	1.180	1237.87	0.52
32-2	48.43	0.93	15.40	1.56	8.27	0.09	12.46	10.67	1.98	0.04	0.17	0.224	1350.22	1.27
32-5	48.27	0.90	15.33	1.55	8.28	0.11	12.49	10.98	1.87	0.05	0.16	0.234	1352.75	1.27
33-1	48.77	0.70	14.83	1.48	8.00	0.11	12.07	11.10	1.70	0.06	1.19	1.204	1315.04	1.11
33-3	48.66	0.82	14.92	1.54	8.25	0.11	12.45	11.41	1.76	0.01	0.07	0.182	1352.55	1.18
33-5	48.40	0.85	14.76	1.57	8.46	0.11	12.74	11.33	1.72	0.02	0.05	0.161	1362.72	1.25
34-1	48.70	0.78	16.13	1.49	7.85	0.10	11.83	10.88	1.72	0.06	0.46	0.500	1323.81	1.10
36-1	48.61	0.89	14.82	1.57	8.49	0.10	12.81	11.09	1.50	0.02	0.10	0.238	1360.86	1.19
36-2	48.53	0.97	14.98	1.57	8.46	0.14	12.75	10.35	1.92	0.06	0.27	0.307	1354.74	1.28
36-3	48.65	0.98	14.91	1.58	8.51	0.12	12.86	10.21	1.84	0.07	0.25	0.285	1356.84	1.27

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
36A	48.52	0.97	14.95	1.57	8.47	0.14	12.77	10.34	1.92	0.06	0.29	0.333	1354.83	1.29
36C	48.54	1.25	14.49	1.57	8.63	0.05	13.01	10.46	1.77	0.03	0.20	0.320	1363.77	1.28
37-5	48.69	0.91	15.10	1.58	8.51	0.12	12.82	10.36	1.74	0.02	0.14	0.255	1358.38	1.23
38-3	48.31	0.99	13.18	1.66	9.44	0.13	14.22	10.30	1.65	0.01	0.11	0.256	1402.84	1.47
38-4	48.38	0.97	12.96	1.68	9.60	0.12	14.48	10.16	1.54	0.01	0.09	0.247	1409.90	1.48
38-6	49.92	0.60	16.11	1.42	7.32	0.11	11.04	10.81	1.78	0.12	0.77	0.678	1289.96	0.88
38C	49.72	0.75	14.49	1.50	8.08	0.08	12.18	10.56	1.74	0.11	0.78	0.661	1320.95	1.01
39-1	48.56	0.91	14.08	1.63	9.02	0.10	13.60	10.34	1.65	0.02	0.11	0.246	1382.36	1.34
39-2	48.04	1.01	13.15	1.67	9.51	0.13	14.35	10.41	1.60	0.04	0.08	0.238	1409.58	1.54
39-3	48.13	0.94	13.11	1.69	9.63	0.13	14.50	10.07	1.68	0.02	0.11	0.236	1411.69	1.56
40-3	50.82	0.63	17.02	1.34	6.66	0.06	10.06	10.60	1.81	0.12	0.88	0.729	1257.97	0.71
41-3	50.91	0.56	17.32	1.25	5.99	0.12	9.04	11.88	2.00	0.04	0.89	0.771	1234.24	0.62
41A	50.68	0.58	17.37	1.24	5.90	0.13	8.90	12.08	1.98	0.06	1.09	0.894	1228.87	0.63
42-1	49.14	0.79	15.15	1.52	8.14	0.12	12.29	10.67	1.83	0.01	0.36	0.426	1336.76	1.11
42-2	49.08	0.82	15.20	1.53	8.12	0.09	12.24	11.02	1.65	0.02	0.22	0.338	1339.09	1.08
42A	48.69	0.82	14.64	1.56	8.47	0.11	12.77	10.72	1.68	0.03	0.52	0.574	1348.84	1.20
43-3	49.02	0.84	15.05	1.51	8.08	0.06	12.18	11.06	1.78	0.05	0.36	0.454	1335.21	1.10
44-1	48.63	0.83	14.62	1.59	8.72	0.12	13.16	10.49	1.66	0.02	0.16	0.287	1368.45	1.27
44-3	48.51	0.82	14.35	1.62	9.00	0.06	13.56	10.34	1.56	0.01	0.16	0.292	1379.83	1.32
BC15-2	48.87	0.89	14.61	1.59	8.69	0.13	13.09	10.48	1.60	0.01	0.06	0.221	1367.31	1.21
M-69084	48.87	1.00	14.97	1.53	8.31	0.11	12.55	10.70	1.66	0.03	0.27	0.374	1347.06	1.15
MD38	49.52	0.37	17.81	1.23	5.89	0.13	8.90	13.38	1.42	0.22	1.14	1.104	1233.89	0.66
MD43	54.56	0.01	19.98	0.84	3.28	0.06	4.99	13.04	1.56	0.98	0.70	0.561	1126.29	0.14

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
Lau Basin														
37.1	50.58	0.39	17.61	1.24	5.85		8.84	12.70	1.47	0.35	0.97	0.888	1229.49	0.59
43.1	49.56	0.46	16.61	1.34	6.66		10.03	12.45	1.26	0.51	1.12	1.125	1260.99	0.78
47.1	52.45	0.34	18.73	1.02	4.45		6.76	12.94	1.41	0.55	1.34	1.051	1167.23	0.32
56.1	52.84	0.27	16.43	1.24	5.92		8.95	11.83	1.18	0.31	1.04	0.983	1220.62	0.36
57.1	53.24	0.26	16.27	1.25	5.93		8.95	11.75	1.12	0.29	0.93	0.894	1220.85	0.32
15_1_2R.01	48.93	0.96	17.59	1.38	6.81	0.12	10.28	11.75	2.02	0.03	0.13	0.231	1288.77	0.94
15_1_4R.01	48.69	0.91	17.61	1.38	6.82	0.11	10.29	12.03	2.02	0.03	0.12	0.227	1290.92	0.96
18_1_2R.01	48.06	1.12	16.41	1.54	7.61	0.15	11.47	11.13	2.32	0.02	0.17	0.270	1325.85	1.25
19-7	47.88	1.63	18.07	1.30	6.29	0.08	9.50	11.71	2.39	0.62	0.54	0.549	1267.01	1.12
23_8_1R.01	50.23	0.79	17.34	1.36	6.67	0.11	10.05	11.70	1.59	0.02	0.13	0.223	1275.31	0.70
24_1_1R.01	49.97	0.83	16.83	1.40	6.94	0.12	10.47	11.70	1.59	0.02	0.13	0.225	1288.10	0.76
41_3_2R.01	50.01	0.74	18.00	1.27	5.99	0.12	9.05	12.67	1.70	0.06	0.39	0.452	1246.79	0.65
CD33/15-1-1	48.87	0.93	17.66	1.37	6.75	0.11	10.20	11.95	2.01	0.03	0.12	0.222	1287.51	0.93
CD33/20-5-2	49.75	0.85	15.72	1.48	7.67	0.14	11.57	10.77	1.71	0.05	0.30	0.374	1314.72	0.93
CD33/22-6-1	49.67	0.91	15.82	1.46	7.55	0.12	11.39	10.73	1.88	0.04	0.43	0.501	1307.52	0.95
CD33/41-2-1	50.00	0.77	17.74	1.29	6.09	0.12	9.20	12.62	1.71	0.06	0.40	0.461	1250.67	0.66
K5-14	48.25	1.70	17.67	1.33	6.49	0.10	9.80	11.65	2.40	0.16	0.47	0.501	1273.66	1.05
K5-15	47.30	1.75	15.88	1.55	8.32	0.12	12.55	9.36	2.43	0.17	0.56	0.621	1347.96	1.54
M-2212-2	49.52	0.74	17.34	1.26	6.11	0.09	9.23	12.47	2.00	0.24	0.99	0.934	1244.85	0.79
M-2218-1	49.65	0.92	17.14	1.26	6.11	0.10	9.21	12.19	2.12	0.22	1.07	0.908	1242.17	0.79
M-2218-10	49.71	0.92	13.67	1.42	7.71	0.14	11.64	11.93	1.94	0.17	0.76	0.852	1311.47	0.98
M-2218-11	49.38	0.94	15.60	1.37	6.89	0.14	10.41	12.31	2.17	0.16	0.64	0.722	1283.25	0.93

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
M-2218-2	49.94	0.93	17.32	1.26	6.11	0.08	9.22	12.17	1.69	0.21	1.06	0.919	1239.70	0.70
M-2218-4	49.17	1.01	16.04	1.42	7.15	0.11	10.78	11.53	2.36	0.10	0.33	0.411	1298.85	1.03
M-2218-7	50.06	0.83	16.48	1.28	6.24	0.12	9.41	12.21	2.10	0.20	1.07	0.915	1245.62	0.76
M-2218-8	49.03	0.90	16.12	1.33	6.67	0.10	10.05	12.28	2.06	0.25	1.20	1.195	1264.63	0.93
M-2218-9	48.50	1.02	15.67	1.48	7.61	0.14	11.48	11.42	2.32	0.08	0.27	0.359	1322.69	1.19
M-2231-2	48.58	1.00	15.57	1.51	7.88	0.11	11.89	11.34	1.99	0.04	0.10	0.196	1336.34	1.17
MIR2231-13	48.74	1.12	15.30	1.51	7.97	0.09	12.01	11.08	2.04	0.03	0.10	0.239	1338.41	1.17
MIR2231-3	48.56	1.05	15.32	1.51	7.88	0.12	11.88	11.40	2.15	0.04	0.08	0.192	1337.30	1.20
MIR-2231-5	50.60	0.87	17.22	1.26	5.95	0.10	8.99	12.66	2.11	0.20	0.04	0.205	1249.86	0.65
MIR-2231-6	48.83	1.11	15.10	1.52	8.06	0.09	12.16	11.02	2.01	0.04	0.07	0.200	1342.77	1.17
MIR-2231-7	48.82	1.14	15.36	1.50	7.88	0.10	11.87	11.12	2.07	0.04	0.10	0.238	1334.15	1.15
MIR2231-8	48.37	1.07	15.73	1.49	7.70	0.14	11.62	11.54	2.14	0.04	0.16	0.259	1329.62	1.19
MIR2239-1	49.36	0.96	15.60	1.43	7.36	0.12	11.10	11.54	1.86	0.06	0.60	0.636	1299.72	0.95
MIR2239-2	49.55	0.82	15.92	1.42	7.25	0.10	10.92	11.69	1.73	0.06	0.56	0.600	1294.55	0.88
NLD-06-01	48.08	1.63	18.06	1.33	6.51	0.15	9.84	11.16	2.54	0.20	0.51	0.540	1274.28	1.11
NLD-07-01	46.75	1.38	16.68	1.51	7.93	0.14	11.98	10.52	2.54	0.21	0.36	0.461	1343.50	1.59
NLD-08-01	47.63	1.56	18.48	1.33	6.55	0.14	9.89	10.82	2.68	0.22	0.71	0.701	1274.05	1.20
NLD-09-02	47.51	1.51	18.58	1.34	6.57	0.13	9.91	11.06	2.57	0.22	0.61	0.614	1277.07	1.20
NLD-10-01	46.46	1.50	17.78	1.45	7.43	0.15	11.21	10.76	2.57	0.26	0.42	0.507	1322.41	1.53
NLD-11-01	47.59	1.55	18.61	1.33	6.51	0.13	9.83	10.95	2.61	0.23	0.65	0.651	1273.72	1.19
NLD-13-01	46.79	1.42	17.49	1.46	7.46	0.14	11.24	11.15	2.58	0.05	0.22	0.293	1326.46	1.45
NLD-14-01	47.19	1.58	18.01	1.42	7.20	0.15	10.85	10.42	2.63	0.14	0.40	0.461	1307.44	1.36
NLD-15-01	47.31	1.61	16.95	1.46	7.52	0.15	11.36	10.61	2.53	0.17	0.34	0.433	1322.66	1.40

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
NLD-16-01	47.28	1.61	16.74	1.48	7.60	0.16	11.45	10.63	2.56	0.16	0.33	0.428	1326.00	1.42
NLD-17-01	47.67	1.44	17.54	1.37	6.82	0.16	10.28	11.59	2.44	0.14	0.55	0.616	1288.42	1.18
NLD-18-01	48.71	1.67	18.78	1.19	5.54	0.10	8.42	11.76	2.69	0.26	0.88	0.682	1229.64	0.92
NLD-18-02	46.07	1.71	18.78	1.43	7.20	0.14	10.85	10.60	2.82	0.15	0.26	0.316	1317.58	1.57
NLD-19-01	47.66	1.82	17.64	1.39	6.94	0.13	10.47	10.62	2.74	0.15	0.43	0.493	1294.50	1.26
NLD-20-01	47.51	1.46	14.68	1.60	8.75	0.16	13.21	9.73	2.44	0.08	0.37	0.521	1371.83	1.61
NLD-21-01	47.06	1.71	16.69	1.45	7.48	0.12	11.30	11.14	2.70	0.10	0.24	0.351	1326.51	1.45
NLD-22-01	46.32	1.43	18.13	1.39	6.97	0.15	10.54	11.83	2.35	0.28	0.61	0.732	1302.62	1.41
NLD-22-02	48.22	1.19	16.96	1.39	6.87	0.16	10.38	12.26	2.30	0.05	0.21	0.268	1296.17	1.08
NLD-23-01	46.38	1.73	17.69	1.46	7.55	0.15	11.40	10.35	2.84	0.12	0.33	0.375	1329.85	1.60
NLD-24-01	46.06	1.68	17.88	1.50	7.79	0.14	11.75	10.22	2.60	0.11	0.27	0.339	1341.79	1.66
NLD-24-02	46.42	1.37	16.99	1.51	7.90	0.17	11.92	10.73	2.62	0.08	0.29	0.389	1345.99	1.63
NLD-24-03	46.01	1.68	17.55	1.49	7.76	0.15	11.68	10.35	2.92	0.10	0.32	0.379	1341.06	1.72
NLD-25-01	47.03	1.48	17.98	1.38	6.87	0.15	10.35	11.53	2.54	0.15	0.54	0.637	1294.31	1.30
NLD-27-01	48.13	0.82	17.44	1.40	6.98	0.17	10.51	11.98	2.23	0.03	0.29	0.383	1297.68	1.10
NLD-28-01	48.50	1.46	17.51	1.34	6.58	0.11	9.93	11.77	2.52	0.10	0.18	0.304	1281.91	1.04
NLD-30-01	47.71	1.38	16.75	1.52	8.03	0.12	12.10	9.29	2.70	0.13	0.27	0.353	1339.74	1.47
NLD-31-01	47.22	1.32	18.19	1.38	6.88	0.14	10.40	11.36	2.56	0.12	0.43	0.530	1296.17	1.28
NLD-32-01	47.71	1.59	17.74	1.34	6.57	0.08	9.92	11.81	2.62	0.20	0.43	0.447	1281.77	1.17
NLD-35-01	48.53	1.52	17.79	1.33	6.51	0.13	9.83	11.21	2.82	0.11	0.21	0.317	1278.19	1.08
NLD-37-01	49.21	1.43	18.67	1.25	5.93	0.12	8.94	11.01	2.70	0.28	0.46	0.469	1245.78	0.92
NLD-38-01	47.01	1.48	16.02	1.52	8.07	0.15	12.17	10.67	2.43	0.08	0.39	0.493	1346.74	1.53
NLD-40-01	47.11	1.22	16.81	1.53	8.06	0.16	12.17	10.37	2.25	0.06	0.25	0.263	1347.38	1.48

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
NLD-41-01	48.02	1.28	17.82	1.33	6.58	0.14	9.91	11.71	2.12	0.17	0.93	0.900	1269.19	1.05
NLD-42-01	47.55	1.12	17.59	1.46	7.39	0.15	11.13	11.31	2.16	0.03	0.09	0.113	1320.27	1.25
NLD-43-01	47.60	1.41	16.18	1.50	7.83	0.13	11.80	11.02	2.31	0.05	0.18	0.295	1337.53	1.36
NLD-43-02	47.69	1.32	16.14	1.50	7.81	0.13	11.78	11.11	2.41	0.03	0.08	0.223	1339.27	1.36
NLD-44-01	48.46	1.37	17.79	1.31	6.38	0.12	9.65	11.93	2.27	0.26	0.47	0.502	1268.94	1.00
NLD-44-02	48.33	1.33	17.95	1.32	6.40	0.13	9.66	11.98	2.22	0.26	0.43	0.476	1270.61	1.01
NLD-45-01	47.17	1.48	15.10	1.59	8.69	0.15	13.10	10.54	2.09	0.03	0.05	0.227	1379.37	1.58
NLD-46-01	47.80	1.32	16.04	1.50	7.81	0.13	11.79	11.38	2.20	0.02	0.00	0.180	1340.85	1.31
NLD-47-01	47.50	1.25	16.17	1.50	7.81	0.16	11.79	11.48	2.21	0.05	0.09	0.237	1340.72	1.36
NLD-48-01	47.20	1.22	17.24	1.49	7.64	0.18	11.51	11.03	2.28	0.04	0.17	0.168	1331.48	1.38
NLD-49-01	47.58	1.21	15.95	1.53	8.06	0.16	12.16	10.96	2.27	0.03	0.09	0.212	1350.01	1.41
NLD-50-01	47.74	1.16	16.78	1.42	7.08	0.16	10.68	12.39	2.37	0.05	0.18	0.242	1308.51	1.19
NLD-51-01	47.79	1.13	16.98	1.39	6.89	0.15	10.39	12.70	2.30	0.06	0.21	0.273	1300.10	1.13
NLD-55-01	47.03	1.41	16.50	1.51	7.78	0.17	11.75	10.84	2.90	0.02	0.10	0.151	1342.77	1.55
NLD-56-01	47.78	0.97	17.21	1.45	7.29	0.17	11.02	11.65	2.34	0.04	0.09	0.105	1317.40	1.23
NLD-57-01	48.21	0.94	16.45	1.48	7.65	0.14	11.55	11.25	2.25	0.01	0.06	0.178	1329.73	1.22
NLD-58-01	48.12	1.04	17.08	1.45	7.35	0.16	11.09	11.18	2.36	0.04	0.12	0.159	1315.84	1.20
NLD-59-01	47.85	1.21	16.96	1.45	7.37	0.16	11.13	11.09	2.54	0.04	0.21	0.275	1316.97	1.27
NLD-60-01	48.24	1.11	18.64	1.32	6.41	0.10	9.65	11.68	2.51	0.04	0.30	0.383	1272.87	1.04
NLD-61-01	48.85	0.71	15.99	1.43	7.16	0.16	10.80	12.82	2.01	0.01	0.06	0.106	1308.55	0.98
NLD-62-01	48.57	0.91	16.34	1.41	6.95	0.16	10.49	12.86	2.24	0.02	0.06	0.095	1301.91	1.02
NLD-63-01	48.53	0.85	15.58	1.48	7.56	0.17	11.40	12.02	2.29	0.01	0.12	0.100	1325.28	1.15
NLD-64-01	48.17	0.92	16.99	1.47	7.53	0.18	11.37	10.97	2.23	0.04	0.13	0.148	1322.50	1.21

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
NLD-65-01	48.35	0.87	16.90	1.46	7.40	0.15	11.16	11.43	2.14	0.03	0.10	0.143	1317.11	1.14
NLD-66-01	47.99	1.15	16.84	1.49	7.73	0.15	11.67	10.58	2.18	0.04	0.18	0.233	1329.60	1.26
PPTU24-1	48.24	1.54	16.64	1.36	6.80	0.13	10.25	12.02	2.22	0.35	0.44	0.471	1287.74	1.09
PPTU36-1	48.23	1.33	14.90	1.54	8.30	0.09	12.52	10.78	2.08	0.16	0.07	0.240	1356.38	1.34
PPTU6-1	47.47	0.72	16.02	1.52	8.03	0.17	12.13	11.48	2.09	0.02	0.35	0.463	1344.82	1.38
RNDB 11-1	48.82	0.88	15.81	1.42	7.35	0.14	11.07	11.75	1.60	0.12	1.04	1.062	1292.60	0.97
RNDB 24-3	49.42	0.94	17.62	1.31	6.36	0.15	9.59	11.72	2.04	0.21	0.64	0.669	1258.68	0.85
RNDB 44-2	49.27	0.76	15.95	1.34	6.96	0.14	10.51	12.21	1.88	0.16	0.82	0.893	1281.77	0.91
RNDB 45-1	49.72	0.80	17.51	1.26	6.04	0.12	9.09	12.27	2.02	0.21	0.95	0.874	1240.62	0.76
RNDB 6-1	50.48	0.53	19.79	1.09	4.45	0.10	6.76	13.52	1.71	0.13	1.44	1.011	1173.91	0.46
SO35/84KD1	49.36	0.63	17.31	1.32	6.55	0.12	9.89	12.26	1.28	0.15	1.13	1.081	1257.24	0.75
SO48/114KD	49.58	0.41	15.77	1.43	7.44	0.13	11.24	11.75	0.96	0.25	1.04	1.023	1291.22	0.82
SO48/114KD C.10	48.10	0.46	11.05	1.74	10.40	0.15	15.69	10.08	0.96	0.19	1.17	1.665	1414.19	1.59
SO48/114KD C.6a1	48.62	0.49	11.15	1.68	10.06	0.11	15.19	9.81	1.02	0.20	1.64	2.168	1382.85	1.41
SO48/114KD C.6b1	48.40	0.47	11.21	1.69	10.05	0.10	15.15	10.26	1.04	0.20	1.43	1.923	1390.48	1.46
SO48/18GA2	48.07	1.24	15.47	1.57	8.41	0.12	12.67	9.85	2.23	0.06	0.31	0.359	1353.67	1.40
SO48/42GC	48.61	0.96	14.80	1.53	8.05	0.14	12.12	11.52	1.99	0.04	0.23	0.312	1340.81	1.19
SO48/46GC	48.29	1.02	14.65	1.58	8.48	0.12	12.78	10.99	1.95	0.04	0.11	0.234	1362.82	1.32
SO48/61GC	50.30	0.62	16.18	1.33	6.61	0.13	9.96	12.08	1.35	0.22	1.22	1.242	1253.61	0.68
SO48/61GC B.4	49.65	0.62	13.51	1.43	7.81	0.19	11.77	11.50	1.49	0.23	1.80	2.011	1291.12	0.94
SO48/61GC B.7a2	49.83	0.62	15.82	1.33	6.76	0.16	10.20	11.99	1.47	0.23	1.58	1.561	1255.60	0.77
SO48/61GC B.8a1	49.97	0.65	13.47	1.50	8.11	0.12	12.21	11.34	1.44	0.22	0.98	1.227	1317.80	0.94
SO48/61GC B.8b1	49.83	0.65	13.65	1.49	8.07	0.14	12.17	11.00	1.42	0.22	1.35	1.665	1308.30	0.96

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
SO48/61GC B.9	49.92	0.70	16.54	1.36	6.79	0.11	10.25	11.69	1.57	0.26	0.82	0.855	1269.48	0.78
SO48/61GC C.1	49.98	0.65	15.43	1.38	7.07	0.10	10.67	11.82	1.47	0.23	1.21	1.286	1273.14	0.80
SO48/61GC C.2	49.87	0.65	16.50	1.33	6.63	0.08	10.01	12.15	1.48	0.25	1.05	1.062	1260.18	0.75
SO48/61GC C.3A1	49.67	0.61	14.87	1.41	7.34	0.14	11.06	12.07	1.36	0.20	1.28	1.392	1283.75	0.84
SO48/61GC C.3B1	50.24	0.68	13.59	1.46	7.97	0.13	12.02	11.42	1.43	0.22	0.84	0.969	1314.50	0.88
SO48/61GC C.4	50.30	0.64	14.31	1.39	7.46	0.18	11.25	11.93	1.36	0.22	0.97	1.061	1291.94	0.79
SO48/61GC C.5	49.72	0.62	15.21	1.39	7.26	0.11	10.95	11.44	1.47	0.25	1.58	1.652	1273.64	0.86
SO48/61GC C.6	49.85	0.62	13.41	1.47	8.09	0.16	12.19	11.41	1.43	0.20	1.17	1.353	1313.58	0.95
SON0048-G007	47.45	0.95	14.52	1.66	9.24	0.14	13.92	10.13	1.82	0.02	0.15	0.188	1397.49	1.61
SON0048-G042	49.22	1.05	15.85	1.47	7.48	0.12	11.27	11.17	2.20	0.05	0.12	0.174	1315.12	1.04
TWD106-4	46.67	1.38	17.44	1.46	7.54	0.13	11.36	10.74	2.51	0.28	0.50	0.521	1323.60	1.51
VG-9750	47.47	0.62	15.71	1.52	7.80		11.77	12.58	1.57	0.07	0.89	0.896	1323.56	1.21
VG-9764	48.15	1.18	14.66	1.59	8.71		13.13	10.69	1.82	0.04	0.03	0.193	1374.37	1.37
VG-9778	49.08	0.60	17.54	1.29	6.34		9.57	12.64	1.96	0.08	0.89	0.858	1256.99	0.84
VG-9779	48.17	1.16	14.62	1.60	8.75		13.21	10.54	1.86	0.04	0.05	0.200	1375.75	1.39
VG-9785	48.04	1.00	16.10	1.49	7.72		11.63	11.75	2.11	0.05	0.11	0.220	1332.84	1.23
VG-9786	48.61	1.08	14.83	1.56	8.37		12.64	10.97	1.87	0.06	0.02	0.201	1358.33	1.24
VG-9789	48.30	0.63	17.63	1.30	6.35		9.59	13.22	1.80	0.13	1.05	0.989	1259.36	0.90
VG-9792	47.01	0.97	16.58	1.53	7.98		12.04	11.34	2.37	0.03	0.15	0.214	1349.42	1.49
VG-9801	49.58	0.90	16.24	1.48	7.74		11.67	10.32	1.70	0.07	0.29	0.341	1317.01	0.97
VG-9809	50.06	0.78	16.52	1.38	6.82		10.28	12.24	1.61	0.08	0.24	0.295	1281.58	0.73
VG-9812	48.85	0.87	16.64	1.45	7.45		11.26	11.22	1.85	0.06	0.37	0.419	1309.81	1.03
VG-9816	49.45	0.85	16.07	1.44	7.40		11.16	11.44	1.83	0.05	0.30	0.397	1306.18	0.93

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
VG-9824	49.53	0.60	18.12	1.24	5.96		9.00	12.65	1.60	0.11	1.19	1.087	1234.17	0.69
VG-9825	49.69	0.88	15.54	1.50	7.84		11.84	10.91	1.63	0.03	0.14	0.250	1325.93	0.95
VG-9831	50.57	0.51	18.70	1.15	5.28		8.02	13.11	1.41	0.10	1.15	1.054	1206.23	0.49
VG-9834	49.63	0.85	15.71	1.48	7.66		11.57	11.37	1.61	0.04	0.08	0.184	1320.98	0.92
VG-9836	49.74	0.62	17.79	1.25	6.03		9.10	12.63	1.60	0.10	1.14	1.059	1236.71	0.68
VG-9838	49.53	0.79	17.07	1.34	6.67		10.05	11.91	1.95	0.06	0.63	0.583	1270.76	0.83
VG-9839	50.90	0.60	18.01	1.21	5.70		8.65	12.44	1.50	0.11	0.88	0.723	1223.83	0.52
VG-9844	48.83	0.86	16.70	1.41	7.22		10.87	11.40	1.99	0.09	0.63	0.666	1295.04	1.01
VG-9847	49.48	0.73	16.26	1.40	6.93		10.44	12.52	1.85	0.08	0.31	0.388	1288.84	0.85
W1	51.95	0.18	18.16	1.15	5.25	0.05	7.99	12.49	1.11	0.59	1.07	0.784	1200.71	0.40
W2	51.86	0.30	18.05	1.16	5.36	0.05	8.15	12.18	1.16	0.51	1.22	0.990	1202.29	0.43
WAS7TOW-086-P	47.39	1.36	15.73	1.50	7.85	0.16	11.83	11.54	2.39	0.12	0.14	0.265	1342.61	1.42
WAS7TOW-095-P	49.09	0.77	15.61	1.43	7.22	0.16	10.88	12.88	1.86	0.02	0.07	0.131	1309.11	0.93
WAS7TOW-106-001	46.37	1.40	17.72	1.46	7.51	0.14	11.32	11.05	2.39	0.30	0.36	0.400	1327.53	1.53
WASPPTU-005-003	49.23	1.45	17.00	1.39	6.92	0.05	10.43	10.99	2.36	0.08	0.09	0.183	1291.38	0.98
WASPPTU-005-005	48.86	1.41	16.88	1.42	7.15	0.09	10.77	10.83	2.41	0.08	0.11	0.194	1302.25	1.08
WASPPTU-005-006	49.28	1.36	17.09	1.39	6.92	0.10	10.45	10.91	2.31	0.07	0.11	0.207	1291.04	0.97
WASPPTU-006-006	49.86	1.29	18.84	1.18	5.46	0.05	8.30	11.30	2.81	0.25	0.65	0.647	1224.18	0.81
WASPPTU-006-007	50.01	1.38	18.87	1.16	5.33	0.03	8.11	11.35	2.84	0.23	0.68	0.670	1218.27	0.78
North Fiji Basin														
KK 16-1	47.45	1.21	17.03	1.52	7.95	0.10	12.00	10.15	2.27	0.08	0.24	0.258	1339.96	1.41
KK 16-2	47.64	1.25	16.29	1.54	8.13	0.07	12.26	10.23	2.27	0.10	0.23	0.273	1347.06	1.42

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
KK 16-3	47.93	1.13	16.10	1.51	7.88	0.09	11.89	10.98	2.24	0.07	0.18	0.259	1337.64	1.31
KK 16-4	47.88	1.25	17.10	1.48	7.61	0.13	11.48	10.47	2.26	0.12	0.22	0.261	1323.94	1.28
KK 16-5	48.15	1.21	16.82	1.48	7.64	0.09	11.52	10.48	2.29	0.09	0.22	0.269	1323.69	1.25
KK 16-6	48.03	1.11	16.21	1.50	7.82	0.10	11.80	10.96	2.22	0.07	0.18	0.254	1334.51	1.28
KK 16-7	47.61	1.14	15.82	1.53	8.02	0.11	12.11	11.17	2.24	0.06	0.18	0.252	1346.79	1.39
KK 16-8	47.30	1.25	16.96	1.53	8.03	0.13	12.11	10.10	2.26	0.08	0.24	0.262	1343.80	1.45
KK 16-10	52.34	0.93	14.96	1.33	6.88	0.12	10.39	9.85	2.35	0.07	0.78	0.838	1262.67	0.65
KK 16-11	48.00	1.12	16.16	1.50	7.83	0.09	11.82	10.99	2.20	0.09	0.18	0.258	1335.23	1.29
KK 16-12	47.34	1.21	16.74	1.53	8.06	0.13	12.17	10.13	2.38	0.10	0.22	0.255	1346.24	1.48
KK 16-13	47.67	1.12	15.89	1.52	8.02	0.12	12.10	11.03	2.22	0.12	0.18	0.261	1345.61	1.39
KK 16-14	47.59	1.16	15.77	1.52	7.98	0.09	12.03	11.29	2.34	0.05	0.18	0.255	1345.36	1.40
KK 16-16	47.86	0.98	15.17	1.55	8.30	0.11	12.53	11.37	2.06	0.03	0.04	0.127	1361.11	1.38
KK 16-17	48.13	0.96	15.84	1.51	7.84	0.10	11.82	11.55	2.13	0.05	0.07	0.137	1338.62	1.25
SPS3 DT-1	48.50	1.40	15.67	1.48	7.59	0.15	11.44	11.26	2.30	0.09	0.10	0.185	1324.90	1.19
SPS3 D1-3	48.01	1.24	15.49	1.55	8.22	0.13	12.38	10.66	2.13	0.08	0.11	0.167	1352.19	1.35
SPS3 D4-2	49.10	1.24	16.63	1.40	6.92	0.19	10.44	11.63	2.16	0.28	0.00	0.142	1295.73	0.99
SPS3 D4-5	47.82	1.23	15.57	1.56	8.26	0.12	12.45	10.85	2.00	0.06	0.10	0.175	1355.55	1.36
K87 ST4 D2-1	48.21	1.29	16.62	1.44	7.31	0.11	11.04	10.82	2.93	0.11	0.12	0.210	1315.07	1.29
K87 ST4 D2-2	48.42	1.33	16.25	1.45	7.41	0.15	11.17	10.69	2.87	0.12	0.15	0.225	1316.78	1.27
K87 ST4 D2-4	48.60	1.34	16.80	1.39	6.93	0.15	10.46	11.25	2.84	0.12	0.11	0.209	1297.76	1.15
K87 ST4 D2-5	48.59	1.33	16.24	1.44	7.33	0.11	11.08	10.71	2.88	0.13	0.14	0.223	1313.46	1.24
K87 ST4 D2-7	48.42	1.37	15.92	1.48	7.68	0.14	11.60	10.49	2.63	0.10	0.16	0.227	1327.52	1.28
K87 ST4 D2-8	48.27	1.32	16.88	1.42	7.11	0.11	10.74	10.97	2.98	0.11	0.11	0.208	1306.98	1.25

Table 2.S3: *cont.* Corrected Fo₉₀ compositions for NW Lau Basin basalts

Sample	SiO ₂ wt.%	TiO ₂ wt.%	Al ₂ O ₃ wt.%	Fe ₂ O ₃ wt.%	FeO wt.%	MnO wt.%	MgO wt.%	CaO wt.%	Na ₂ O wt.%	K ₂ O wt.%	H ₂ O wt.%	H ₂ O _(8.0) wt.%	T °C	P GPa
K87 ST4 DTA-3	48.74	2.03	18.05	1.26	5.86	0.15	8.91	10.94	2.60	0.79	0.66	0.822	1244.41	1.02
K87 ST4 DTA-4	47.76	1.51	14.56	1.63	9.14	0.14	13.80	9.46	1.36	0.15	0.49	0.578	1379.19	1.45
K87 ST4 DTA-7	47.49	1.53	14.56	1.60	8.90	0.10	13.41	9.56	2.20	0.13	0.52	0.599	1372.50	1.59
K87 ST4 DTB-1	48.89	1.05	15.04	1.51	7.49	0.14	11.31	12.00	1.83	0.08	0.64	0.983	1308.47	1.02
K87 ST4 DTB-2	48.70	2.03	18.29	1.23	5.70	0.14	8.68	11.22	2.46	0.79	0.76	0.919	1237.19	0.98
K87 ST6 D4-1	48.36	1.31	15.90	1.54	8.04	0.10	12.13	10.07	2.39	0.04	0.13	0.167	1341.42	1.31
K87 ST6 D4-3	48.63	1.27	16.11	1.50	7.73	0.14	11.67	10.38	2.42	0.05	0.10	0.161	1328.22	1.22
K87 ST6 D4-5	48.87	1.31	16.12	1.49	7.64	0.19	11.52	10.14	2.56	0.05	0.12	0.162	1322.50	1.19
K87 ST6 DTA-1	48.30	1.24	17.36	1.41	7.05	0.10	10.64	10.32	2.73	0.41	0.44	0.512	1295.36	1.24
K87 ST8 D5-5	48.99	2.10	18.35	1.24	5.75	0.11	8.73	10.96	2.51	0.96	0.29	0.359	1244.02	0.98
K87 ST8 D5-6	47.99	1.51	15.03	1.58	8.49	0.14	12.79	10.18	1.99	0.12	0.18	0.274	1360.92	1.39
K87 ST14 D10-1	47.80	1.37	15.71	1.57	8.31	0.14	12.53	10.13	2.25	0.07	0.13	0.173	1355.96	1.43
K87 ST14 D10-2	47.60	1.38	15.65	1.58	8.46	0.16	12.77	9.90	2.25	0.09	0.14	0.178	1363.33	1.50
K87 ST14 D10-6	48.15	1.45	16.14	1.49	7.74	0.11	11.68	10.67	2.24	0.17	0.15	0.252	1330.59	1.27
K87 ST14 D10-10	47.96	1.50	16.31	1.50	7.75	0.13	11.69	10.44	2.39	0.17	0.15	0.236	1331.65	1.33
K87 ST15 D11-2	47.56	1.69	16.87	1.47	7.52	0.09	11.35	10.58	2.52	0.16	0.19	0.254	1323.96	1.36
K87 ST15 D11-8	47.44	1.67	16.42	1.52	7.91	0.15	11.91	10.11	2.56	0.13	0.20	0.262	1339.30	1.46
K87 ST21 D3-6	47.79	1.86	16.61	1.44	7.41	0.14	11.19	9.76	2.83	0.41	0.57	0.669	1310.01	1.39
Y90 S53.D9.1	49.03	1.21	16.85	1.32	6.51	0.13	9.82	11.64	2.44	0.39	0.65	0.737	1268.12	0.99
Y90 S53.D9.3	48.95	1.24	17.07	1.32	6.47	0.11	9.75	11.66	2.38	0.39	0.64	0.715	1266.71	0.99
Y90 S55.D11.3	47.53	1.17	16.47	1.51	7.85	0.16	11.83	10.99	2.22	0.06	0.20	0.215	1337.87	1.36
NLD-05-01-01	48.29	1.12	16.02	1.52	7.94	0.14	11.96	10.84	2.03	0.05	0.09	0.107	1338.82	1.23
NLD-05-02-01	47.81	1.10	16.54	1.51	7.77	0.16	11.71	11.02	2.21	0.06	0.11	0.119	1334.73	1.30

Figure 2.1 **A)** Detailed map of the Mariana Trough, showing samples from Volpe et al., 1987; Hawkins et al., 1990; Gribble et al., 1996; Gribble et al., 1998; Pearce et al., 2005. Spreading segments are the Northern Mariana Trough (NMT) from 19-22°N, the Central Mariana Trough (CMT) from 17-19°N, and the Southern Mariana Trough (SMT) from 15-17°N. **B)** Detailed map of East Scotia Ridge, showing samples from Fretzdorff et al., 2002. Spreading segments are E2 - E9. **C)** Detailed map of the Manus Basin, showing samples from Danyushevsky et al., 1993; Kamenetsky et al., 2001; Sinton et al., 2003; Shaw et al., 2004; Shaw et al., 2012. Spreading segments are Manus Spreading Center (MSC), Eastern Transitional Zone (ETZ), Southern Rifts (SR), and Eastern Rifts (ER). **D)** Detailed map of the Lau Basin, showing samples from Hawkins, 1976; Aggrey et al., 1988; Jambon and Zimmermann, 1990; Danyushevsky et al., 1993; Sinton et al., 1993; Pearce et al., 1995; Kamenetsky et al., 1997; Peate et al., 2001; Melson et al., 2002; Keller et al., 2008; Bézous et al., 2009; Escrig et al., 2009; Tian et al., 2011; Escrig et al., 2012; Lytle et al., 2012. Spreading segments are Rochambeau Rifts (RR), Northwest Lau Spreading Center (NWLSC), Peggy Ridge (PR), Central Lau Spreading Center (CLSC), Intermediate Lau Spreading Center (ILSC), Eastern Lau Spreading Center (ELSC), Fonualei Rifts Spreading Center (FSC), and Mangatolu Triple Junction (MTJ). **E)** Detailed map of the North Fiji Basin, showing samples from Aggrey et al., 1988; Danyushevsky et al., 1993; Sinton et al., 1993; Eissen et al., 1991; Eissen et al., 1994; Nohara et al., 1994. Spreading segments are the Triple Junction (TJ), the N15 spreading center (N15), and the North-South spreading center (N-S). Basemaps were created using GeoMapApp (<http://www.geomapapp.org>; Ryan et al., 2009).

Figure 2.2 A) Plot of CO₂ vs. H₂O, showing samples from four global back-arc basins. Degassing paths, shown by the dashed gray (closed system) and dashed black (open system) lines, are calculated using Volatile Calc [Newman and Lowenstern, 2002] with the following constraints: 49 wt.% SiO₂, 1.4 wt.% H₂O, 240 ppm CO₂, 1000°C, and for closed system degassing 0.5 wt.% exsolved volatiles. **B)** Plot of hydrostatic pressure at collection depth vs. pressure of volatile saturation (see panel A) for glasses from the Mariana Trough (squares), Manus Basin (circles), Lau Basin (diamonds), and North Fiji Basin (stars). A 1:1 line is plotted with an uncertainty in collection pressure of 50 bars, to account for the possibility that lava flowed downhill from the initial eruption site.

Figure 2.3 Plot of $\text{MgO}_{\text{mineral-in}}$ vs. average $\text{H}_2\text{O}_{(8.0)}$ values, showing point of plagioclase (diamonds) and clinopyroxene (squares) saturation for modeled liquid lines of descent of varying H_2O contents (0.21 – 1.25 wt.%), determined using Petrolog3 (Danyushevsky and Pelchov, 2011). The equation determined from the plagioclase trend is $\text{MgO}_{\text{plag-in}} = -0.6(\text{H}_2\text{O}_{(8.0)}) + 9.3789$ and the equation for clinopyroxene crystallization is $\text{MgO}_{\text{cpx-in}} = -0.2654(\text{H}_2\text{O}_{(8.0)}) + 7.8617$.

Figure 2.4 A) Regionally averaged $\text{Na}_{(\text{F090})}$ vs. axial depth in global MORB and back-arc basins. The Na_2O concentrations are corrected to equilibrium with Fo_{90} (see section 2.6). The small black circles are MORB samples from Klein and Langmuir (1987). The back-arc basin samples from this study are regional averages of the dry ($\text{H}_2\text{O} < 0.5$ wt.%) basalts. Symbols for the BABBs are squares (Mariana Trough), crosses (East Scotia Ridge), circles (Manus Basin), diamonds (Lau Basin), and stars (North Fiji Basin). **B)** Regionally averaged $\text{Na}_{(\text{F090})}$ vs. $\text{Fe}_{(\text{F090})}$, where the Na_2O and FeO concentrations are corrected to equilibrium with Fo_{90} . The gray circles are MORBs from Langmuir et al., 1992. The MORB model potential temperature curve, shown by the black line and open circles, is pooled fractional melts from Langmuir et al., 1992. The back-arc basin samples are regional averages of the dry basalts in each basin.

Figure 2.5 Major element systematics vs. H_2O of primary melt compositions. The concentrations were corrected to equilibrium with Fo90 (see section 2.6). Back-arc basin symbols are the same as in Figure 4. **A)** Plot of $TiO_{2(Fo90)}$ vs. $H_2O_{(Fo90)}$. **B)** Plot of $Na_2O_{(Fo90)}$ vs. $H_2O_{(Fo90)}$. **C)** Plot of $FeO^*_{(Fo90)}$ vs. $H_2O_{(Fo90)}$.

Figure 2.6 Nb/Zr vs. TiO₂/Y plot showing variations in mantle source enrichment for the back-arc basin samples. The symbols are the same as in Figure 2.4.

Figure 2.7 Plot of temperature vs. pressure for hydrous melting model. The solid thick gray line is the adiabat for a mantle potential temperature of ~1255°C. The solid black line is the melt path for heat of fusion of 180 cal/g. The melt contours (5%, 10%, 15%, 20%, 30%) are calculated from equations in section 4.2 in the text. **A)** The dashed black line is the wet solidus is for $C_{\text{H}_2\text{O}}^0$ of 0.2 wt.% (Kelley et al., 2010). **B)** The dashed black line is the dry solidus is for $C_{\text{H}_2\text{O}}^0$ of 0.0 wt.% (Kelley et al., 2010).

Figure 2.8 Melt fraction (F) vs. $C_{\text{H}_2\text{O}}^\circ$ for all five back-arc basins. Symbols are the same as in Figure 4 and color coded for spreading segment within each basin. The combined random uncertainties in model input variables, using a Monte Carlo simulation, are shown for 10 example points as error ellipses (90% confidence). The example points are identified by thicker black outlines. The solid black lines are five mantle potential temperature curves from the hydrous adiabatic melting model (see section 4.2 for model details). The dashed lines are melt curves calculated from Kelley et al., 2010. **A)** Mariana Trough. Segments are Northern Mariana Trough (NMT; 19-22°C), Central Mariana Trough (CMT; 17-19°C), and Southern Mariana Trough (SMT; 15-17°C). The T_p for Mariana Trough is 1320°C. **B)** East Scotia Ridge. The T_p is 1315°C. **C)** Manus Basin. Spreading segments are Eastern Transform Zone (ETZ), Manus Spreading Center (MSC), and Southern Rifts (SR). Manus Basin T_p is 1480°C. **D)** Lau Basin. Segments are Central Lau Spreading Center (CLSC), Eastern Lau Spreading Center (ELSC), Intermediate Lau Spreading Center (ILSC), Fonualei Spreading Center (FSC), Rochambeau Rifts (RR), Northwest Lau Spreading Center (NWLSC), and Peggy Ridge (PR). The T_p is 1400°C. **E)** North Fiji Basin. Spreading segments are Triple Junction (TJ), N15 spreading center, and N-S spreading center. The T_p for North Fiji Basin is 1412°C.

Figure 2.S1 Plots of MgO versus major elements and ratios in glasses from the Mariana Trough. Samples are divided into four categories, those with < 0.3 wt.% H₂O_(8.0) (circles), those with 0.3 – 0.75 wt.% H₂O_(8.0) (squares), those with 0.75 – 1.2 wt.% H₂O_(8.0) (diamonds), and those with > 1.2 wt.% H₂O_(8.0) (triangles). Liquid lines of descent are shown on Figures 2.S1b-2.S1d, modeled using slopes (Table 2.2) determined from both Petrolog3 (Dayushevsky and Plechov, 2011) and natural samples. The black dashed line is for the wet melt case and the black solid line is for the dry melt case. **A)** Plot of MgO versus H₂O. Thin lines show predicted variations of H₂O during fractional crystallization for variable initial H₂O contents, used to constrain H₂O_(8.0) (Taylor and Martinez, 2003). **B)** Plot of MgO versus Al₂O₃. **C)** Plot of MgO versus CaO. **D)** Plot of MgO versus CaO/Al₂O₃.

Figure 2.S2 Plots of MgO versus major elements and ratios in glasses from the East Scotia Ridge. Samples are divided into four categories, those with < 0.3 wt.% $H_2O_{(8.0)}$ (circles), those with 0.3 – 0.75 wt.% $H_2O_{(8.0)}$ (squares), those with 0.75 – 1.2 wt.% $H_2O_{(8.0)}$ (diamonds), and those with > 1.2 wt.% $H_2O_{(8.0)}$ (triangles). Liquid lines of descent are shown on Figures 2.S2b-2.S2d, modeled using slopes (Table 2.2) determined from both Petrolog3 (Dayushevsky and Plechov, 2011) and natural samples. The black dashed line is for the wet melt case and the black solid line is for the dry melt case. **A)** Plot of MgO versus H_2O . Thin lines show predicted variations of H_2O during fractional crystallization for variable initial H_2O contents, used to constrain $H_2O_{(8.0)}$ (Taylor and Martinez, 2003). **B)** Plot of MgO versus Al_2O_3 . **C)** Plot of MgO versus CaO. **D)** Plot of MgO versus CaO/Al_2O_3 .

Figure 2.S3 Plots of MgO versus major elements and ratios in glasses from the Manus Basin. Samples are divided into four categories, those with $< 0.3 \text{ wt.}\% \text{ H}_2\text{O}_{(8.0)}$ (circles), those with $0.3 - 0.75 \text{ wt.}\% \text{ H}_2\text{O}_{(8.0)}$ (squares), those with $0.75 - 1.2 \text{ wt.}\% \text{ H}_2\text{O}_{(8.0)}$ (diamonds), and those with $> 1.2 \text{ wt.}\% \text{ H}_2\text{O}_{(8.0)}$ (triangles). Liquid lines of descent are shown on Figures 2.S3b-2.S3d, modeled using slopes (Table 2.2) determined from both Petrolog3 (Dayushevsky and Plechov, 2011) and natural samples. The black dashed line is for the wet melt case and the black solid line is for the dry melt case. **A)** Plot of MgO versus H_2O . Thin lines show predicted variations of H_2O during fractional crystallization for variable initial H_2O contents, used to constrain $\text{H}_2\text{O}_{(8.0)}$ (Taylor and Martinez, 2003). **B)** Plot of MgO versus Al_2O_3 . **C)** Plot of MgO versus CaO. **D)** Plot of MgO versus $\text{CaO}/\text{Al}_2\text{O}_3$.

Figure 2.S4 Plots of MgO versus major elements and ratios in glasses from the Lau Basin. Samples are divided into four categories, those with < 0.3 wt.% H₂O_(8.0) (circles), those with 0.3 – 0.75 wt.% H₂O_(8.0) (squares), those with 0.75 – 1.2 wt.% H₂O_(8.0) (diamonds), and those with > 1.2 wt.% H₂O_(8.0) (triangles). Liquid lines of descent are shown on Figures 2.S4b-2.S4d, modeled using slopes (Table 2.2) determined from both Petrolog3 (Dayushevsky and Plechov, 2011) and natural samples. The black dashed line is for the wet melt case and the black solid line is for the dry melt case. **A)** Plot of MgO versus H₂O. Thin lines show predicted variations of H₂O during fractional crystallization for variable initial H₂O contents, used to constrain H₂O_(8.0) (Taylor and Martinez, 2003). **B)** Plot of MgO versus Al₂O₃. **C)** Plot of MgO versus CaO. **D)** Plot of MgO versus CaO/Al₂O₃.

Figure 2.S5 Plots of MgO versus major elements and ratios in glasses from the North Fiji Basin. Samples are divided into four categories, those with < 0.3 wt.% $\text{H}_2\text{O}_{(8.0)}$ (circles), those with 0.3 – 0.75 wt.% $\text{H}_2\text{O}_{(8.0)}$ (squares), those with 0.75 – 1.2 wt.% $\text{H}_2\text{O}_{(8.0)}$ (diamonds), and those with > 1.2 wt.% $\text{H}_2\text{O}_{(8.0)}$ (triangles). Liquid lines of descent are shown on Figures 2.S5b-2.S5d, modeled using slopes (Table 2.2) determined from both Petrolog3 (Dayushevsky and Plechov, 2011) and natural samples. The black dashed line is for the wet melt case and the black solid line is for the dry melt case. **A)** Plot of MgO versus H_2O . Thin lines show predicted variations of H_2O during fractional crystallization for variable initial H_2O contents, used to constrain $\text{H}_2\text{O}_{(8.0)}$ (Taylor and Martinez, 2003). **B)** Plot of MgO versus Al_2O_3 . **C)** Plot of MgO versus CaO. **D)** Plot of MgO versus $\text{CaO}/\text{Al}_2\text{O}_3$.

MANUSCRIPT III

**DETERMINING THE ORIGIN OF SLAB-DERIVED FLUIDS BENEATH
BACK-ARC SPREADING CENTERS**

by

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Abstract

The relationship between water and trace elements in back-arc basin basalts relate closely to the compositions of the subducted inputs, the conditions and mineralogy of the subducting slab, and fluid pathways through the mantle wedge. These factors combine to create the fluids that modify back-arc mantle sources, yet there are competing ideas for how slab-derived fluids reach the back-arc source. A variety of models suggest many possibilities including amphibole breakdown reactions, diapiric flow, mixing of shallow, arc-like fluids with low-water fractional melts, or fluids generated at depth. Here, we present new SIMS measurements of magmatic volatiles (H_2O , CO_2 , S, Cl, F) and new LA-ICP-MS trace element data for basaltic glasses (>5 wt.% MgO) from the Manus, North Fiji, and Lau Basins. In combination with previously-published data for these basins and the Mariana Trough and the East Scotia Ridge, we use recent geochemical models of slab conditions based on $\text{H}_2\text{O}/\text{Ce}$ ratios, coupled with geodynamic models of slab surface temperatures (SST) at each subduction zone to provide a robust test of the origination conditions of back-arc slab-derived fluids. The $\text{H}_2\text{O}/\text{Ce}$ ratios of these BABB span a wide range (250-3900) from normal mid-ocean ridge basalt (MORB; 150-250) to high, arc-like ratios. Average SSTs for these global back arc basin spreading segments, referenced to 4 GPa, range from ~ 775 - 1000°C , hotter on average than global arc SSTs referenced to the same pressure (730 - 850°C), suggesting that back-arc basin fluids are derived from hotter domains of the subducted slab than those that supply their respective arcs. Here we explore three possible explanations: (1) back-arc slab-derived fluids are created at greater slab depth, and thus, higher temperature than arc fluids, (2) back-arc fluids

come from the same depth as arcs but from the hotter edges of the slab, or (3) thermal models predict slab surface geotherms that are too cold. The back-arc basin slab-derived fluids may reflect a combination of thermal variations in the slab and an underprediction of slab surface geotherms.

1. Introduction

Back-arc basin basalts (BABB) have elevated H₂O contents compared to mid-ocean ridge basalts (MORB), which is often taken as evidence of the incorporation of H₂O-rich slab derived fluids in the back-arc mantle source (Taylor and Martinez, 2003). Yet, many back-arc spreading centers do not vertically overlie the subducting plate, and the origin and transport pathways of slab-derived fluids to the back-arc are not well constrained. The question thus remains, from where in the subducted plate do these fluids originate, and how are they incorporated into the back-arc mantle source? Although a broad spectrum of models for fluid transport in the mantle wedge have been proposed (e.g., Davies and Stevenson, 1992; Hall and Kincaid, 2001), few constraints have drawn from the geochemistry of back-arc basin lavas themselves. Here, we present new measurements of H₂O and trace elements in back-arc basin basalt glasses, to address the questions of where back-arc fluids originate in the subducting plate, and how they are delivered to the mantle sources of back-arc spreading centers.

The question of how slab derived fluids reach the back-arc is an interesting and widely debated topic. Fluid migration in the mantle wedge of a subduction zone is commonly simplified to a vertical pathway, where fluids released from the slab travel

directly upwards through the mantle to volcanic centers at the surface (e.g., Tatsumi, 1989). This surely represents an oversimplification, as the subducting slab is not always vertically present beneath back-arc spreading centers (e.g., Mariana Trough; Creager and Jordan, 1986). Several proposed mechanisms for delivering slab derived fluids to the back-arc mantle source derive from both dynamical and geochemical viewpoints. For example, amphibole formation/breakdown reactions are proposed as a mechanism for transporting H₂O horizontally away from the subducted plate (Davies and Stevenson, 1992). Another concept for fluid migration that has been investigated is diapiric flow where the release of H₂O, in a fluid fluxed mantle wedge, forms a partially molten melt region from which diapirs form at the top. The diapiric flow can rise to the surface either as isolated diapirs with trailing conduits or networked flow of coalescing diapirs and resultant thick conduits, in which melt diapirs rise rapidly to the surface ($\sim 10^4$ to 10^6 years; Tatsumi, 1989; Hall and Kincaid, 2001; Gerya and Yuen, 2003; Weatherly and Katz, 2012).

Another approach to addressing the question of fluid migration is geochemical modeling, which places fewer constraints on the migration processes or specific pathways, but uses geochemical characteristics of natural samples to constrain where the fluids originate in the slab. Analysis of back-arc basin submarine glasses using trace elements (i.e., Ba/Nb, Th/Nb, Th/Ta, and Nb/Ta) as tracers of total subduction input, mantle depletion, and shallow vs. deep subduction components provide constraints on shallow vs. deep origin of the back-arc fluids (Pearce et al., 2006). Measurements of H₂O in submarine glasses from Lau, North Fiji, Manus, and Woodlark Basins, in combination with major elements (i.e., K₂O and TiO₂) provided

geochemical constraints for determining whether the subduction-related component in BABBs was a fluid or a melt (Danyushevsky et al., 1993). A focused, comprehensive study of the Mariana Trough investigated the role of water in BABBs and proposed a positive correlation between extent of melting and H₂O concentration of the mantle (Stolper and Newman, 1994). The Mariana Trough fluids reaching the back-arc source were proposed to go through a sort of chromatographic geochemical exchange with the mantle that partly controls the fluid composition (Stolper and Newman, 1994). Another model proposes mixing melts from a shallow, arc-like fluid with low-water, fractional melts beneath the back-arc spreading center (Langmuir et al., 2006), based on observations of low FeO* in the wettest BABB melts that are suggestive of shallow hydrous melting. An alternative model proposes a fluid released at depth that enters the back-arc source from below (Kelley et al., 2006), which expands the melt region beneath back-arc spreading centers to greater depths than observed at mid-ocean ridges. There is a large diversity of geochemical models for the origin of slab-derived fluids, despite obvious limitations caused by few quantitative constraints.

However, before the question of fluid migration can be addressed, constraints on the source location of the slab-derived back-arc basin fluids must first be determined. The relative release conditions of fluids from the slab can be constrained using slab fluid geothermometry, which provides the temperature conditions of slab fluid origination. Recent work on slab fluid geothermometry has developed two new thermometers dependent on two different geochemical ratios (H₂O/Ce and K₂O/H₂O; Plank et al., 2009). The H₂O/Ce geothermometer requires the slab to be saturated in monazite or allanite to control the REE budget of the fluid and the K₂O/H₂O

geothermometer requires the presence of phengite to control the concentration of K in the fluid (Plank et al., 2009). When these conditions are met, the ratios of these elements in a fluid are sensitive to temperature, as the presence of the accessory minerals keep Ce and K concentrations in the fluid constant while H₂O concentration decreases with increasing temperature as the total solute content of the fluid increases. At arc volcanoes, these geothermometers reveal slab surface temperatures (SST) ranging from 750-950°C, indicating solute-rich fluids or melts released at shallow depths (100-180 km).

These models have since been refined to isolate the slab fluid signature from the mantle contributions to H₂O and Ce using Nb/Ce systematics (Cooper et al., 2012), giving SSTs of ~730-900°C beneath global arc volcanoes that correlate with robust 2D thermal models (Syracuse et al., 2010). Similar to arcs, back-arc lavas have elevated H₂O contents and H₂O/Ce ratios over MORB because of the presence of a slab-derived fluid in the mantle sources beneath back-arc basin spreading centers. MORBs have a well known H₂O/Ce ratio of 150-250 (Dixon et al., 2002), whereas BABBs have a wider range of H₂O/Ce ratios from MORB-like (H₂O/Ce = 250) to arc-like (H₂O/Ce = 3900), and arcs range from H₂O/Ce of 400 to 20,000 (Cooper et al., 2012). The new thermometers have yet to be used at back-arcs, but they present great promise for aiding in the resolution of models for the origin of back-arc fluids and how they may be delivered to back-arc mantle sources.

With this work, we will address the origins of elevated H₂O contents and H₂O/Ce ratios in back-arc basin basalts with new and existing geochemical data for major and trace elements and dissolved volatiles for a large suite of submarine glasses

from five global back-arc spreading centers. Using this comprehensive data suite, we will apply the new thermometers (Plank et al., 2009; Cooper et al., 2012) to these global back-arc lavas to determine the temperature conditions of slab fluid release. We will show that slab fluids that reach the back-arc basin mantle source reflect ~60-100°C higher slab temperatures than arcs, when referenced at a common pressure, and they therefore originate from hotter parts of the slab than the fluids that reach arc mantle sources. With respect to slab thermal models for these settings, these constraints suggest that the fluids supplying back-arc mantle either derive from much higher pressures (≥ 8 GPa), or indicate a significant 3-D component to slab thermal structure that current 2-D models do not capture. Additionally, we explore along-strike variations and the consequences of these observations for models of mantle flow in global back-arc basin settings.

2. Samples and Methods

2.1 Geologic Context

The samples in this global back-arc basin study are selected from five back-arc basins located in both the Pacific and Atlantic Oceans (Figure 3.1). The first of four Pacific back-arc basins is the Mariana Trough (Figure 3.1a), a crescent-shaped back-arc spreading center opening behind the Mariana Arc, formed from the subduction of the Pacific Plate beneath the Philippine Sea plate (Fryer, 1995; Pearce et al., 2005). Deep Sea Drilling Project (DSDP) Leg 60 determined that spreading in the back-arc began about 6.5 Ma at a rate of 2.15 cm/yr (Hussong and Uyeda, 1981; Fryer, 1995). The Mariana Trough can be divided into three spreading segment regions based on

latitude: the Northern Mariana Trough (NMT) from 19-22°N, the Central Mariana Trough (CMT) from 17-19°N, and the Southern Mariana Trough (SMT) from 15-17°N.

South of the Mariana Trough is the complex, rapidly opening Manus Back-arc Basin (Figure 3.1c), located behind the New Britain arc in the Bismarck Sea. About 10 Ma, the subduction direction changed as a result of collision of the Ontong Java Plateau with New Ireland and the North Solomon Arc (Cooper and Taylor, 1987; Beier et al., 2010). The Solomon Sea Plate, plate created by spreading in the nearby Woodlark Basin, subducts northwards beneath the New Britain Arc at a rate of 15.4 cm/yr (Lee and Ruellan, 2006; Joshima and Honza, 1987). The Manus Basin consists of four spreading segments: the Southern Rifts (SR), Eastern Rifts (ER), the Manus Spreading Center (MSC), and the Eastern Transitional Zone (ETZ).

The third back-arc basin is found in the Tonga-Lau system, an oceanic subduction zone in the southwest Pacific, where the Pacific Plate subducts beneath the Indo-Australian Plate. Behind the Tonga Arc, back-arc spreading initiated at ~6 Ma in the Lau Basin (Figure 3.1d; Taylor et al. 1996), which is a V-shaped basin with several actively spreading segments that impinge upon the Tonga Arc towards the south. The rates of both plate convergence and back-arc spreading are highest at the north end of the subduction zone (Hawkins 1995), which exhibits the fastest back-arc opening on Earth, spreading at a rate of 160 mm/yr, decreasing southwards to rates of 60 mm/yr (e.g., Bevis et al., 1995; Taylor et al., 1996). The six spreading segments discussed in this study are the Eastern Lau Spreading Center (ELSC), Central Lau Spreading Center (CLSC), Intermediate Lau Spreading Center (ILSC), Peggy Ridge

(PR), Fonualei Rifts Spreading Center (FSC), and the Mangatolu Triple Junction (MTJ).

Located to the west of the Lau Basin is the North Fiji Basin (NFB; Figure 3.1e), which is opening behind the Vanuatu Arc. The New Hebrides subduction zone, the western boundary of the NFB, is subducting at a rate of 9-12 cm/yr (Maillet et al., 1989), and evolves into the Hunter Fracture Zone, a transform fault, at the southern end of the NFB. The two spreading segments focused on in this study are the Triple Junction (TJ) and the N15 spreading center (N15).

The last back-arc basin, East Scotia Ridge (Figure 3.1b), is located in the South Atlantic Ocean. The South American Plate is subducting beneath the Sandwich Plate at a rate of 70-85 km/Myr (Pelayo and Wiens, 1989), forming the South Sandwich Islands and Trench. Located to the west of the South Sandwich Islands, the East Scotia Ridge Back-arc Basin formed ca 11 Ma, with an average basin-wide spreading rate of 65 mm/yr over the last 1.7 Ma (Barker, 1995; Livermore et al., 1995; Livermore et al., 1997; Bruguier and Livermore, 2001; Fretzdorff et al., 2002). The East Scotia Ridge spreading segments focused on in this study are E2, E3, E4, E5, E6, and E9.

2.2 Samples and Preparation

The 327 basaltic glass samples in this study are a combination of compiled, previously-published data and newly collected data for submarine glasses from the Mariana Trough, East Scotia, Lau, Manus, and North Fiji back-arc basin spreading centers. We present new trace element and dissolved volatile data from submarine glasses for the Lau, Manus, and North Fiji basins (Table 3.S1; Eissen et al., 1991;

Sinton et al., 1993; Eissen et al., 1994; Nohara et al., 1994; Melson et al., 2002; Sinton et al., 2003; Shaw et al., 2004; Shaw et al., 2012). The basaltic glass samples reported here are from the glassy rims of basaltic pillow lavas and flow tops collected by sea floor dredging. Submarine glasses are important for this study because the glass is a representative snapshot of the basaltic liquid upon eruption, recording the volatile and trace element composition of the magma before eruptive degassing removes most volatiles from the lava. Samples analyzed in this study are from the publicly accessible repositories of the Smithsonian Institution Volcanic Glass Collection (Melson et al., 2002), the URI/GSO Marine Geological Samples Laboratory (Eissen et al., 1991; Eissen et al., 1994; Nohara et al., 1994; Lytle et al., 2012), or were contributed by John Sinton (Sinton et al., 2003). Additional samples include previously published volatile and trace element data from the Mariana Trough, East Scotia Ridge, and Lau Basin (Hawkins, 1976; Volpe et al., 1987; Aggrey et al., 1988; Hawkins et al., 1990; Jambon and Zimmermann, 1990; Danyushevsky et al., 1993; Sinton et al., 1993; Pearce et al., 1995; Gribble et al., 1996; Kamenetsky et al., 1997; Gribble et al., 1998; Kamenetsky et al., 2001; Peate et al., 2001; Fretzdorff et al., 2002; Pearce et al., 2005; Keller et al., 2008; Bézoz et al., 2009; Escrig et al., 2009; Tian et al., 2011; Escrig et al., 2012; Lytle et al., 2012).

2.3 Secondary Ionization Mass Spectrometry (SIMS)

Glass chips from Manus Basin, Lau Basin, and North Fiji Basin lavas were mounted in indium for analysis of dissolved volatiles (H₂O, CO₂, S, Cl, F) by secondary ionization mass spectrometry (SIMS) at the Carnegie Institution of

Washington. Volatile analysis (Table 3.S1) was done in triplicate using the CAMECA IMS 6f ion microprobe with a 5-10 nA Cs⁺ primary beam following procedures outlined by Hauri (2002) and Hauri et al. (2002), using ¹⁶O¹H as the mass for determination of H₂O. Combined reproducibility and accuracy are typically ≤5% RSD for all the volatile elements.

2.4 Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-IPC-MS)

Trace elements (Li, Be, K₂O, Sc, TiO₂, V, Cr, Co, Ni, Cu, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U) were determined by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS; Table S1) using a New Wave UP 213nm Nd:YAG deep penetration laser coupled with a Thermo XSeriesII quadrupole ICP-MS at the Graduate School of Oceanography, University of Rhode Island following procedures described by Lytle et al. (2012). Analyses were run using an 80µm spot size, 10 Hz repeat rate, and 80-90% energy output. Nine natural glass standards from United States Geological Survey (BIR-1g, BHVO-2g, BCR-2g) and Max Planck Institute (Jochum et al., 2006; GOR132-G, StHls-G, ATHO-G, T1-G, ML3B-G, KL2-G) were used to produce calibration curves that were linear to $r^2 > 0.99$ for all elements reported. Analysis of glass chips were done in triplicate with an average reproducibility of 4% RSD for all elements.

3. Results

3.1 Effects of Low-Pressure Differentiation

Volatile loss from magma results from exsolution of dissolved gases from the magma during depressurization upon ascent from the mantle to the surface.

Assessment of volatile loss from each glass is possible as major volatile species (e.g., H₂O, CO₂) have different vapor/melt solubilities. Carbon dioxide has lower solubility in silicate melt at low pressure and is expected to begin degassing before H₂O (Dixon and Stolper, 1995), and the mixed CO₂-H₂O content of a glass reflects the minimum pressure of final equilibration of vapor with melt if the latter was volatile-saturated. Figure 3.2a shows CO₂ vs. H₂O in the glasses from Mariana Trough, Manus Basin, Lau Basin, North Fiji Basin, and East Scotia Ridge, which indicate vapor saturation at pressures of 200-600 bars. Model degassing paths show that CO₂ is more sensitive to the early stages of degassing, and that H₂O loss is not significant until most CO₂ has been removed from the melt (Dixon and Stolper, 1995; Newman and Lowenstern, 2002). Samples without measured CO₂ data were treated as having no CO₂ in the glass. Based on this analysis, most glasses have likely lost variable amounts of CO₂, but H₂O concentrations are relatively unmodified from the original magmatic values.

Figure 3.2b compares the calculated pressure at H₂O-CO₂ saturation with the hydrostatic pressure at the mean collection depth of each sample. Most samples are found to be vapor-oversaturated or saturated at the pressure of collection, which is typical of mid-ocean ridge basalts and reflects relatively fast transport and eruption of magma from mid-crustal depths (Danyushevsky et al., 1993). However, for the samples with no CO₂ data, the samples were only used in this study if they appeared undersaturated on Figure 3.2b. Samples were considered undegassed for H₂O when they lay along or below the zone of saturation (gray field in Figure 3.2b; n = 246),

where the pressure of H₂O-CO₂ saturation was equal to or less than the pressure at the sample collection depth. Those that are interpreted as having lost some H₂O were excluded from modeling.

Beyond degassing, H₂O/Ce ratio is unlikely to be affected by magmatic processes such as crystallization. This lack of fractionation occurs due to a similarity in the partitioning ($D_{\text{H}_2\text{O}}$ and D_{Ce}) of H₂O and Ce between mafic silicate minerals and melt (Michael, 1995; Dixon et al., 2002; Hauri et al., 2006). During melting or crystallization, mafic components such as olivine and orthopyroxene have $D_{\text{H}_2\text{O}}/D_{\text{Ce}} > 1$ and clinopyroxene and garnet have $D_{\text{H}_2\text{O}}/D_{\text{Ce}} < 1$ but the bulk lithology of spinel lherzolite has $D_{\text{H}_2\text{O}}/D_{\text{Ce}} \approx 1$, and therefore, there is little overall fractionation of H₂O and Ce during mantle melting or crystallization (Michael, 1995; Hauri et al., 2006).

3.2. Water and Trace Element Variations in BABBs

H₂O/Ce ratio is a useful indicator of subduction influence, as the H₂O content of the lavas generally increases with decreasing distance to the arc (e.g., Kelley et al., 2006), while Ce, a non-fluid mobile trace element, remains approximately constant. The BABBs in this study show wide ranges in both the H₂O content and H₂O/Ce ratios, where H₂O ranges from “dry” (0.09 wt.% H₂O) to “wet” (2.23 wt.% H₂O) and H₂O/Ce ratios span 250 - 3900. The Mariana Trough lavas are among the wettest with H₂O contents of 0.21 – 2.23 wt.% and H₂O/Ce ratios of 269 – 2189. Lau Basin basalts have a similar range of H₂O contents (0.09 – 1.45 wt.%), but also have the highest H₂O/Ce ratios (348 – 3900). The Manus Basin is equally wet with H₂O ranging from 0.09 – 1.45 wt.% and H₂O/Ce ratios of 250 – 2667, the East Scotia Ridge shows a

similar variation in H₂O contents (0.24 – 1.63 wt.%) with H₂O/Ce ratios of 259 – 1373, and the North Fiji Basin is the driest basin with H₂O ranging from 0.21 – 0.31 wt.% and H₂O/Ce ratios of 270-301.

An additional ratio that is sensitive to subduction influence is Nb/Nb*, where Nb* is the projected concentration of Nb based on neighboring Th and La abundances. Nb prefers to remain in the slab rather than partitioning into an aqueous fluid or melt due to its compatibility in residual rutile in the slab phase assemblage. As a result, Nb is only mobile in melts if there is no rutile present in the subducting slab. Th and La, are melt mobile, and therefore, in a subduction influenced mantle, Th and La are often present in higher concentrations than Nb. Negative Nb anomalies (Nb/Nb* <1) are characteristic of subduction-influenced magmas and correlate, as defined here, with increasing Th and La additions, relative to comparatively immobile Nb, from the slab to the mantle source. The basalts from all five back-arc basins show a range of Nb anomalies ($0.2 \leq \text{Nb/Nb}^* \leq 1.4$), which broadly correlate with H₂O/Ce ratios (Figure 3.3a). As the increasing influence of subduction on the basalts is observed through the increasing H₂O/Ce ratio, the Nb anomaly becomes increasingly negative (Nb/Nb* <1), also indicative of increasing subduction influence or more “arc-like” characteristics. Although the NFB samples show much smaller variation in the H₂O/Ce and Nb/Nb* ratios than other back-arcs, a similar correlation between increasing H₂O/Ce ratio and increasing negative Nb anomalies is observed at NFB (see inset on Figure 3.3a). The extent of subduction influence can also be observed by comparing the H₂O/Ce ratio with H₂O content of the samples (Figure 3.3b). MORB samples (Dixon et al., 2002) plot at low H₂O and H₂O/Ce ratios and arc samples (Cooper et al., 2012) plot at higher

H₂O and H₂O/Ce ratios. The BABB samples from this study fall in between the MORB and arc samples, showing the influence of subduction on the BABB samples, as the H₂O/Ce ratio and H₂O content increases from MORB-like values to Arc-like values.

3.3. Application of the H₂O/Ce Slab Surface Thermometer

A number of criteria must be met before the thermometer can be accurately applied. These include determining whether slab fluids have influenced the source of a given basalt, constraining the mantle source composition, constraining the contributions of H₂O, Ce, and Nb to back-arc slab fluids, and assessing whether the slab mineralogy required for accurate application of this model is appropriate for BABB fluids. Here, we first assess these key criteria, and then use these new and existing data to apply the H₂O/Ce thermometer to basalts from global back-arc basin settings.

3.3.1. Slab Mineralogy

An important concern in the application of the geothermometer is whether the BABB fluids derive from slabs that are saturated with allanite and/or monazite, which control the Ce budget of the fluids (Plank et al., 2009). The point of monazite-out is calculated through mass balance at ~950°C and 40% melting (Plank et al., 2009) or through experiments at ~780°C and 55% melting with 15% H₂O (Skora and Blundy, 2010). Under conditions where monazite has been exhausted, Ce will become diluted and the resultant fluid H₂O/Ce ratio will reach high values (> 100,000). Such

extremely high H₂O/Ce ratios are not observed in the BABB fluids, thus suggesting that monazite has not been exhausted, and that the geothermometer can be applied.

3.3.2 Identifying Slab Contributions to Magmatic H₂O in BABBs

Determination of the temperature and pressure of slab fluid release relies on accurate constraints on the H₂O/Ce ratios of the fluids derived from the subducted slab. The average H₂O/Ce ratio of MORBs is 192 ± 57 ppm (Dixon et al., 2002), which is the nominal baseline for BABBs with no slab-derived fluids in their mantle sources. Samples from the five back-arc basins that fall within the MORB range for H₂O/Ce ratio are removed from further consideration in this study, as slab fluid contributions to magmatic H₂O cannot be resolved. However, the samples that lie above the average MORB H₂O/Ce ratio ($n = 135$) have likely been influenced by slab fluids released during subduction, and these are considered in our modeling. Although it is possible that some of the BABB within the MORB H₂O/Ce range do have low H₂O/Ce slab fluids in their sources, the exclusion of these samples ultimately yields robust maxima for H₂O/Ce ratios, and robust minima for temperatures constrained by each spreading segment.

3.3.3 Constraints on mantle source composition

The H₂O and Ce contents of back-arc basin basalts derive from two sources, the MORB-like mantle and the fluid added to it from the subducted slab. In order to isolate the slab fluid composition, the mantle contributions to these element abundances must be determined, and then subtracted, from each basalt. This mantle

unmixing process, to remove the effect of the mantle contribution to the $\text{H}_2\text{O}/\text{Ce}$ ratio, requires each basalt to be referenced to an appropriate mantle source composition.

Cooper et al. (2012) used the Nb/Ce ratio to constrain the bulk composition of the mantle sources beneath arc volcanoes. Constraints on the source composition can also be determined using high field strength elements (HFSE), such as Nb and Zr, which are comparatively immobile during subduction. The advantage of using Nb/Zr ratio to determine the source composition is that we can determine the appropriate mantle source for each sample, rather than choosing one source for all samples within the basin (see Cooper et al., 2012). Therefore, following the approach of Langmuir et al. (2006), we use Nb/Zr systematics to split the BABB samples into three groups of varying source enrichment (Figure 3.4; depleted, $\text{Nb}/\text{Zr} < 0.02$; normal, $0.02 > \text{Nb}/\text{Zr} > 0.03$; enriched, $\text{Nb}/\text{Zr} > 0.03$). Depleted samples were referenced to the H-DMM source of Workman and Hart (2005), normal samples to the NMORB source composition of Sun and McDonough (1989), and enriched samples to the EMORB source of Sun and McDonough (1989).

Within each basin, we find a range of mantle source compositions, from enriched to depleted. Both the Mariana Trough and East Scotia Ridge have been viewed as having depleted mantle sources, but the Nb/Zr systematics show that the mantle sources of both basins are on average more enriched (e.g., Langmuir et al., 2006). A hot spot signature has been identified in the basalts from the Manus Basin (Sinton et al., 2003; Shaw et al., 2004; Shaw et al., 2012), and although hot spots are generally considered to be enriched, the Nb/Zr ratios show that the majority of basalts from Manus Basin require a depleted to normal source. The Lau Basin basalts are

mainly depleted, consistent with inferences of a highly depleted mantle beneath the Tonga Arc (Ewart and Hawkesworth, 1987; Woodhead et al., 1993; Ewart et al., 1998; Caulfield et al., 2008), and BABBs from North Fiji Basin show a variety of source enrichment.

3.3.4 Nb/Ce of the Slab Fluid

The Nb/Ce ratio of the arc slab fluid was set at 0.04, the minimum Nb/Ce value observed at arcs (Cooper et al., 2012), but the BABB fluids are likely to be more solute-rich (e.g., as modeled by Stolper and Newman, 1994) and perhaps capable of carrying more Nb. The importance of Nb mobility in slab fluids is significant and must be considered in the case of the BABB slab fluids. For this study, we chose a Nb/Ce ratio of 0.06, the minimum Nb/Ce value observed in back-arc basins (i.e., Lau Basin and Manus Basin samples). The lowest Nb/Ce ratio for BABB is higher than the lowest observed Nb/Ce ratio for arcs, and the Nb/Ce ratio could be significantly higher for the Mariana Trough based on the fluid concentrations of Ta and the light REE from Stolper and Newman (1994). The impact of choosing a higher fluid Nb/Ce ratio than 0.06 would be a decrease in the projected fluid H₂O/Ce ratio, which will result in higher calculated SSTs.

3.3.5 Slab Surface Temperatures Derived from the H₂O/Ce Model

After determining an appropriate mantle source for each back-arc basin basalt (Figure 3.4), the samples can now be “unmixed” to separate the slab fluid composition from the mantle composition, via Nb/Ce and H₂O/Ce ratios (Figure 3.5). As the slab

fluid travels through the mantle, the slab fluid composition is altered through elemental exchange with the background mantle. For example, in the case of H₂O/Ce and Nb/Ce ratios (Figure 3.5), the slab fluid starts with a minimum Nb/Ce ratio = 0.06 and H₂O/Ce ratio >250. As the slab fluid composition mixes with melt produced from the background mantle composition, the observed range in H₂O/Ce and Nb/Ce ratios in Figure 3.5 reflect variable mixtures of fluid and melt.

Figure 3.5 shows Nb/Ce vs. H₂O/Ce for all five back-arc basins, which span a range of Nb/Ce concentrations and require a range of mantle source compositions. The measured H₂O/Ce ratios in the BABBs are “unmixed” to separate out the mantle H₂O/Ce and slab fluid H₂O/Ce contributions by projecting the measured H₂O/Ce ratios along a mixing line between the appropriate mantle source (Figure 3.4) and the slab fluid Nb/Ce ratio (0.06). The BABBs are projected along this mixing line to a slab fluid composition with Nb/Ce = 0.06 and the corresponding H₂O/Ce ratio at Nb/Ce = 0.06 is considered the projected slab fluid H₂O/Ce ratio. The projected H₂O/Ce ratios for BABB fluids range from 288 to 13393 for the five back-arc basins. Using the H₂O/Ce geothermometer ($\ln(\text{H}_2\text{O}/\text{Ce}) = 16.81 - 0.0109 * T_{4\text{GPa}}$; Plank et al., 2009; Cooper et al., 2012), we input the H₂O/Ce ratio of the lavas to determine the slab surface temperature at which the slab fluid for each back-arc basin segment was released, referenced at a pressure of 4 GPa ($\text{SST}_{4\text{GPa}}$; ~820 - 1000°C; Figure 3.6; Table 3.1).

4. Discussion

4.1 The Slab Surface Temperatures Recorded by Back-Arc vs. Arc Fluids

The global range of corrected SSTs for the arcs reported by Cooper et al. (2012) is $\sim 730 - 900^{\circ}\text{C}$. The geothermometer is calibrated at 4 GPa, but a pressure limitation arises as the fluids may have released from the subducting slab at a pressure other than 4 GPa. Therefore, the resultant temperatures from the geothermometer at 4 GPa must be projected to the pressure at which the fluid was released in order to constrain the actual temperature of fluid release from the slab. The pressure correction projects the $\text{H}_2\text{O}/\text{Ce}$ temperatures along lines of constant H_2O (i.e. H_2O isopleths; Figure 3.6), which maintains both the H_2O and Ce concentrations of the fluid, and therefore, maintains the slab fluid $\text{H}_2\text{O}/\text{Ce}$ ratio (for detailed procedure see Cooper et al., 2012).

For arcs, Cooper et al. (2012) projected SSTs to a depth, h , which is the vertical distance from the volcanic center to the seismically-defined slab surface (Syracuse and Abers, 2006). Comparison between the back-arcs and their partner arcs provides a direct contrast of the origin of arc vs. back-arc fluid sources. However, we cannot project back-arc SSTs to a depth, h , because these constraints are unavailable for back-arcs, and because slabs, at least at shallow depths, are not vertically present beneath some back-arcs. 2D thermal models (i.e., Syracuse et al., 2010) give the P-T geotherms of the slab surfaces for global subduction zones that could be used to project $\text{SST}_{4\text{GPa}}$ to the pressure and temperature of intersection with the modeled slab surface. Therefore, back-arcs may be projected to a depth, d , which is the depth in the mantle, along which the appropriate H_2O isopleth intersects the slab surface PT conditions determined from the D80 thermal models of Syracuse et al., 2010.

The South Sandwich, New Britain, and Vanuatu Arcs, relevant to the East Scotia, Manus, and North Fiji basins of this study, were not included in the global arc study of Cooper et al. (2012) because no combined volatile and trace element data are available for these arcs. Therefore, the average temperatures of the slab fluids for these arcs must be estimated using an alternative approach. Due to the global agreement shown by Cooper et al. (2012) between $\text{H}_2\text{O}/\text{Ce}$ temperatures calculated from magmatic compositions and those indicated by the D80 thermal models of Syracuse et al (2010) at the depth of the slab surface beneath the arc volcanoes, we estimate SSTs for the New Britain Arc, Vanuatu Arc, and South Sandwich Arc directly from the D80 thermal models at the depth h . The temperature for the New Britain Arc is 819°C , the temperature for the Vanuatu Arc is 772°C , and the temperature for the South Sandwich Arc is 840°C . The temperature for the Mariana Arc is also recalculated using newly published data for Agrigan melt inclusions (Kelley and Cottrell, 2012), resulting in a slightly warmer temperature ($\sim 773^\circ\text{C}$) than calculated by Cooper et al. (2012).

There are multiple approaches to estimating the slab fluid composition and temperature within the back-arc basins. Taking the sample with the maximum $\text{H}_2\text{O}/\text{Ce}$ ratio at each back-arc spreading center constrains the minimum SST for each global back-arc basin ($\sim 760\text{-}1000^\circ\text{C}$; Table 3.2), but these are all within error (50°C) of the arc SSTs and are unlikely to represent the mean characteristics of the slab fluids of these basins. Averaging $\text{H}_2\text{O}/\text{Ce}$ instead over each spreading segment provides an estimate of SST that likely represents the mean slab P-T conditions of fluid release, rather than the extreme outliers (i.e., minimum and maximum $\text{H}_2\text{O}/\text{Ce}$ ratios; Figure

3.7). The average slab surface temperatures constrained for each spreading segment within each back-arc basin (Table 3.1), as well as the average SST for each basin as a whole, are generally hotter than the associated arcs (Figure 3.6, 3.7). However, one segment in the East Scotia Ridge, E9, overlaps with the estimated SST of the South Sandwich Arc.

Comparison between the back-arc spreading segment average slab fluid temperatures (Table 3.1) and the arc fluid temperatures generally shows that the temperatures in the back-arcs are hotter than the associated arcs at 4 GPa (Figure 3.6), although one segment in the East Scotia Ridge (E9) is cooler than the South Sandwich Arc. The temperatures for the Mariana Trough segments range from 824 - 873°C, which is ~50 - 115°C warmer than the Mariana Arc. The East Scotia Ridge segments are between 823 - 950°C, and, excluding segment E9, are ~45 - 100°C warmer than the South Sandwich Arc. The Manus Basin segments have fluid temperatures between 828 - 882°C, which is ~15 - 70°C warmer than the New Britain Arc. The Tonga-Lau system has back-arc segment temperatures ranging from 776 - 936°C, and shows the largest contrast in temperatures between the back-arc and the arc (~40 - 210°C). The North Fiji Basin is the hottest back-arc basin at 991 - 1004°C, ~160 - 175°C warmer than the Vanuatu Arc. The arc temperatures are broadly consistent with the 2D numerical models of SST (within ~30°C; Figure 3.6; Syracuse et al., 2010; Cooper et al., 2012), when projected to depth h . However, a complication arises with projecting the back-arc basin segment temperatures along the H₂O-isopleths, as the hotter temperatures at 4 GPa do not lie along H₂O-isopleths that intersect the slab surface at depths given by the D80 model (Figure 3.6; Syracuse et al., 2010).

We present three possible scenarios to explain the complication of projecting the back-arc basin segment temperatures to depth: (1) back-arc slab-derived fluids come from deeper than the 8 GPa limit of the 2D thermal models, (2) back-arc fluids come from the same depth as arcs but from hotter edges of the slab, or (3) thermal models predict slab surface geotherms that are too cold. The first scenario projects the back-arc slab-derived fluids to depths greater than 8 GPa, as the D80 models stop at 8 GPa, in a region where the SST is modeled to be nearly isothermal. Figure 3.8a shows a hypothetical schematic of the slab surface geotherm, where the SST eventually reaches an inflection point and becomes hotter with minimal increase in depth, which could occur when slabs stall and flatten out in the mantle, as at locations such as the core-mantle boundary or the transition zone at ~440-660 km depth (van der Hilst et al., 1991; van der Hilst, 1995; Billen, 2008). Following this schematic (Figure 3.8a), the back-arc basin segments could be projected along H₂O-isopleths to intersect the SST at depths greater than 8 GPa. The second scenario proposes 3D variations in slab surface temperature, which the 2D models from Syracuse et al. (2010) do not capture (Figure 3.8b). The third scenario considers the possibility that the 2D thermal models under-predict the slab temperature. Therefore, due to the complications that have arisen with projecting the SST to depth and the inability to constrain pressure, we will discuss the SST variations relative to the 4 GPa reference pressure of the model.

4.2. Local Variations in Back-Arc SSTs

The back-arc basin SST_{4GPa} are warmer than the respective arcs (Figure 3.6), but the question remains of how the fluids may vary with space in the subduction

zone. The fluids measure the temperature of origin and the depth of release remains unconstrained. Therefore, the fluids either reflect the location of the slab as it presumably deepens or reflect the position within the slab, contrasting the plate edge and plate center. To answer these questions we look at the back-arc basin segment $SST_{4\text{GPa}}$ across-arc variations (Figure 3.9) and along-strike variations (Figure 3.10).

Within each back-arc basin, the calculated temperatures of the slab-derived fluids vary (Figure 3.6). Each back-arc basin also exhibits unique structural characteristics, such as the v-shaped opening of the Lau Basin or the arc-oblique opening of the Manus Basin. An important question to consider is whether the geographic orientation of the back-arc basins, specifically the locations of the spreading centers, can help us resolve any spatial patterns in SST variations within back-arcs, relative to the geometry or structure of each system.

Variations in $SST_{4\text{GPa}}$ within each back-arc basin correlate with increasing distance from the arc (Figure 3.9). When referenced at 4 GPa, back-arc segments that are <150 km from the arc appear within the 50°C error of the geothermometer relative to the arc SST, some at greater distances show elevated temperatures outside the model uncertainty, and there is an overall increasing trend in $SST_{4\text{GPa}}$ with distance from the arc. The North Fiji Basin appears to sample the hottest slab fluids, whereas the SSTs within the other basins encompass a common range.

Considering the hypothetical scenario of a superadiabatic SST geotherm at depths >8 GPa (Figure 3.8a), we also project the SST for each segment that appears hotter than the D80 SST models of Syracuse et al. along the H_2O -isopleths to 8 GPa (Figure 3.6). This exercise shows that, were this scenario an accurate reflection of the

origin of slab-derived fluids that reach back-arc sources, the SST required would be ~200 - 400°C higher than that beneath arcs. The further the spreading segment is from the arc, the H₂O content has been observed to decrease closer to MORB-like H₂O values (< 1.0 wt.%). The expected decrease in the presence of slab-derived fluids due to distance from the arc is also observed in the H₂O/Ce values of BABB (250-3900) compared to arc basalts (400-20,000). The temperatures for the back-arc basin spreading segments, projected to 8 GPa, are ~1100 - 1350°C, which are higher than 950°C, the temperature predicted by Plank et al. (2009) where fluids will no longer be saturated with monazite and allanite. Therefore, as the fluids are assumed to be saturated in monazite (see section 3.3.1), the back-arc basin slab-derived fluids do not likely originate at depths greater than 8 GPa.

The effect of the decrease in amount of slab fluids in the back-arc is shown in Figure 3.9, which illustrates hotter temperatures (and lower H₂O/Ce values) in the back-arc with increasing distance from the arc. Therefore the slab-derived fluids that reach the back-arc must come, on average, from hotter temperatures. The depth of fluid generation for back-arc fluids is probably greater than that for arcs, but the thermal variation could suggest a hotter slab edge or influence from toroidal flow, rather than increased depth of origin. Thus, the hotter back-arc fluids signify that the slab section from which the fluid originated is hotter, but cannot constrain what depth in the slab the fluid came from.

Significant along-strike variations in SST may illustrate how the thermal state of the slab varies from plate edge to center, or to what extent fluids from plate edges reach towards the midline of back-arc spreading centers. Two of the five back-arc

basins, East Scotia Ridge and Lau Basin, show variations in SST that are outside of the model uncertainty. The other three back-arc basins, Mariana Trough, Manus Basin, and North Fiji Basin, might show SST variations, but these variations can't be fully resolved with the models at present (Figure 3.10a, 3.10c, 3.10e). The East Scotia Ridge samples show fluids reaching the mantle source at the southern end of the system are colder than those that reach the spreading center interior (Figure 3.10b). This temperature relationship is consistent with models of temperature variations in a subducting slab experiencing symmetric rollback (Kincaid and Griffiths, 2003).

For a comprehensive examination of the SST variations along the Tonga/Lau subducting slab (Figure 3.10d), we look at the near-arc trend (ELSC, FSC, and MTJ). MTJ is close to the northern boundary of the subducting slab, and displays a hotter temperature (879°C) than FSC, the next closest spreading region (818°C), suggesting that the subducting plate edge may be warmer than the center (Figure 3.8b, Figure 3.10d). The along-arc trend shown by the ELSC, FSC, and MTJ are consistent with laboratory models of non-symmetrical slab rollback, where the northern most part of the subducting slab experiences stronger flow around the plate edge and thus warmer temperatures (Figure 3.11; Kincaid and Griffiths, 2003). Contrasting the near-arc trend (ELSC, FSC, MTJ) with the distal-arc trend (>150km from the arc; CLSC, ILSC, PR), hotter SSTs are observed for CLSC, ILSC, and PR. This provides strong evidence that the slab fluids increase in temperature, and originate from greater slab depths, as distance from the arc increases.

We may also assess variations in temperatures for the individual back-arc basins as a whole. Taking the maximum and minimum H₂O/Ce ratios for each back-

arc basin provides minimum and maximum temperature constraints on the origin of the slab-derived fluids that reach the back-arc. Table 3.2 shows the maximum and minimum temperature variations within each back-arc basin using the maximum and minimum $\text{H}_2\text{O}/\text{Ce}$ ratios. In Figure 3.7, at 4 GPa, the slab-fluid temperatures for the arc and the minimum back-arc temperatures overlap within the 50°C uncertainty of the model for all the back-arc basins except NFB. The minimum constraints on temperature thus show that a small proportion of the fluids that reach the back-arc may start at very similar PT conditions as those that reach arcs.

Using the maximum and minimum constraints on temperature, however, biases the perspective towards the extreme outliers, but when the segment weighted averages for each basin are calculated (Table 3.1), the mean temperatures are hotter outside of uncertainty. The large difference between the arc and minimum back-arc temperature in NFB is due to the location of the spreading centers >450 km from the arc. Figure 3.7 shows the comparison between the arcs and several constraints on the back-arc basin temperatures, where both the segment weighted average temperatures and the maximum temperatures for each back-arc are warmer than the arc, outside error (Tables 3.1, 3.2), thus suggesting a deeper depth of origin when projected.

4.3 Constraints on back-arc basin slab fluid origins

Observations from Figures 3.6 and 3.9 show that back-arc basins have hotter fluids than their respective arcs, but not how or why the back-arc fluids are hotter. Here we discuss three possibilities presented by these observations: (1) back-arc slab-derived fluids come from deeper, (2) back-arc fluids come from the same depth as arcs

but from hotter edges of the slab, or (3) thermal models predict slab surface geotherms that are too cold.

The first scenario considers the possibility that the back-arc slab-derived fluids come from deeper depths than the associated arc. As observed in Figure 3.6, the back-arc basin $SST_{4\text{GPa}}$ are hotter than the arcs. When these back-arc segments are projected along H_2O -isopleths to intersect the slab surface at depth, the BAB $SST_{4\text{GPa}}$ do not intersect the D80 thermal model SSTs. The D80 thermal models stop at 8 GPa in a region where the subducting slab geotherm is adiabatic (Syracuse et al., 2010), and a schematic of the slab surface profile (Figure 3.8a) shows the SST eventually reaching an inflection point and becoming hotter with minimal increase in depth. Using the schematic in Figure 3.8a, the back-arc basin segment $SST_{4\text{GPa}}$ can be projected to depth >8 GPa. In this scenario, back-arc basin slab derived fluids originate significantly deeper than respective arcs and come from deep in the mantle (>8 GPa). The temperatures projected for the back-arc basin spreading segments at 8 GPa range from $\sim 1100 - 1350^\circ\text{C}$ (Figure 3.9b), which are higher than the upper temperature limits on monazite and allanite saturation. Plank et al. (2009) predicts a temperature of 950°C , above which slab-derived fluids will no longer be saturated with monazite and allanite. If the slab-derived fluids are not saturated with monazite and allanite, then the basic premise of the H_2O/Ce geothermometer is no longer valid and can not be applied to back-arc slab-derived fluids (Plank et al., 2009; Cooper et al., 2012). However, the H_2O/Ce ratios suggest that the fluids are saturated in monazite (see section 3.3.1), and therefore, the back-arc basin slab-derived fluids do not likely come from depths greater than 8 GPa.

The second scenario proposes that back-arc fluids come from the same depth as arcs, but from hotter sections of the subducting slab. There are variations within $SST_{4\text{GPa}}$ of slab fluid origin for each back-arc basin, shown by the average temperature per spreading segment (Figure 3.6, 3.9, 3.10). The temperatures within each basin increase with increasing distance from the arc (Figure 3.9), suggesting thermal variations within the subducting slab, assuming the fluids are released at the same depth as the arc fluids. If the back-arc fluids originate at the same depth as the arc fluids, the increase in distance and temperature reflects a variation in the thermal structure of the subducting plate. 2D thermal models do not capture the full scenario of fluid movement, while 3D laboratory models incorporate toroidal flow, shown to have an important temperature effect (Kincaid and Griffiths, 2003). Models by Kincaid and Griffiths (2003; 2004) show thermal differences between the plate edge and plate center, based on both the rollback and downdip motions of the subduction slab. The transition from downdip motion to rollback motion leads to an increase of 3°C in the SST in the center of the slab, which, when scaled to mantle temperatures, is an excess of 200°C . A schematic of the thermal variations is shown in Figure 3.8b, which simplifies the thermal structure of the subducting slab into two end members. The subducting slab thermal variations explain the observed back-arc segments $SST_{4\text{GPa}}$ variations relative to the arc $SST_{4\text{GPa}}$.

The third scenario addresses the possibility in which the 2D thermal models predict too cold geotherms for the subducting slabs. While laboratory models have shown that 3D slab subduction has thermal variations within the slab, the laboratory models, when scaled to mantle values, have also been found to have higher

temperatures than 2D numerical models (Kincaid and Griffiths, 2004). The inclusion of back-arc spreading in numerical modeling increases the mantle wedge temperature (Kincaid and Hall, 2003), which in turn increases the subducting slab surface temperature through coupling and thermal exchange between the wedge and slab surface particles (Kincaid and Hall, 2004). Therefore, if the current models of slab surface temperatures predict too cold SSTs, warmer SSTs might help with projecting the back-arc basins SSTs to depth. Warmer SSTs will enable the projection of BABB fluids to temperatures that intersect the subducting slab at depths constrained by the thermal models (<8 GPa).

The most likely scenario for the origin of the back-arc basin fluids is a combination of the last two scenarios, in which the thermal models may underpredict SST and the slab-derived fluids reflect thermal variations in the subducting slab (see section 4.2; Figures 3.9 and 3.10). One important consideration is that the thermal models from Syracuse et al. (2010) are 2D models and may not capture the 3D thermal variations, and therefore may also underpredict the SST. Figure 3.11 shows the potential scenario where back-arc basin fluids originate from depth and reflect potential thermal variations due to 3D flow around the edges of the subducting slab. The motion of the subducting plate plays a significant role in the thermal structure of the mantle wedge, where only down-dip motion of the subducting plate results in warmer plate edges and cooler center, and roll-back motion of the subducting plate results in cooler plate edges and warmer center (Kincaid and Griffiths, 2003).

5. Conclusions

The geochemical data, combined with the application of the $\text{H}_2\text{O}/\text{Ce}$ geothermometer, and geodynamic models for slab surface temperatures (SST) at each subduction zone provides a robust test of the depth origin of back-arc slab-derived fluids. The $\text{H}_2\text{O}/\text{Ce}$ ratios of these BABB span a wide range (250-3900), with the average $\text{SST}_{4\text{GPa}}$ for these global back arc basin spreading range from $\sim 760\text{-}1000^\circ\text{C}$. There are many approaches to analyzing the back-arc basin fluids (i.e., minimum temperature, maximum temperature, etc.), but a segment weighted average provides a more representative view of the $\text{H}_2\text{O}/\text{Ce}$ ratios and the SSTs of the slab-derived fluids. The minimum and maximum temperatures emphasize the outliers in the back-arc basins. The back-arc basin spreading segments have hotter on average temperatures than global arc slab-derived fluids ($730\text{-}850^\circ\text{C}$). The back-arc segments show a trend of increasing temperature with increasing distance from the arc, suggesting that the fluids reaching the back-arc are originating deeper and influenced by the thermal effects of 3D toroidal flow. Although the geothermometer is calibrated to 4 GPa, the temperatures should be projected along H_2O -isopleths to depths that intersect the SST and therefore, are relevant to the origin of back-arc slab-derived fluids. Complications arise when attempting to project the back-arc basin fluid $\text{SST}_{4\text{GPa}}$ to depths which intersect the SST, as the D80 thermal models stop at 8 GPa, in a region where the SST is adiabatic (Syracuse et al., 2010). The challenges with projecting the fluid temperature to depth highlight an important question of what happens with the subducting slab profile at depth. Here we present three possible explanations for how and why back-arc fluids are hotter: (1) back-arc slab-derived fluids come from deeper, (2) back-arc fluids come from the same depth as arcs but from hotter edges of the slab,

or (3) thermal models predict slab surface geotherms that are too cold. The first scenario is unlikely as fluids projected to depths greater than 8 GPa are likely to not be saturated in monazite, and therefore the H₂O/Ce geothermometer is not applicable. However, the second two scenarios are not mutually exclusive and therefore, the origin of the back-arc basin fluids is a combination of thermal variations caused by 3D flow and 2D thermal models underpredicting the slab surface temperatures.

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Table 3.1: Back-arc basin and spreading segment average slab fluid temperatures

Variable Units Pressure	Slab Fluid		
	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
	°C	km	°C
	4 GPa		d
Mariana Trough			
NMT	873	248	1183
CMT	824	248	1134
SMT	831	248	1141
Average	843		1153
East Scotia Ridge			
E2	930	248	1240
E3	908	248	1218
E4	930	248	1240
E5	950	248	1260
E6	898	248	1208
E9	823	139	861
Average	906		1171
Manus Basin			
SR	828	248	1138
ER	854	248	1164
MSC	882	248	1192
ETZ	874	248	1184
Average	859		1169
Lau Basin			
ELSC	776	248	1086
CLSC	893	248	1203
ILSC	936	248	1246
PR	915	248	1225
FSC	826	248	1136
MTJ	886	248	1196
Average	872		1182
North Fiji Basin			
TJ	991	248	1301
N15	1004	248	1314
Average	998		1308

Spreading segments for the Mariana Trough are the Northern Mariana Trough (NMT) from 19-22°N, Central Mariana Trough (CMT) from 17-19°N, Southern Mariana Trough (SMT) from 15-17°N. Spreading segments for the Manus Basin are the Southern Rifts (SR), Eastern Rifts (ER), Manus Spreading Center (MSC), and Eastern Transitional Zone (ETZ). Spreading segments for the Lau Basin are the Eastern Lau Spreading Center (ELSC), Central Lau Spreading Center (CLSC), Intermediate Lau Spreading Center (ILSC), Peggy Ridge (PR), Fonualei Rifts Spreading Center (FSC), and Mangatolu Triple Junction (MTJ). Spreading segments for the North Fiji Basin are the Triple Junction (TJ) and N15 spreading center (N15). FSC is data from Keller et al., 2008 and Escrig et al., 2012. Data from MTJ is whole rock trace element data (Falloon et al., 1992) and glass H₂O data (Danyushevsky et al., 1993). Basin averages are calculated weighted average from individual spreading segment averages. ¹d is the minimum depth of slab fluid origination, constrained by slab surface PT conditions from D80 thermal models (Syracuse et al., 2010).

Table 3.2: Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures

	Sample	Eruptive							Slab Fluid						
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ^l	Temp. (corr.)	
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C	
Pressure												4 GPa		d	
Projected from									H-DMM	N-MORB	E-MORB				
Mariana Trough															
Max. H ₂ O/Ce	S-DS74:2-1	2.08	9.50	2.51	57.0	2189	0.264	0.044			3596	791	248	1101	
Min. H ₂ O/Ce	S-DS84:2-1	0.21	7.81	1.14	83.8	269	0.146	0.014	369			1000	248	1310	
East Scotia Ridge															
Max. H ₂ O/Ce	wx65	0.92	6.70	2.04	46.0	1373	0.304	0.044			2527	823	139	861	
Min. H ₂ O/Ce	96DS-1	0.24	9.26	2.45	70.6	259	0.265	0.035			301	1019	248	1329	
Manus Basin															
Max. H ₂ O/Ce	18-3	1.30	4.89	0.331	22.8	2667	0.068	0.015	2806			814	248	1124	
Min. H ₂ O/Ce	35-5	1.39	58.0	7.90	128	239	0.136	0.062			246	1037	248	1347	
Lau Basin															
Max. H ₂ O/Ce	VG-9831	1.24	3.26	0.290	27.8	3810	0.089	0.010	4711			766	248	1076	
Min. H ₂ O/Ce	VG-9792	0.17	4.87	0.317	70.8	348	0.065	0.004	354			1004	248	1314	
North Fiji Basin															
Max. H ₂ O/Ce	KK 16-11	0.23	7.30	1.57	71.1	312	0.215	0.022		495		973	248	1283	
Min. H ₂ O/Ce	KK 16-4	0.25	9.23	2.04	66.9	270	0.221	0.031			304	1018	248	1328	

Table 3.2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures

	Sample	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	h ²	Temp. (corr.)
Units		wt. %	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
Agrigan (Mariana Arc)		3.52	11.1	0.799	42.5	3606	0.071	0.019	4402			773	169	885

¹d is the minimum depth of slab fluid origination, constrained by slab surface PT conditions from D80 thermal models (Syracuse et al., 2010).

²h is the projected depth to slab surface, which was determined by Syracuse et al., 2010 for Mariana Arc. Agrigan data is from Kelley and Cottrell, 2012.

Table 3.S1: New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
Manus Basin												
15-9	1.13	2	456	60	1677	5.24	0.764	1.28	32.9	0.451	281	14.4
16-12	1.21	3	270	75	1671	5.42	0.758	0.662	32.5	0.596	245	48.1
18-2	1.35	3	132	92	712	6.27	0.0356	0.352	34.7	0.653	323	35.5
18-3	1.30	3	110	103	634	4.67	0.204	0.284	33.5	0.509	280	69.0
20-3	1.18	4	100	293	358	4.66	0.307	0.212	40.8	0.648	262	217
21-1	1.29	11	117	726	444	5.11	0.434	0.209	41.4	0.865	323	21.8
21-2	1.10	26	91	622	403	3.78	0.216	0.161	36.3	0.601	233	223
22-4	1.18	15	88	397	491	3.47	0.154	0.193	37.5	0.546	235	489
22-5	0.73	111	118	1034	228	5.47	0.483	0.109	43.1	1.13	353	194
23-3	0.09	112	49	543	39	3.99	0.117	0.00895	45.7	0.672	273	334
24-3	0.33	224	147	1253	118	6.66	0.251	0.0529	45.0	1.42	417	150
25-2	0.23	108	117	989	113	4.95	0.419	0.0349	42.2	1.00	293	306
25-3	0.35	146	154	1337	121	6.10	0.526	0.0448	48.2	1.43	374	83.6
26-6	0.38	108	102	1009	158	4.69	0.590	0.0408	46.4	1.02	300	63.4
27-4	0.24	128	124	1104	88	4.89	0.240	0.0334	51.6	1.12	311	209
28-2	0.70	76	128	1111	326	5.78	0.320	0.117	44.7	1.11	369	260
28-PD	0.71	77	131	1127	334	4.75	0.303	0.0931	32.6	0.851	299	207
29-3	0.18	116	99	925	73	4.62	0.338	0.0295	42.7	0.983	309	323
29-5	1.28	5	100	359	445	4.39	0.305	0.118	37.2	0.751	238	223

¹Volatiles were determined by SIMS at Carnegie Institution of Washington. ²Trace elements were determined by laser ablation ICP-MS at Graduate School of Oceanography, University of Rhode Island.

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Manus Basin												
15-9	33.5	16.5	110	76.2	21.6	692	11.6	33.0	0.702	0.397	214.44	6.31
16-12	24.8	31.2	80.9	61.6	11.0	453	15.0	47.5	0.727	0.301	182.02	5.23
18-2	35.5	32.1	128	82.8	4.88	178	15.0	33.0	0.458	0.151	79.0	2.35
18-3	36.4	46.4	107	73.2	4.05	212	11.2	22.8	0.331	0.134	70.8	1.83
20-3	33.0	74.2	96.7	62.4	3.26	175	17.0	29.6	0.401	0.0944	44.2	1.78
21-1	37.0	33.1	160	77.3	2.73	172	22.3	38.6	0.493	0.0570	39.4	2.10
21-2	26.9	65.1	78.1	62.9	1.54	210	17.4	32.4	0.320	0.0285	32.0	1.69
22-4	33.9	99.0	93.6	59.5	2.00	262	13.2	23.5	0.342	0.0378	40.0	1.81
22-5	41.3	64.3	113	85.2	1.37	117	25.3	53.0	0.533	0.0332	17.4	1.83
23-3	50.3	177	164	60.3	0.103	63.7	21.2	29.7	0.227	0.000169	1.24	0.733
24-3	48.1	68.6	127	110	0.921	80.1	32.5	66.2	1.44	0.0150	9.12	2.22
25-2	44.9	92.7	116	78.5	0.662	78.9	23.8	48.9	0.918	0.0110	6.69	1.59
25-3	41.1	48.7	105	93.1	0.760	77.9	38.1	74.8	1.34	0.0131	9.08	2.32
26-6	38.9	52.1	115	71.1	0.615	78.2	28.4	50.6	0.760	0.0120	7.53	1.53
27-4	42.3	61.8	111	79.1	0.598	70.1	33.0	61.9	1.10	0.0112	6.08	1.89
28-2	44.7	70.1	122	93.9	1.80	101	27.4	50.8	1.13	0.0328	19.7	2.09
28-PD	35.3	54.8	98.8	76.6	1.44	76.9	19.6	36.8	0.862	0.0276	15.2	1.55
29-3	48.2	94.3	128	83.7	0.531	71.4	23.3	43.2	0.853	0.0072	4.97	1.38
29-5	32.8	70.2	93.3	62.6	1.73	172	18.4	41.0	1.06	0.0571	29.3	2.97

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Manus Basin												
15-9	12.4	1.83	8.77	2.20	0.730	2.51	0.369	2.13	0.453	1.21	0.211	1.26
16-12	11.2	1.74	8.42	2.22	0.733	2.49	0.405	2.50	0.555	1.60	0.246	1.59
18-2	6.09	0.946	4.81	1.52	0.606	2.17	0.404	2.60	0.561	1.74	0.317	1.83
18-3	4.89	0.738	3.80	1.20	0.494	1.70	0.284	1.95	0.428	1.25	0.208	1.36
20-3	4.88	0.830	4.40	1.58	0.625	2.39	0.428	2.81	0.621	1.87	0.298	1.91
21-1	5.77	1.03	5.75	2.02	0.797	3.02	0.544	3.58	0.817	2.36	0.377	2.42
21-2	4.50	0.810	4.52	1.66	0.627	2.45	0.429	2.96	0.642	1.91	0.294	1.86
22-4	4.61	0.778	4.30	1.38	0.582	1.96	0.339	2.25	0.502	1.47	0.255	1.49
22-5	6.48	1.15	6.51	2.44	0.947	3.56	0.650	4.23	0.967	2.68	0.436	2.82
23-3	3.12	0.61	3.50	1.36	0.653	2.40	0.464	3.46	0.74	2.49	0.406	2.63
24-3	7.73	1.44	8.15	2.95	1.12	4.57	0.840	5.36	1.21	3.55	0.553	3.52
25-2	5.67	1.05	5.92	2.26	0.870	3.43	0.612	3.96	0.889	2.66	0.445	2.56
25-3	7.21	1.45	8.62	3.21	1.17	5.13	0.946	6.18	1.42	4.20	0.669	4.07
26-6	4.97	1.02	5.96	2.35	0.901	3.84	0.708	4.59	1.06	3.16	0.513	3.09
27-4	5.63	1.16	7.12	2.78	0.975	4.37	0.809	5.40	1.22	3.58	0.551	3.47
28-2	6.68	1.22	6.71	2.46	0.960	3.69	0.679	4.57	1.01	2.93	0.445	3.05
28-PD	5.28	0.898	5.06	1.79	0.696	2.71	0.485	3.19	0.713	2.11	0.318	2.08
29-3	5.04	0.941	5.50	2.09	0.833	3.12	0.555	3.92	0.856	2.56	0.369	2.46
29-5	7.09	1.11	5.53	1.75	0.678	2.52	0.442	3.03	0.655	1.97	0.305	1.99

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu ppm	Hf ppm	Ta ppm	Pb ppm	Th ppm	U ppm
Manus Basin						
15-9	0.204	0.928	0.0408	3.44	0.657	0.415
16-12	0.259	1.43	0.0472	2.31	0.444	0.277
18-2	0.298	0.976	0.0271	1.41	0.189	0.122
18-3	0.216	0.683	0.0238	1.13	0.143	0.0978
20-3	0.284	0.971	0.0282	0.949	0.108	0.0883
21-1	0.378	1.24	0.0327	0.832	0.105	0.0683
21-2	0.286	0.980	0.0185	0.656	0.102	0.0506
22-4	0.243	0.716	0.0198	0.770	0.102	0.0540
22-5	0.415	1.61	0.0387	0.537	0.0704	0.0443
23-3	0.407	0.961	0.0166	0.108	0.0172	0.0112
24-3	0.558	2.09	0.0942	0.402	0.0949	0.0337
25-2	0.394	1.58	0.0551	0.332	0.0629	0.0201
25-3	0.634	2.46	0.0994	0.336	0.0954	0.0315
26-6	0.473	1.69	0.0516	0.283	0.0668	0.0224
27-4	0.554	2.12	0.0792	0.299	0.0939	0.0225
28-2	0.471	1.71	0.0703	0.591	0.110	0.0525
28-PD	0.329	1.20	0.0526	0.470	0.0842	0.0486
29-3	0.374	1.41	0.0471	0.296	0.0565	0.0225
29-5	0.292	1.28	0.0638	0.846	0.283	0.145

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
30-4	1.37	4	192	749	554	8.25	0.367	0.145	37.8	1.41	440	1.50
30-8	1.37	3	166	442	588	7.26	0.390	0.159	37.5	1.14	350	3.64
31-4	0.26	240	141	1208	88	6.06	0.271	0.0467	42.6	1.24	361	81.7
31-9	0.57	123	203	1333	178	6.72	0.577	0.133	41.3	1.58	429	99.0
32-2	0.22	178	114	1007	94	4.91	0.305	0.0292	40.5	1.00	303	227
33-1	1.45	2	274	498	937	11.1	0.716	0.307	54.3	2.09	653	4.43
33-5	0.18	152	107	1071	85	4.52	0.277	0.0221	49.5	1.03	318	109
35-2	1.36	2	272	298	830	11.4	0.728	0.632	28.9	0.798	244	52.1
35-5	1.39	2	274	328	863	13.1	0.542	0.852	30.1	1.03	336	70.7
36-1	0.31	235	133	1214	119	7.10	0.275	0.0434	45.2	1.27	385	90.2
36-3	0.26	213	104	962	138	5.02	0.276	0.0381	41.4	0.944	306	319
36-8	0.73	198	264	1610	613	9.55	0.386	0.0914	43.5	2.06	451	60.0
37-5	0.30	150	134	1166	107	6.44	0.169	0.0427	44.9	1.19	342	153
38-4	0.34	134	153	1332	135	7.45	0.0986	0.0480	45.0	1.44	424	93.8
38-6	1.16	115	163	1282	836	7.55	0.580	0.175	38.4	1.19	397	10.3
39-2	0.34	94	152	1319	138	7.59	0.176	0.0495	46.3	1.46	426	92.0
39-3	0.28	139	124	1171	102	6.55	0.295	0.0395	44.7	1.24	371	77.8
40-3	1.21	9	151	881	1101	7.06	0.398	0.144	40.2	0.923	297	49.2
41-3	1.18	10	122	806	1382	3.96	0.149	0.0965	41.8	0.925	311	107
42-2	0.48	120	137	1276	327	7.19	0.394	0.0582	46.8	1.28	395	49.6
43-2	0.84	70	238	1575	736	10.8	0.480	0.103	43.6	1.68	450	7.78
43-3	0.60	90	144	1505	477	6.83	0.114	0.0731	45.0	1.15	360	65.0

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
30-4	41.8	7.66	53.9	107	2.30	144	33.1	71.1	1.67	0.0684	34.7	4.20
30-8	37.8	14.3	71.9	93.7	2.53	162	28.0	62.1	1.59	0.0904	40.7	4.44
31-4	49.3	57.7	119	100	0.830	77.2	27.6	54.4	1.35	0.00730	7.74	1.90
31-9	51.1	48.8	117	114	2.66	108	31.1	77.3	3.69	0.0365	21.7	3.77
32-2	49.3	90.6	118	84.2	0.516	71.6	22.7	43.3	0.87	0.0111	4.96	1.40
33-1	57.3	10.5	91.8	155	5.38	333	58.8	140	3.36	0.210	114	14.3
33-5	46.1	58.0	145	79.6	0.319	70.4	28.6	48.4	0.64	0.00447	3.58	1.33
35-2	23.4	35.2	73.8	63.6	11.0	658	17.6	135	6.14	0.364	251	24.2
35-5	31.9	46.8	106	89.2	14.5	798	16.1	128	7.90	0.473	327	26.3
36-1	48.3	63.5	133	113	0.777	71.5	26.1	53.8	1.13	0.0158	8.21	1.74
36-3	45.4	111	123	86.2	0.643	71.5	18.6	39.2	1.04	0.00967	7.45	1.43
36-8	46.4	40.5	87.5	147	1.69	79.8	45.5	111	2.38	0.0267	16.3	3.60
37-5	44.5	73.9	110	104	0.808	69.4	26.3	55.1	1.10	0.0132	7.34	1.74
38-4	50.3	55.5	117	127	0.829	72.3	27.5	57.9	1.23	0.0096	8.84	1.97
38-6	43.4	39.7	108	116	2.57	123	22.4	46.1	1.05	0.0454	28.4	2.10
39-2	47.5	46.3	119	128	0.882	71.4	27.8	58.1	1.21	0.0127	8.71	1.90
39-3	46.5	59.5	119	115	0.680	69.0	24.5	48.8	0.95	0.0119	7.18	1.58
40-3	31.9	40.5	109	76.1	1.60	141	26.2	56.2	0.86	0.0462	27.0	2.54
41-3	34.5	62.7	130	81.5	0.748	156	21.7	46.8	0.96	0.0197	17.2	2.21
42-2	45.9	51.3	135	111	0.790	89.8	27.7	60.3	1.37	0.0158	10.8	2.14
43-2	45.0	24.7	101	147	1.58	84.5	42.2	97.8	2.04	0.0137	18.8	3.39
43-3	43.6	58.8	129	107	1.00	111	27.0	58.7	1.41	0.0418	15.8	2.50

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
30-4	10.9	1.73	9.33	3.07	1.12	4.49	0.806	5.35	1.19	3.56	0.540	3.51
30-8	10.73	1.65	8.35	2.73	0.978	3.78	0.677	4.59	1.00	2.96	0.439	3.00
31-4	7.02	1.26	7.01	2.62	1.00	3.85	0.697	4.60	1.00	2.93	0.444	2.93
31-9	12.9	1.98	10.0	3.29	1.26	4.57	0.814	5.23	1.12	3.23	0.488	3.28
32-2	5.27	0.991	5.60	2.14	0.824	3.18	0.566	3.79	0.838	2.35	0.366	2.44
33-1	27.7	4.03	19.6	5.73	1.90	7.98	1.40	9.24	2.04	6.08	0.928	6.24
33-5	4.66	0.984	5.85	2.36	0.902	3.78	0.691	4.68	1.04	3.13	0.467	2.97
35-2	43.9	5.18	19.3	3.49	0.982	3.13	0.534	3.15	0.683	1.81	0.298	1.88
35-5	58.0	6.22	21.0	3.62	1.14	3.08	0.503	2.97	0.601	1.71	0.296	1.83
36-1	6.54	1.24	6.88	2.49	0.984	3.52	0.705	4.64	1.05	2.97	0.495	3.08
36-3	5.22	0.927	5.37	1.91	0.776	2.76	0.529	3.43	0.740	2.10	0.355	2.34
36-8	12.5	2.33	13.1	4.74	1.57	6.63	1.26	8.39	1.79	5.08	0.875	5.52
37-5	6.00	1.19	6.89	2.54	0.966	3.86	0.731	4.79	1.04	3.11	0.517	3.24
38-4	7.32	1.38	7.73	2.87	1.08	4.07	0.778	5.20	1.12	3.21	0.533	3.51
38-6	7.35	1.28	7.04	2.43	0.934	3.42	0.634	4.19	0.920	2.64	0.446	2.85
39-2	7.27	1.37	7.66	2.90	1.11	4.18	0.774	5.33	1.15	3.28	0.543	3.47
39-3	5.80	1.14	6.60	2.44	0.947	3.64	0.698	4.68	1.01	2.90	0.479	3.06
40-3	6.89	1.21	6.79	2.43	0.864	3.81	0.639	4.71	0.993	3.04	0.493	2.83
41-3	6.62	1.09	6.02	1.97	0.777	2.96	0.530	3.72	0.820	2.48	0.432	2.47
42-2	7.57	1.42	7.60	2.59	1.06	4.08	0.720	5.02	1.05	3.06	0.554	3.17
43-2	12.1	2.18	12.1	4.12	1.50	6.02	1.09	7.63	1.62	4.64	0.850	4.87
43-3	8.17	1.43	7.82	2.75	1.01	3.98	0.709	5.04	1.05	3.13	0.511	3.07

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu ppm	Hf ppm	Ta ppm	Pb ppm	Th ppm	U ppm
30-4	0.562	2.19	0.100	1.03	0.331	0.171
30-8	0.468	2.00	0.0889	1.16	0.387	0.197
31-4	0.451	1.76	0.0816	0.382	0.0791	0.0350
31-9	0.481	2.29	0.211	0.655	0.200	0.0937
32-2	0.380	1.36	0.0452	0.310	0.0600	0.0242
33-1	1.03	4.19	0.197	2.68	1.50	0.71
33-5	0.472	1.65	0.0391	0.242	0.0477	0.0135
35-2	0.283	3.31	0.361	5.18	4.68	1.35
35-5	0.274	3.25	0.370	6.52	4.81	1.86
36-1	0.453	1.85	0.0649	0.449	0.111	0.0313
36-3	0.348	1.38	0.0629	0.351	0.103	0.0302
36-8	0.829	3.91	0.150	0.747	0.268	0.0801
37-5	0.483	1.96	0.0822	0.437	0.110	0.0318
38-4	0.504	2.19	0.0776	0.342	0.121	0.0381
38-6	0.407	1.74	0.0617	0.824	0.181	0.0790
39-2	0.513	2.14	0.0863	0.471	0.141	0.0398
39-3	0.471	1.90	0.0645	0.402	0.0846	0.0311
40-3	0.507	1.59	0.0558	0.737	0.170	0.0682
41-3	0.415	1.47	0.0636	0.570	0.154	0.0505
42-2	0.544	1.82	0.0760	0.421	0.117	0.0428
43-2	0.848	2.87	0.115	0.637	0.190	0.0743
43-3	0.531	1.76	0.0803	0.449	0.128	0.0650

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
44-3	0.38	157	131	1239	239	6.56	0.164	0.0435	44.0	1.18	374	65.9
45-3	1.48	3	588	626	2583							
46-3	1.10	60	455	2171	1581	15.1	0.298	0.152	37.2	2.33	254	1.96
47-2	0.68	90	237	1695	635	9.26	0.321	0.0902	41.8	1.80	459	36.0
BC15-2	0.32	149	141	1231	123	6.45	0.212	0.0447	48.1	1.36	380	82.5
BC19-1	0.70	103	181	1336	524	7.73	0.0968	0.0784	44.1	1.48	419	19.1
Lau Basin												
VG-9831	1.24	3	83	257	510	3.78	0.0278	0.113	39.4	0.596	219	207
VG-9836	1.28	3	104	315	759	4.37	0.176	0.111	38.2	0.759	257	154
VG-9809	0.31	122	74	849	165	5.00	0.106	0.0539	40.9	0.845	290	389
VG-9844	0.82	87	101	898	493	5.34	0.210	0.0940	38.3	1.06	294	116
VG-9838	0.96	49	122	991	868	5.77	0.272	0.111	39.8	1.29	335	37.7
VG-9816	0.52	170	111	1022	457	6.48	0.261	0.0773	38.8	1.19	313	68.5
VG-9839	1.20	3	100	350	523	5.77	0.136	0.161	39.6	1.02	329	75.7
VG-9801	0.42	138	93	972	202	6.09	0.284	0.0591	41.7	1.06	326	151
VG-9834	0.21	164	82	943	88	6.22	0.218	0.0374	41.2	1.07	353	184
VG-9825	0.30	133	92	1002	82	6.21	0.194	0.0446	39.7	1.05	328	109
VG-9792	0.17	131	95	897	34	3.77	0.202	0.0171	39.2	1.03	205	285
VG-9847	0.36	125	71	752	95	3.75	0.200	0.0686	39.7	0.769	232	351
VG-9789	1.20	2	129	251	719	4.47	0.204	0.138	34.3	0.787	269	129
VG-9785	0.26	115	111	1127	369	5.18	0.206	0.0499	45.1	1.26	286	277

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
44-3	45.8	56.4	141	122	0.678	76.8	25.6	51.6	0.98	0.00385	7.67	1.73
45-3												
46-3	42.6	7.78	56.2	273	2.08	82.5	60.2	135	3.08	0.0357	25.3	4.95
47-2	48.4	38.4	106	183	1.18	81.4	36.7	82.7	1.75	0.0222	15.5	3.02
BC15-2	44.2	48.7	105	117	0.768	68.0	30.0	62.5	1.12	0.00923	7.92	1.91
BC19-1	43.1	34.6	99.8	131	1.26	75.6	34.1	72.8	1.38	0.0119	15.2	2.48
Lau Basin												
VG-9831	29.9	64.3	75.8	46.4	1.51	125	14.8	27.84	0.290	0.0364	17.5	1.07
VG-9836	33.6	61.6	95.9	68.8	1.44	177	19.4	37.18	0.410	0.0231	14.4	1.40
VG-9809	42.3	100	99.5	79.7	1.06	59.8	21.0	38.07	0.868	0.0123	8.53	1.29
VG-9844	42.1	67.2	85.8	70.8	1.87	107	22.7	51.8	0.785	0.0374	16.4	1.82
VG-9838	40.4	34.8	84.1	89.5	2.24	111	29.8	69.1	1.09	0.0464	22.8	2.43
VG-9816	41.1	47.1	90.1	87.4	1.65	80.9	27.4	57.1	1.64	0.0170	13.2	2.08
VG-9839	34.4	40.5	90.1	89.5	2.87	112	22.6	48.0	0.795	0.102	40.8	1.89
VG-9801	43.4	64.2	99.3	95.3	1.23	65.9	27.3	51.5	0.952	0.0159	8.77	1.61
VG-9834	48.4	72.8	100	99.0	0.619	63.1	24.6	49.3	0.770	0.00626	5.59	1.49
VG-9825	45.7	63.8	87.0	81.8	0.698	63.4	24.0	48.8	0.657	0.0119	6.33	1.40
VG-9792	44.7	178	102	51.9	0.133	107	27.7	70.8	0.317	0.00158	1.31	1.28
VG-9847	39.5	89.6	93.5	64.4	1.37	87.1	19.4	39.3	1.33	0.0181	13.5	1.74
VG-9789	48.8	123	129	69.5	2.91	240	17.0	36.2	2.58	0.0230	23.8	3.53
VG-9785	39.6	66.7	106	64.6	0.715	89.6	30.8	62.8	1.12	0.00877	8.38	1.92

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
44-3	6.60	1.25	6.97	2.53	1.04	3.85	0.712	4.96	1.03	2.99	0.541	3.06
45-3												
46-3	20.3	3.58	19.6	6.85	2.49	9.51	1.76	12.0	2.57	7.13	1.30	7.56
47-2	11.8	2.14	11.6	4.15	1.53	5.60	1.06	7.45	1.56	4.57	0.786	4.55
BC15-2	6.57	1.29	7.89	2.93	1.10	4.54	0.867	5.70	1.26	3.59	0.629	3.80
BC19-1	8.33	1.59	9.17	3.37	1.21	4.98	0.943	6.59	1.40	4.08	0.692	4.36
Lau Basin												
VG-9831	3.26	0.631	3.76	1.37	0.548	2.12	0.394	2.58	0.560	1.60	0.253	1.63
VG-9836	4.53	0.840	4.86	1.82	0.736	2.73	0.496	3.27	0.738	2.16	0.325	2.13
VG-9809	4.31	0.780	4.43	1.81	0.702	2.74	0.529	3.59	0.818	2.36	0.391	2.34
VG-9844	6.10	1.10	6.13	2.33	0.909	3.35	0.613	3.95	0.888	2.55	0.403	2.53
VG-9838	7.84	1.39	7.87	2.92	1.10	4.36	0.774	5.17	1.13	3.28	0.521	3.33
VG-9816	6.76	1.21	6.92	2.57	0.957	3.98	0.716	4.88	1.06	2.97	0.473	2.94
VG-9839	5.98	1.05	5.98	2.21	0.860	3.23	0.603	3.95	0.861	2.50	0.390	2.52
VG-9801	5.32	1.00	5.72	2.31	0.872	3.62	0.675	4.60	1.03	2.97	0.483	3.05
VG-9834	5.43	1.00	5.59	2.19	0.849	3.41	0.643	4.21	0.938	2.79	0.438	2.86
VG-9825	5.02	0.955	5.54	2.18	0.840	3.35	0.607	4.16	0.927	2.70	0.433	2.82
VG-9792	4.87	1.06	6.57	2.52	0.987	3.85	0.707	4.69	1.03	3.05	0.464	2.89
VG-9847	4.92	0.867	4.75	1.76	0.709	2.69	0.493	3.26	0.727	2.09	0.331	2.10
VG-9789	10.2	1.43	6.74	1.92	0.756	2.58	0.453	3.02	0.642	1.85	0.277	1.83
VG-9785	6.34	1.25	7.30	2.81	1.08	4.47	0.801	5.43	1.20	3.38	0.543	3.30

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu ppm	Hf ppm	Ta ppm	Pb ppm	Th ppm	U ppm
44-3	0.532	1.66	0.0641	0.377	0.0771	0.0311
45-3						
46-3	1.29	4.28	0.183	1.07	0.237	0.116
47-2	0.793	2.71	0.111	0.637	0.146	0.0653
BC15-2	0.564	2.40	0.0795	0.395	0.134	0.0333
BC19-1	0.665	2.80	0.0974	0.563	0.194	0.0517
Lau Basin						
VG-9831	0.263	0.845	0.0238	0.459	0.0618	0.0285
VG-9836	0.344	1.08	0.0257	0.515	0.0558	0.0259
VG-9809	0.389	1.12	0.0522	0.316	0.0712	0.0224
VG-9844	0.394	1.41	0.0502	0.447	0.0865	0.0376
VG-9838	0.512	1.92	0.0675	0.537	0.121	0.0489
VG-9816	0.463	1.69	0.102	0.375	0.130	0.0376
VG-9839	0.397	1.38	0.0526	0.700	0.114	0.0561
VG-9801	0.480	1.53	0.0608	0.354	0.0671	0.0258
VG-9834	0.432	1.40	0.0488	0.354	0.0543	0.0200
VG-9825	0.433	1.40	0.0474	0.355	0.0525	0.0206
VG-9792	0.456	1.91	0.0257	0.318	0.0271	0.00905
VG-9847	0.331	1.08	0.0822	0.303	0.102	0.0314
VG-9789	0.280	1.09	0.135	0.573	0.227	0.0773
VG-9785	0.516	1.97	0.0805	0.327	0.0879	0.0254

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
VG-9778	1.08	5	81	496	373	4.93	0.212	0.0895	35.9	0.819	273	205
VG-9786	0.31	159	158	1361	535	7.17	0.432	0.0814	41.5	1.67	367	42.3
VG-9779	0.27	296	135	1326	323	7.56	0.341	0.0682	41.3	1.57	389	107
VG-9764	0.27	170	150	1418	645	8.00	0.344	0.0701	40.2	1.57	379	114
VG-9751	0.35	85	251	2065	637	12.4	0.446	0.101	40.3	2.13	470	24.8
VG-9768	1.45	17	829	760	10043	19.2	1.19	0.374	28.3	1.54	175	5.55
VG-9758	0.43	123	227	1899	690	7.83	0.525	0.104	34.3	2.14	429	4.42
VG-9812	0.49	109	89	936	343	5.65	0.289	0.0506	44.5	1.02	270	209
VG-9760	0.52	148	284	2319	1441	11.6	0.501	0.113	44.3	2.59	507	3.79
VG-9750	1.13	3	110	195	894	4.60	0.156	0.0788	42.4	0.820	263	77.0
VG-9824	1.33	3	111	313	808	4.73	0.116	0.116	39.7	0.751	244	141
VG-9775	1.33	10	759	658	4869	25.6	1.51	0.420	23.9	1.26	42.5	1.38
VG-9842	1.40	4	220	948	705	9.68	0.376	0.171	38.3	2.01	402	1.57
North Fiji Basin												
KK 16-1	0.23	145	110	1009	88	5.02	0.387	0.0851	41.1	1.24	274	336
KK 16-2	0.26	126	129	1080	88	5.62	0.349	0.111	42.1	1.36	305	349
KK 16-3	0.23	131	106	1001	90	5.07	0.291	0.0840	40.7	1.22	275	337
KK 16-4	0.25	147	121	1009	78	5.19	0.341	0.107	39.9	1.32	280	336
KK 16-5	0.27	126	130	1088	90	5.13	0.374	0.0987	42.3	1.32	279	318
KK 16-6	0.22	136	108	1009	87	4.94	0.236	0.0832	39.5	1.22	275	335
KK 16-7	0.21	116	101	1038	102	4.68	0.296	0.0599	39.8	1.16	264	335

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
VG-9778	39.9	68.8	116	80.4	1.08	188	17.9	30.7	0.631	0.00383	12.2	1.72
VG-9786	42.9	38.2	86.5	102	1.29	84.9	44.2	97.6	1.97	0.0151	12.8	3.20
VG-9779	47.1	56.9	97.5	102	1.06	78.3	36.4	73.5	1.46	0.0113	9.98	2.37
VG-9764	44.2	56.8	92.5	88.4	0.967	74.4	36.6	75.4	1.42	0.0124	9.24	2.32
VG-9751	50.2	29.9	87.5	126	1.52	72.1	51.5	107.35	2.11	0.0179	12.8	3.24
VG-9768	24.8	9.13	42.9	120	6.62	83.5	142	517.35	6.85	0.0716	42.5	14.77
VG-9758	41.8	18.0	74.2	142	1.66	66.2	55.1	126.14	2.50	0.0195	14.6	4.39
VG-9812	37.3	60.3	86.9	65.5	1.06	72.8	27.5	51.6	0.896	0.0103	7.80	1.53
VG-9760	48.3	17.2	81.8	147	1.86	77.9	65.0	147.19	2.77	0.0226	15.7	4.43
VG-9750	37.1	48.1	123	74.0	0.803	303	20.9	37.0	0.732	0.00214	9.01	2.39
VG-9824	31.1	57.2	86.1	55.2	1.35	164	19.6	35.9	0.372	0.0147	12.7	1.34
VG-9775	14.4	1.88	24.3	138	8.15	81.6	181	627.19	7.90	0.0864	51.6	16.6
VG-9842	32.8	6.86	28.9	113	2.95	98.4	50.1	121.94	2.29	0.0667	35.3	4.01
North Fiji Basin												
KK 16-1	47.9	159	105	84.2	0.857	126	23.5	62.7	1.67	0.0108	8.77	2.48
KK 16-2	49.0	133	109	89.9	1.06	126	24.8	69.2	2.05	0.0108	11.0	2.80
KK 16-3	48.7	165	109	87.0	0.852	122	22.7	60.2	1.58	0.0105	8.20	2.36
KK 16-4	46.0	138	90.1	86.4	1.10	134	23.4	66.9	2.04	0.0137	11.3	2.83
KK 16-5	44.1	121	96.5	83.6	1.04	125	24.9	69.3	1.96	0.0123	10.7	2.80
KK 16-6	48.0	165	103	85.7	0.794	125	22.6	59.9	1.61	0.0092	8.40	2.37
KK 16-7	48.8	174	108	80.1	0.400	121	22.0	57.2	1.06	0.00533	4.88	1.95

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
VG-9778	5.66	0.909	4.71	1.67	0.705	2.60	0.481	3.15	0.682	1.97	0.296	2.00
VG-9786	10.5	1.95	10.8	4.05	1.43	6.21	1.13	7.58	1.63	4.76	0.761	4.63
VG-9779	8.61	1.55	8.78	3.35	1.26	5.10	0.947	6.28	1.35	3.90	0.617	3.91
VG-9764	7.99	1.54	8.94	3.44	1.27	5.24	0.964	6.40	1.40	4.00	0.646	3.96
VG-9751	11.0	2.11	12.3	4.75	1.67	7.33	1.35	8.96	1.92	5.62	0.908	5.69
VG-9768	43.9	7.47	40.0	13.1	3.01	18.7	3.34	22.3	4.95	14.9	2.34	14.8
VG-9758	14.2	2.58	13.6	5.15	1.74	7.62	1.38	9.17	2.02	5.93	0.969	5.54
VG-9812	4.58	0.953	5.73	2.32	0.843	3.96	0.712	4.87	1.02	2.97	0.476	3.01
VG-9760	13.9	2.62	15.9	5.94	1.99	9.56	1.75	11.57	2.51	7.12	1.09	7.18
VG-9750	6.40	1.19	6.32	1.98	0.762	3.07	0.554	3.74	0.808	2.27	0.351	2.25
VG-9824	3.89	0.800	4.86	1.82	0.679	2.84	0.527	3.54	0.752	2.18	0.334	2.16
VG-9775	45.6	8.51	48.4	16.8	3.87	25.9	4.64	30.8	6.71	19.6	3.09	19.1
VG-9842	11.9	2.24	13.1	4.73	1.59	7.29	1.31	8.74	1.88	5.30	0.842	5.38
North Fiji Basin												
KK 16-1	9.33	1.53	8.22	2.85	1.10	3.93	0.701	4.66	0.956	2.63	0.401	2.64
KK 16-2	7.95	1.31	7.13	2.53	1.00	3.41	0.643	4.29	0.888	2.49	0.368	2.48
KK 16-3	9.23	1.50	8.09	2.69	1.08	3.79	0.659	4.37	0.892	2.48	0.365	2.50
KK 16-4	9.00	1.46	8.23	2.73	1.10	3.86	0.699	4.54	0.938	2.73	0.402	2.69
KK 16-5	8.06	1.35	7.27	2.54	1.03	3.48	0.652	4.18	0.871	2.50	0.366	2.58
KK 16-6	7.10	1.22	6.69	2.35	0.957	3.41	0.613	4.08	0.861	2.46	0.365	2.48
KK 16-7	9.33	1.53	8.22	2.85	1.10	3.93	0.701	4.66	0.956	2.63	0.401	2.64

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu ppm	Hf ppm	Ta ppm	Pb ppm	Th ppm	U ppm
VG-9778	0.288	0.97	0.0370	0.349	0.0783	0.0328
VG-9786	0.744	2.97	0.137	0.487	0.155	0.0528
VG-9779	0.590	2.26	0.0944	0.421	0.104	0.0416
VG-9764	0.594	2.35	0.0941	0.421	0.103	0.0411
VG-9751	0.857	3.33	0.142	0.604	0.151	0.0588
VG-9768	2.35	13.7	0.438	1.65	1.06	0.404
VG-9758	0.913	3.74	0.171	0.720	0.227	0.0678
VG-9812	0.458	1.60	0.0662	0.281	0.0794	0.0213
VG-9760	1.09	4.36	0.188	0.651	0.232	0.0752
VG-9750	0.335	1.16	0.0557	0.460	0.0885	0.0305
VG-9824	0.331	1.12	0.0287	0.488	0.0584	0.0264
VG-9775	3.03	17.6	0.604	2.21	1.25	0.338
VG-9842	0.817	3.55	0.165	0.840	0.250	0.0792
North Fiji Basin						
KK 16-1	0.379	1.93	0.135	0.536	0.151	0.0597
KK 16-2	0.356	1.68	0.104	0.454	0.122	0.0452
KK 16-3	0.363	1.85	0.128	0.483	0.154	0.0580
KK 16-4	0.405	1.91	0.126	0.469	0.154	0.0532
KK 16-5	0.379	1.67	0.100	0.451	0.125	0.0511
KK 16-6	0.346	1.59	0.0685	0.374	0.0712	0.0339
KK 16-7	0.379	1.93	0.135	0.536	0.151	0.0597

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
KK 16-8	0.24	133	114	1042	92	5.21	0.349	0.0872	40.2	1.26	285	346
KK 16-10	0.82	49	476	990	403	5.20	0.961	0.613	36.5	1.93	242	174
KK 16-11	0.23	139	108	1003	87	4.40	0.338	0.0726	45.3	1.19	237	292
KK 16-12	0.24	129	112	1024	91	4.84	0.286	0.0876	39.0	1.24	291	334
KK 16-13	0.23	135	110	1020	88	4.83	0.347	0.0875	40.2	1.24	282	328
KK 16-14	0.21	117	103	1047	105	4.13	0.357	0.0575	41.7	1.17	259	317
KK 16-16	0.14	154	92	1090	77	5.51	0.281	0.0454	49.0	1.17	319	194
KK 16-17	0.14	158	94	1095	78	5.92	0.329	0.0480	46.0	1.15	340	217
SPS3 DT-1	0.20	211	136	1212	134	6.37	0.437	0.0894	45.9	1.53	330	249
SPS3 D1-3	0.17	218	119	1177	73	5.76	0.483	0.0849	44.5	1.45	330	309
SPS3 D4-2	0.18	157	126	1186	47	5.85	0.302	0.0711	41.5	1.38	316	306
SPS3 D4-5	0.18	152	131	1231	49	6.07	0.393	0.0768	42.9	1.47	338	323
K87 ST4 D2-1	0.23	132	153	1106	129	4.55	0.476	0.111	45.4	1.28	240	118
K87 ST4 D2-2	0.24	135	161	1136	133	4.93	0.406	0.125	42.3	1.33	265	128
K87 ST4 D2-4	0.24	132	157	1113	134	5.12	0.399	0.124	41.6	1.31	265	129
K87 ST4 D2-5	0.24	326	160	1164	121	4.93	0.555	0.127	41.2	1.32	274	132
K87 ST4 D2-7	0.24	335	158	1166	116	4.60	0.503	0.113	44.9	1.31	243	119
K87 ST4 D2-8	0.23	321	156	1134	113	4.50	0.259	0.117	46.3	1.31	248	119
K87 ST4 DTA-3	0.65	114	424	671	273	4.89	1.00	0.773	28.2	1.80	200	221
K87 ST4 DTA-4	0.65	104	420	674	276	4.97	0.900	0.827	30.0	1.89	208	229
K87 ST4 DTA-7	0.67	175	438	683	278	5.21	0.921	0.920	28.6	1.93	220	241
K87 ST4 DTB-1	0.67	113	434	683	284	5.41	1.27	0.943	31.1	2.06	233	256

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
KK 16-8	48.4	161	105	83.2	0.819	127	22.7	60.8	1.63	0.00678	8.69	2.35
KK 16-10	30.9	73.7	62.2	76.0	17.0	243	34.1	186	25.9	0.147	199	19.4
KK 16-11	42.0	143	90.7	70.3	0.676	123	27.2	71.1	1.57	0.00493	7.72	2.56
KK 16-12	46.4	155	101	81.5	0.816	120	22.9	62.1	1.55	0.0111	8.43	2.43
KK 16-13	46.8	163	103	81.3	0.796	123	24.2	65.3	1.61	0.0128	8.57	2.53
KK 16-14	45.9	174	105	73.4	0.423	124	25.2	66.5	1.08	0.0101	4.84	2.17
KK 16-16	46.7	63.0	147	89.8	0.317	89.68	27.9	59.0	0.775	0.00819	3.59	1.80
KK 16-17	49.1	67.6	158	97.8	0.357	87.63	25.4	54.3	0.744	0.00473	3.52	1.70
SPS3 DT-1	42.4	67.6	73.2	94.8	0.984	103	34.8	88.2	2.14	0.0174	10.3	3.29
SPS3 D1-3	44.8	78.2	81.2	95.8	0.886	103	30.2	74.3	1.80	0.00588	8.61	2.79
SPS3 D4-2	43.6	84.0	76.0	96.0	0.844	85.01	31.0	71.1	1.66	0.0159	8.34	2.44
SPS3 D4-5	44.8	80.2	80.1	101	0.953	86.94	32.9	75.2	1.76	0.0186	8.77	2.60
K87 ST4 D2-1	36.6	44.6	75.3	70.8	2.20	123	32.4	88.9	3.11	0.0286	22.7	3.80
K87 ST4 D2-2	39.6	45.8	86.3	80.6	2.46	124	28.2	78.2	3.18	0.0103	24.4	3.65
K87 ST4 D2-4	39.8	44.8	87.8	80.6	2.52	127	28.5	79.1	3.25	0.0350	24.8	3.62
K87 ST4 D2-5	40.6	47.9	85.8	80.9	2.56	126	27.1	76.2	3.21	0.0201	25.4	3.56
K87 ST4 D2-7	36.6	42.8	77.1	72.4	2.25	126	31.9	87.9	3.27	0.0327	23.8	3.80
K87 ST4 D2-8	38.0	44.3	79.2	71.8	2.29	126	33.4	90.5	3.24	0.0298	23.7	3.88
K87 ST4 DTA-3	34.0	148	49.6	66.5	17.3	265	22.5	123	24.6	0.202	196	15.9
K87 ST4 DTA-4	35.3	150	52.1	68.4	18.4	277	23.8	130	25.9	0.225	204	16.6
K87 ST4 DTA-7	38.0	176	55.6	72.1	20.3	277	22.5	128	27.1	0.243	214	16.8
K87 ST4 DTB-1	40.0	178	59.3	75.5	21.0	301	25.3	138	28.3	0.242	220	17.7

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
KK 16-8	8.13	1.34	7.14	2.46	1.00	3.36	0.636	4.07	0.904	2.50	0.369	2.52
KK 16-10	36.6	5.05	21.9	5.54	1.79	6.39	1.08	6.42	1.37	3.75	0.561	3.43
KK 16-11	7.30	1.35	7.70	2.70	1.02	4.12	0.752	4.98	1.04	2.95	0.445	2.91
KK 16-12	8.07	1.37	7.21	2.47	0.989	3.55	0.623	4.09	0.886	2.38	0.371	2.42
KK 16-13	8.19	1.40	7.56	2.63	1.03	3.81	0.660	4.33	0.927	2.55	0.399	2.53
KK 16-14	7.06	1.31	7.20	2.60	1.01	3.73	0.678	4.40	0.952	2.58	0.413	2.63
KK 16-16	6.10	1.18	6.68	2.54	1.00	3.99	0.714	4.81	1.06	2.92	0.452	2.96
KK 16-17	6.21	1.14	6.43	2.45	0.961	3.63	0.662	4.42	0.971	2.61	0.410	2.73
SPS3 DT-1	9.99	1.80	10.0	3.54	1.23	5.16	0.882	5.95	1.30	3.82	0.569	3.70
SPS3 D1-3	9.30	1.64	8.94	3.12	1.17	4.50	0.822	5.39	1.13	3.48	0.499	3.39
SPS3 D4-2	8.27	1.52	8.47	3.08	1.10	4.52	0.776	5.43	1.19	3.38	0.522	3.41
SPS3 D4-5	8.75	1.65	9.28	3.30	1.18	4.86	0.865	5.70	1.26	3.58	0.547	3.67
K87 ST4 D2-1	9.72	1.80	9.91	3.37	1.21	4.94	0.886	5.73	1.21	3.49	0.520	3.25
K87 ST4 D2-2	10.3	1.76	9.47	3.13	1.16	4.36	0.740	5.07	1.06	3.07	0.474	2.97
K87 ST4 D2-4	10.4	1.79	9.44	3.13	1.15	4.42	0.779	5.02	1.07	2.98	0.448	2.89
K87 ST4 D2-5	10.8	1.78	9.43	3.08	1.19	4.25	0.772	4.90	1.05	2.96	0.438	3.01
K87 ST4 D2-7	9.91	1.81	9.99	3.37	1.23	4.78	0.875	5.73	1.24	3.50	0.513	3.43
K87 ST4 D2-8	10.1	1.79	10.0	3.46	1.24	5.07	0.930	5.78	1.27	3.49	0.568	3.29
K87 ST4 DTA-3	34.4	4.37	18.6	4.48	1.58	4.72	0.746	4.26	0.888	2.27	0.337	2.04
K87 ST4 DTA-4	35.1	4.51	19.6	4.66	1.61	4.82	0.778	4.56	0.934	2.38	0.329	2.12
K87 ST4 DTA-7	37.6	4.59	19.5	4.72	1.64	4.79	0.764	4.28	0.867	2.27	0.333	2.06
K87 ST4 DTB-1	38.5	4.88	20.6	4.98	1.71	5.28	0.839	4.87	0.966	2.59	0.367	2.13

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu ppm	Hf ppm	Ta ppm	Pb ppm	Th ppm	U ppm
KK 16-8	0.365	1.67	0.109	0.426	0.121	0.0517
KK 16-10	0.499	4.28	1.80	1.15	2.36	0.525
KK 16-11	0.446	1.97	0.112	0.364	0.139	0.0382
KK 16-12	0.363	1.73	0.0992	0.407	0.108	0.0480
KK 16-13	0.377	1.82	0.0986	0.399	0.111	0.0452
KK 16-14	0.402	1.84	0.0712	0.328	0.0650	0.0270
KK 16-16	0.446	1.80	0.0537	0.336	0.0477	0.0217
KK 16-17	0.418	1.63	0.0486	0.381	0.0487	0.0255
SPS3 DT-1	0.572	2.53	0.137	0.510	0.154	0.0536
SPS3 D1-3	0.494	2.15	0.111	0.496	0.113	0.0473
SPS3 D4-2	0.486	2.12	0.107	0.469	0.112	0.0431
SPS3 D4-5	0.537	2.19	0.101	0.467	0.129	0.0422
K87 ST4 D2-1	0.535	2.54	0.208	0.481	0.271	0.0650
K87 ST4 D2-2	0.453	2.13	0.196	0.530	0.248	0.0628
K87 ST4 D2-4	0.450	2.17	0.199	0.515	0.246	0.0804
K87 ST4 D2-5	0.433	2.17	0.191	0.578	0.269	0.0687
K87 ST4 D2-7	0.506	2.50	0.217	0.525	0.286	0.0637
K87 ST4 D2-8	0.515	2.69	0.208	0.509	0.283	0.0546
K87 ST4 DTA-3	0.317	3.27	1.47	1.27	2.09	0.550
K87 ST4 DTA-4	0.315	3.26	1.56	1.32	2.07	0.559
K87 ST4 DTA-7	0.318	3.28	1.54	1.52	2.10	0.604
K87 ST4 DTB-1	0.336	3.49	1.64	1.42	2.22	0.636

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	H ₂ O ¹ wt.%	CO ₂ ppm	F ppm	S ppm	Cl ppm	Li ² ppm	Be ppm	K ₂ O wt.%	Sc ppm	TiO ₂ wt.%	V ppm	Cr ppm
K87 ST4 DTB-2	0.75	110	477	676	315	4.74	0.732	0.874	29.0	1.91	193	195
K87 ST6 D4-1	0.16	142	116	1107	60	5.13	0.246	0.0578	44.5	1.21	267	276
K87 ST6 D4-3	0.16	140	118	1129	62	6.49	0.209	0.0623	41.2	1.21	280	296
K87 ST6 D4-5	0.16	137	115	1115	60	5.74	0.254	0.0601	40.6	1.20	277	297
K87 ST6 DTA-1	0.51	196	199	975	169	6.21	0.699	0.434	36.2	1.20	223	255
K87 ST8 D5-5	0.30	121	184	1337	167	6.56	0.346	0.132	45.3	1.55	288	74.60
K87 ST8 D5-6	0.31	117	185	1343	167	7.31	0.564	0.123	49.7	1.71	305	67.17
K87 ST14 D10-1	0.17	139	121	1161	76	6.85	0.425	0.0796	41.5	1.39	315	311
K87 ST14 D10-2	0.17	142	121	1166	76	7.18	0.356	0.0837	41.1	1.40	336	330
K87 ST14 D10-6	0.29	204	182	1205	118	7.38	0.672	0.219	39.3	1.61	336	164
K87 ST14 D10-10	0.26	238	171	1146	135	6.58	0.607	0.139	40.2	1.63	302	287
K87 ST15 D11-2	0.26	211	175	1171	137	5.89	0.793	0.130	45.0	1.67	283	269
K87 ST15 D11-8	0.26	215	175	1168	138	7.05	0.656	0.141	42.1	1.68	306	290
K87 ST21 D3-6	0.64	132	311	934	179	6.86	1.77	0.449	36.2	2.12	276	310
Y90 S53.D9.1	0.72	121	288	854	284	4.87	1.24	0.416	37.5	1.31	260	317
Y90 S53.D9.3	0.71	114	284	852	282	5.02	0.871	0.393	40.7	1.34	245	299
Y90 S55.D11.3	0.20	216	121	950	31	5.08	0.573	0.0851	40.8	1.21	225	314
NLD-05-01-01	0.10	270	83	1051	51	4.87	0.299	0.0399	50.3	1.06	249	339
NLD-05-02-01	0.11	182	79	1008	80	4.81	0.195	0.0364	40.2	1.04	250	369

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
K87 ST4 DTB-2	31.5	126	47.6	62.4	19.2	286	24.8	142	27.7	0.231	212	18.2
K87 ST6 D4-1	37.8	66.1	66.4	82.0	0.613	90.5	31.3	69.4	1.23	0.0223	6.70	2.24
K87 ST6 D4-3	39.5	69.7	67.5	84.6	0.642	88.4	27.5	60.9	1.21	0.00344	6.59	2.09
K87 ST6 D4-5	39.5	68.5	67.6	87.7	0.596	88.7	27.1	59.5	1.19	0.0137	6.77	2.12
K87 ST6 DTA-1	34.2	95.8	56.2	82.1	8.67	132	31.7	130	12.1	0.128	85.8	10.2
K87 ST8 D5-5	39.5	33.0	69.3	96.5	2.10	110	39.0	95.9	3.49	0.0293	24.2	4.28
K87 ST8 D5-6	40.4	31.3	66.6	90.1	2.17	120	44.7	114	3.92	0.0183	25.6	4.72
K87 ST14 D10-1	43.3	94.3	71.6	94.3	0.954	86.1	30.0	66.0	1.95	0.0162	11.4	2.58
K87 ST14 D10-2	45.5	99.8	74.5	98.3	1.07	87.0	29.1	64.6	2.04	0.0138	11.4	2.56
K87 ST14 D10-6	45.5	73.9	63.4	100	3.24	142	28.5	79.4	5.39	0.0578	37.5	4.74
K87 ST14 D10-10	40.2	92.3	68.9	86.0	1.43	115	32.4	93.9	3.38	0.0151	17.1	3.98
K87 ST15 D11-2	37.7	86.6	65.4	79.4	1.37	121	38.9	111	3.38	0.0239	16.4	4.33
K87 ST15 D11-8	40.1	92.1	70.7	84.7	1.50	120	35.0	101	3.36	0.0139	17.1	4.15
K87 ST21 D3-6	40.4	144	49.3	84.4	6.13	256	33.8	151	12.3	0.0847	77.8	10.8
Y90 S53.D9.1	38.9	119	73.0	69.2	9.56	217	21.7	80.5	12.3	0.162	110	8.74
Y90 S53.D9.3	36.3	106	66.9	63.9	9.03	219	24.1	89.5	12.4	0.114	106	9.05
Y90 S55.D11.3	43.2	143	74.8	69.7	1.16	152	27.5	74.9	2.22	0.0163	13.8	3.12
NLD-05-01-01	40.3	89.7	78.4	72.5	0.357	77.0	33.3	69.1	0.916	0.000330	3.88	1.73
NLD-05-02-01	42.4	102	87.8	74.3	0.275	85.0	23.5	51.9	0.761	0.00219	3.32	1.44

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
K87 ST4 DTB-2	35.8	4.81	20.8	5.03	1.66	5.25	0.792	4.70	0.956	2.45	0.333	2.18
K87 ST6 D4-1	6.87	1.32	7.88	2.98	1.06	4.48	0.784	5.40	1.19	3.29	0.541	3.14
K87 ST6 D4-3	7.09	1.29	7.13	2.61	1.00	3.91	0.705	4.61	1.03	2.92	0.441	2.85
K87 ST6 D4-5	7.10	1.25	7.11	2.62	1.02	3.92	0.704	4.57	1.03	3.00	0.425	2.77
K87 ST6 DTA-1	20.7	2.93	13.7	3.97	1.34	5.20	0.876	5.49	1.24	3.38	0.515	3.24
K87 ST8 D5-5	11.0	1.98	10.9	3.97	1.37	5.76	1.02	6.71	1.47	4.20	0.639	3.89
K87 ST8 D5-6	11.6	2.14	12.3	4.30	1.47	6.39	1.16	7.48	1.66	4.82	0.762	4.55
K87 ST14 D10-1	7.97	1.41	7.87	2.93	1.07	4.21	0.766	5.08	1.12	3.32	0.507	3.38
K87 ST14 D10-2	8.29	1.41	7.77	2.89	1.08	4.15	0.760	4.89	1.10	3.15	0.496	3.29
K87 ST14 D10-6	13.0	2.03	10.4	3.31	1.23	4.28	0.780	4.78	1.04	3.01	0.474	2.94
K87 ST14 D10-10	12.0	2.03	11.0	3.63	1.29	4.94	0.866	5.51	1.22	3.41	0.530	3.42
K87 ST15 D11-2	11.5	2.12	11.9	4.04	1.38	5.84	1.02	6.67	1.46	4.22	0.646	4.12
K87 ST15 D11-8	12.0	2.08	11.6	3.75	1.32	5.22	0.943	5.97	1.32	3.69	0.580	3.58
K87 ST21 D3-6	26.1	3.73	17.6	4.91	1.71	5.83	0.970	6.01	1.23	3.55	0.533	3.42
Y90 S53.D9.1	19.5	2.64	12.0	3.08	1.12	3.68	0.605	3.81	0.799	2.27	0.318	2.17
Y90 S53.D9.3	18.8	2.73	12.6	3.29	1.15	4.13	0.692	4.27	0.887	2.54	0.402	2.33
Y90 S55.D11.3	8.36	1.50	8.43	2.96	1.07	4.17	0.744	4.81	1.02	3.03	0.451	3.00
NLD-05-01-01	5.08	1.02	6.58	2.60	0.931	4.57	0.838	5.64	1.20	3.52	0.534	3.30
NLD-05-02-01	5.01	0.946	5.55	2.15	0.876	3.47	0.625	4.08	0.878	2.53	0.388	2.40

Table 3.S1: *cont.* New volatile and trace element data for samples from Manus Basin, Lau Basin and North Fiji Basin

Sample	Lu	Hf	Ta	Pb	Th	U
	ppm	ppm	ppm	ppm	ppm	ppm
K87 ST4 DTB-2	0.343	3.62	1.73	1.30	2.31	0.561
K87 ST6 D4-1	0.510	2.17	0.09	0.360	0.101	0.0327
K87 ST6 D4-3	0.449	1.80	0.08	0.377	0.0968	0.0352
K87 ST6 D4-5	0.436	1.83	0.08	0.355	0.0880	0.0335
K87 ST6 DTA-1	0.511	3.41	0.798	0.971	1.44	0.342
K87 ST8 D5-5	0.631	2.88	0.228	0.545	0.292	0.0764
K87 ST8 D5-6	0.745	3.26	0.283	0.526	0.346	0.0820
K87 ST14 D10-1	0.529	2.05	0.127	0.388	0.145	0.0499
K87 ST14 D10-2	0.503	2.00	0.125	0.398	0.122	0.0590
K87 ST14 D10-6	0.478	2.15	0.304	0.595	0.414	0.142
K87 ST14 D10-10	0.538	2.58	0.195	0.493	0.224	0.0893
K87 ST15 D11-2	0.669	3.07	0.228	0.489	0.247	0.0699
K87 ST15 D11-8	0.568	2.75	0.209	0.560	0.234	0.0943
K87 ST21 D3-6	0.532	3.57	0.734	1.12	0.850	0.317
Y90 S53.D9.1	0.341	2.08	0.698	1.03	0.955	0.272
Y90 S53.D9.3	0.414	2.38	0.745	0.914	1.00	0.257
Y90 S55.D11.3	0.465	2.12	0.158	0.410	0.175	0.0459
NLD-05-01-01	0.531	2.05	0.0648	0.266	0.0900	0.0265
NLD-05-02-01	0.377	1.43	0.0549	0.262	0.0642	0.0206

Table 3.S2: Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
Mariana Trough														
S-DS84:2-1	SMT	0.21	7.81	1.14	83.8	269	0.146	0.014	369			1000	248	1310
S-DS88:1-2	SMT	1.3	16.6	6.12	134	783	0.368	0.046			1757	857	248	1167
S-DS-80:23-2	SMT	1.52	8.01	2.35	54.8	1898	0.293	0.043			3424	796	248	1106
S-DS-79:2-2	SMT	0.97	11.3	3.59	83.9	860	0.318	0.043			1586	866	248	1176
S-DS18:1-6	SMT	2.03	9.44	2.38	56.1	2150	0.252	0.042			3396	796	248	1106
S-GTVA75:1-1	SMT	2.21	14.6	3.30	74.8	1510	0.225	0.044			2171	837	248	1147
S-DS74:3-1	SMT	1.18	12.7	4.78	85.5	931	0.377	0.056			2252	834	248	1144
S-DS74:2-3	SMT	2.16	12.0	2.41	65.8	1794	0.200	0.037			2427	827	248	1137
S-DS74:2-1	SMT	2.08	9.50	2.51	57.0	2189	0.264	0.044			3596	791	248	1101
S-DS22:2-2	SMT	0.48	11.8	4.38	98.2	405	0.370	0.045			753	934	248	1244
S-GTVA71:1-7	SMT	1.34	9.33	3.56	62.5	1436	0.382	0.057			3755	787	248	1097

Spreading segments for the Mariana Trough are the Northern Mariana Trough (NMT; 19-22°N), Central Mariana Trough (CMT; 17-19°N), and Southern Mariana Trough (SMT; 15-17°N). Spreading segments for the Manus Basin are the Southern Rifts (SR), Eastern Rifts (ER), Manus Spreading Center (MSC), and Eastern Transitional Zone (ETZ). Spreading segments for the Lau Basin are the Eastern Lau Spreading Center (ELSC), Central Lau Spreading Center (CLSC), Intermediate Lau Spreading Center (ILSC), and Peggy Ridge (PR). Spreading segments for the North Fiji Basin are the Triple Junction (TJ) and N15 spreading center (N15).

¹d is the minimum depth of slab fluid origination, constrained by slab surface PT conditions from D80 thermal models (Syracuse et al., 2010).

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
T7-82:1-1	CMT	1.69	13.6	2.69	94.8	1241	0.198	0.028		2508		824	248	1134
T7-80:1-3	NMT	0.57	7.70	1.25	54.5	741	0.163	0.023		1115		898	248	1208
T7-75:1-2	NMT	0.72	18.0	7.72	128	400	0.429	0.060			993	909	248	1219
T7-76:1-1	NMT	0.73	15.3	4.50	123	478	0.295	0.036			732	937	248	1247
T7-74:1-1	NMT	1.00	14.1	4.95	88.8	710	0.351	0.056			1447	875	248	1185
T7-73:2-1	NMT	1.15	16.3	5.66	113	708	0.348	0.050			1420	876	248	1186
T7-72:2	NMT	2.23	18.8	6.69	105	1184	0.355	0.064			2653	819	248	1129
T7-71:1-14	NMT	1.82	20.5	4.93	92.1	889	0.241	0.054			1288	885	248	1195
T7-46:1-6	NMT	1.41	10.8	2.62	79.1	1310	0.243	0.033			1966	846	248	1156
T7-46:1-8	NMT	1.76	11.4	2.65	81.8	1544	0.233	0.032			2268	833	248	1143
T7-47:1-5	NMT	1.76	11.0	2.19	64.2	1594	0.199	0.034			2140	839	248	1149
T7-48:1-3	NMT	1.57	19.0	3.05	51.1	825	0.160	0.060			984	910	248	1220
T7-48:3-1	NMT	1.56	18.4	2.69	45.9	848	0.147	0.059			986	910	248	1220
T7-68:1-2	NMT	1.84	19.7	3.68	85.5	933	0.187	0.043			1187	893	248	1203
T7-51:1-1	NMT	1.51	11.6	1.72	71.9	1304	0.148	0.024		1905		849	248	1159
T7-54:1-1	NMT	1.69	17.9	2.48	77.4	942	0.138	0.032			1082	901	248	1211

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
East Scotia Ridge														
wx43	E2	0.77	20.7	7.79	114	372	0.376	0.068			680	944	248	1254
wx42	E2	1.02	24.3	9.72	144	420	0.400	0.068			908	917	248	1227
96DS-1	E3	0.24	9.26	2.45	70.6	259	0.265	0.035			301	1019	248	1329
96DS-3	E3	0.43	11.9	3.44	89.0	361	0.289	0.039			501	972	248	1282
98DS-1	E3	1.63	13.1	3.91	80.9	1244	0.298	0.048			2223	835	248	1145
100DS-1	E4	0.69	12.3	3.10	92.7	561	0.252	0.033			791	930	248	1240
wx50	E5	0.29	11.0	2.43	108	264	0.221	0.023		377		998	248	1308
104DS-1	E5	0.63	14.3	2.91	113	441	0.203	0.026		762		933	248	1243
104DS-3	E5	0.64	14.5	2.99	112	441	0.206	0.027		778		931	248	1241
wx51	E6	0.36	11.7	2.28	118	308	0.195	0.019	1742			858	248	1168
107DS-3	E6	0.28	8.31	2.67	66.9	337	0.321	0.040			491	974	248	1284
wx65	E9	0.92	6.70	2.04	46.0	1373	0.304	0.044			2527	823	139	861
Manus Basin														
15-9	ER	1.13	12.4	0.702	33.0	910	0.057	0.021		901		918	248	1228
16-12	ER	1.21	11.2	0.727	47.5	1077	0.065	0.015	1108			899	248	1209
18-2	ER	1.35	6.09	0.458	33.0	2221	0.075	0.014	2458			826	248	1136

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
18-3	ER	1.30	4.89	0.331	22.8	2667	0.068	0.015	2806			814	248	1124
20-3	SR	1.18	4.88	0.401	29.6	2421	0.082	0.014	2824			813	248	1123
21-1	SR	1.29	5.77	0.493	38.6	2242	0.086	0.013	2678			818	248	1128
22-4	SR	1.18	4.61	0.342	23.5	2569	0.074	0.015	2829			813	248	1123
22-5	SR	0.73	6.48	0.533	53.0	1133	0.082	0.010	1302			884	248	1194
23-3	Smt	0.09	3.12	0.227	29.7	280	0.073	0.008	288			1023	248	1333
24-3	MSC	0.33	7.73	1.44	66.2	429	0.187	0.022		663		946	248	1256
25-2	MSC	0.23	5.67	0.918	48.9	411	0.162	0.019	907			917	248	1227
25-3	MSC	0.35	7.21	1.34	74.8	491	0.186	0.018	2458			826	248	1136
26-6	ETZ	0.38	4.97	0.760	50.6	758	0.153	0.015	1758			857	248	1167
27-4	ETZ	0.24	5.63	1.10	61.9	434	0.196	0.018	3969			782	248	1092
28-2	MSC	0.70	6.68	1.13	50.8	1046	0.169	0.022		1697		860	248	1170
28-PD	MSC	0.71	5.28	0.862	36.8	1352	0.163	0.023		2159		838	248	1148
29-3	ETZ	0.18	5.04	0.853	43.2	361	0.169	0.020	850			923	248	1233
29-5	ETZ	1.28	7.09	1.06	41.0	1807	0.150	0.026		2703		817	248	1127
30-4	ETZ	1.37	10.9	1.67	71.1	1262	0.153	0.024		1890		850	248	1160
30-8	ETZ	1.37	10.7	1.59	62.1	1278	0.148	0.026		1859		852	248	1162
31-4	ETZ	0.26	7.02	1.35	54.4	374	0.193	0.025		568		960	248	1270

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
31-9	ETZ	0.57	12.9	3.69	77.3	439	0.286	0.048			642	949	248	1259
32-2	ETZ	0.22	5.27	0.866	43.3	416	0.164	0.020		570		960	248	1270
33-1	ETZ	1.45	27.7	3.36	140	524	0.121	0.024		628		951	248	1261
33-5	ETZ	0.18	4.66	0.635	48.4	392	0.136	0.013	604			955	248	1265
35-2	MSC	1.36	43.9	6.14	135	309	0.140	0.045			330	1010	248	1320
36-1	MSC	0.31	6.54	1.13	53.8	481	0.172	0.021		710		940	248	1250
36-3	MSC	0.26	5.22	1.04	39.2	495	0.199	0.027		861		922	248	1232
36-8	MSC	0.73	12.5	2.38	111	581	0.189	0.021		988		910	248	1220
37-5	MSC	0.30	6.00	1.10	55.1	503	0.183	0.020	2208			836	248	1146
38-4	MSC	0.34	7.32	1.23	57.9	465	0.168	0.021		666		946	248	1256
38-6	MSC	1.16	7.35	1.05	46.1	1580	0.142	0.023		2254		834	248	1144
39-2	MSC	0.34	7.27	1.21	58.1	467	0.167	0.021		663		946	248	1256
39-3	MSC	0.28	5.80	0.953	48.8	485	0.164	0.020	1211			891	248	1201
40-3	MSC	1.21	6.89	0.858	56.2	1762	0.125	0.015	3019			807	248	1117
41-3	MSC	1.18	6.62	0.963	46.8	1776	0.145	0.021		2589		821	248	1131
42-2	MSC	0.48	7.57	1.37	60.3	628	0.181	0.023		1027		906	248	1216
43-2	MSC	0.84	12.1	2.04	97.8	693	0.169	0.021		1070		902	248	1212
43-3	MSC	0.60	8.17	1.41	58.7	739	0.173	0.024		1177		893	248	1203

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
44-3	MSC	0.38	6.60	0.983	51.6	571	0.149	0.019	1160			895	248	1205
46-3	MSC	1.10	20.3	3.08	134.9	543	0.152	0.023		740		936	248	1246
47-2	MSC	0.68	11.8	1.75	82.7	577	0.148	0.021		782		931	248	1241
BC15-2	MSC	0.32	6.57	1.12	62.5	481	0.170	0.018	1356			881	248	1191
BC19-1	MSC	0.70	8.33	1.38	72.8	841	0.165	0.019	2526			823	248	1133
Lau Basin														
VG-9750	CLSC	1.13	6.40	0.732	37.0	1760	0.114	0.020	2693			818	248	1128
VG-9751	CLSC	0.35	11.0	2.11	107	314	0.191	0.020	1371			880	248	1190
VG-9758	CLSC	0.43	14.2	2.50	126	301	0.177	0.020	715			939	248	1249
VG-9760	CLSC	0.52	13.9	2.77	147	375	0.200	0.019	5097			759	248	1069
VG-9764	CLSC	0.27	7.99	1.42	75.4	342	0.178	0.019	953			913	248	1223
VG-9768	CLSC	1.45	43.9	6.85	517	331	0.156	0.013	587			957	248	1267
VG-9775	CLSC	1.33	45.6	7.90	627	293	0.173	0.013	623			952	248	1262
VG-9778	CLSC	1.08	5.66	0.631	30.7	1906	0.111	0.021		2346		830	248	1140
VG-9779	CLSC	0.27	8.61	1.46	73.5	311	0.169	0.020	647			948	248	1258
VG-9785	CLSC	0.26	6.34	1.12	62.8	402	0.176	0.018	1211			891	248	1201
VG-9786	CLSC	0.31	10.5	1.97	97.6	298	0.189	0.020		401		992	248	1302

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
VG-9789	CLSC	1.20	10.2	2.58	36.2	1177	0.253	0.071			1805	854	248	1164
VG-9792	ILSC	0.17	4.87	0.317	70.8	348	0.065	0.004	354			1004	248	1314
VG-9801	ELSC	0.42	5.32	0.952	51.5	787	0.179	0.018	3474			794	248	1104
VG-9809	ELSC	0.31	4.31	0.868	38.1	709	0.201	0.023		1365		880	248	1190
VG-9812	ELSC	0.49	4.58	0.896	51.6	1068	0.195	0.017	13393			670	248	980
VG-9816	ELSC	0.52	6.76	1.64	57.1	774	0.242	0.029		2279		833	248	1143
VG-9824	ELSC	1.33	3.89	0.372	35.9	3420	0.096	0.010	4465			771	248	1081
VG-9825	ELSC	0.30	5.02	0.657	48.8	590	0.131	0.013	962			912	248	1222
VG-9831	ELSC	1.24	3.26	0.290	27.8	3810	0.089	0.010	4711			766	248	1076
VG-9834	ELSC	0.21	5.43	0.770	49.3	386	0.142	0.016	628			951	248	1261
VG-9836	ELSC	1.28	4.53	0.410	37.2	2833	0.090	0.011	3531			793	248	1103
VG-9838	ELSC	0.96	7.84	1.09	69.1	1228	0.139	0.016	2445			826	248	1136
VG-9839	ELSC	1.20	5.98	0.795	48.0	1999	0.133	0.017	3814			786	248	1096
VG-9842	ELSC	1.40	11.9	2.29	122	1171	0.192	0.019	11337			686	248	996
VG-9844	ELSC	0.82	6.10	0.785	51.8	1351	0.129	0.015	2387			829	248	1139
VG-9847	ILSC	0.36	4.92	1.33	39.3	728	0.271	0.034			1122	898	248	1208
NLD-55-01	PR	0.12	3.97	0.649	46.6	311	0.164	0.014	590			957	248	1267
NLD-56-01	PR	0.10	3.63	0.719	42.3	267	0.198	0.017	1582			866	248	1176

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
NLD-57-01	PR	0.21	5.18	0.706	48.3	400	0.136	0.015	622			952	248	1262
NLD-58-01	CLSC	0.15	5.42	1.02	45.1	282	0.188	0.023		368		1000	248	1310
NLD-59-01	CLSC	0.28	6.82	1.32	55.6	413	0.194	0.024		657		947	248	1257
NLD-60-01	CLSC	0.54	8.04	1.59	73.4	666	0.198	0.022		1234		889	248	1199
NLD-61-01	CLSC	0.09	2.65	0.494	28.4	340	0.186	0.017	1277			886	248	1196
NLD-64-01	CLSC	0.14	4.21	0.698	35.8	324	0.166	0.020	659			947	248	1257
NLD-65-01	CLSC	0.14	3.84	0.756	43.5	363	0.197	0.017	3022			807	248	1117
NLD-66-01	CLSC	0.23	5.91	1.31	62.2	394	0.221	0.021		741		936	248	1246
North Fiji Basin														
KK 16-1	TJ	0.23	8.24	1.67	62.7	283	0.203	0.027		392		994	248	1304
KK 16-2	TJ	0.26	9.33	2.05	69.2	280	0.220	0.030		419		988	248	1298
KK 16-3	TJ	0.23	7.95	1.58	60.2	286	0.198	0.026		391		995	248	1305
KK 16-4	TJ	0.25	9.23	2.04	66.9	270	0.221	0.031			304	1018	248	1328
KK 16-5	TJ	0.27	9.00	1.96	69.3	295	0.217	0.028		454		981	248	1291
KK 16-6	TJ	0.22	8.06	1.61	59.9	278	0.200	0.027		377		998	248	1308
KK 16-7	TJ	0.21	7.10	1.06	57.2	294	0.149	0.019	446			983	248	1293
KK 16-8	TJ	0.24	8.13	1.63	60.8	292	0.200	0.027		408		991	248	1301

Table 3.S2: *cont.* Back-arc eruptive and slab fluid H₂O/Ce compositions and temperatures for individual samples

	Segment	Eruptive							Slab Fluid					
Variable		H ₂ O	Ce	Nb	Zr	H ₂ O/Ce	Nb/Ce	Nb/Zr	H ₂ O/Ce	H ₂ O/Ce	H ₂ O/Ce	Temp. (H ₂ O/Ce)	d ¹	Temp. (corr.)
Units		wt.%	ppm	ppm	ppm	ppm/ppm	ppm/ppm	ppm/ppm				°C	km	°C
Pressure												4 GPa		d
Projected from									H-DMM	N-MORB	E-MORB			
KK 16-11	TJ	0.23	7.30	1.57	71.1	312	0.215	0.022		495		973	248	1283
KK 16-12	TJ	0.24	8.07	1.55	62.1	292	0.192	0.025		394		994	248	1304
KK 16-13	TJ	0.23	8.19	1.61	65.3	281	0.197	0.025		378		998	248	1308
KK 16-14	TJ	0.21	7.06	1.08	66.5	301	0.154	0.016	486			975	248	1285
K87 ST8 D5-5	N15	0.30	11.0	3.49	95.9	276	0.318	0.036			359	1003	248	1313
K87 ST8 D5-6	N15	0.31	11.6	3.92	114	264	0.337	0.034			346	1006	248	1316

Figure 3.1 **A)** Detailed map of the Mariana Trough, showing samples from Volpe et al., 1987; Hawkins et al., 1990; Gribble et al., 1996; Gribble et al., 1998; Pearce et al., 2005. Spreading segments are the Northern Mariana Trough (NMT) from 19-22°N, the Central Mariana Trough (CMT) from 17-19°N, and the Southern Mariana Trough (SMT) from 15-17°N. **B)** Detailed map of East Scotia Ridge, showing samples from Fretzdorff et al., 2002. Spreading segments are E2 - E9. **C)** Detailed map of the Manus Basin, showing samples from Danyushevsky et al., 1993; Kamenetsky et al., 2001; Sinton et al., 2003; Shaw et al., 2004; Shaw et al., 2012. Spreading segments are Manus Spreading Center (MSC), Eastern Transitional Zone (ETZ), Southern Rifts (SR), and Eastern Rifts (ER). **D)** Detailed map of the Lau Basin, showing samples from Hawkins, 1976; Aggrey et al., 1988; Jambon and Zimmermann, 1990; Danyushevsky et al., 1993; Sinton et al., 1993; Pearce et al., 1995; Kamenetsky et al., 1997; Peate et al., 2001; Melson et al., 2002; Keller et al., 2008; Bézous et al., 2009; Escrig et al., 2009; Tian et al., 2011; Escrig et al., 2012; Lytle et al., 2012. Spreading segments are Rochambeau Rifts (RR), Northwest Lau Spreading Center (NWLSC), Peggy Ridge (PR), Central Lau Spreading Center (CLSC), Intermediate Lau Spreading Center (ILSC), Eastern Lau Spreading Center (ELSC), Fonualei Rifts Spreading Center (FSC), and Mangatolu Triple Junction (MTJ). **E)** Detailed map of the North Fiji Basin, showing samples from Aggrey et al., 1988; Danyushevsky et al., 1993; Sinton et al., 1993; Eissen et al., 1991; Eissen et al., 1994; Nohara et al., 1994. Spreading segments are the Triple Junction (TJ), the N15 spreading center (N15), and the North-South spreading center (N-S). Basemaps were created using GeoMapApp (<http://www.geomapapp.org>; Ryan et al., 2009). Thick black lines show the location of the arc cross-section used in the 2D thermal models (Syracuse et al., 2010).

Figure 3.2 A) Plot of CO₂ vs. H₂O, showing samples from five global back-arc basins. Degassing paths, shown by the dashed gray (closed system) and dashed black (open system) lines, are calculated using Volatile Calc [Newman and Lowenstern, 2002] with the following constraints: 49 wt.% SiO₂, 1.4 wt.% H₂O, 240 ppm CO₂, 1000°C, and for closed system degassing 0.5 wt.% exsolved volatiles. **B)** Plot of hydrostatic pressure at collection depth vs. pressure of volatile saturation (see panel A) for glasses from the Mariana Trough, East Scotia Ridge, Manus Basin, Lau Basin, and North Fiji Basin. A 1:1 line is plotted with an uncertainty in collection pressure of 50 bars, to account for the possibility that lava flowed downhill from the initial eruption site.

Figure 3.3 **A)** Plot of Nb/Nb^* vs. H_2O/Ce . Nb^* is the projected concentration of Nb based on Th and La abundances, where Nb/Nb^* is calculated as $Nb_N / (Th_N \times La_N)^{1/2}$. The solid black line is the H_2O/Ce ratio cut-off ($H_2O/Ce = 250$). **B)** Plot H_2O vs. H_2O/Ce . Small open circles are MORB data from Dixon et al., 2002. Skewed triangles are arc data from Cooper et al., 2012.

Figure 3.4 Plot of Nb/Ce vs. Nb/Zr to determine the source composition for the back-arc basin samples. The three mantle source compositions are high depleted MORB mantle [H-DMM], normal MORB mantle [NMORB], and enriched MORB mantle [EMORB]. The Nb/Ce and Nb/Zr of H-DMM is from Workman and Hart, 2005 (0.205; 0.02), NMORB (0.311; 0.03) and EMORB (0.553; 0.11)) are from Sun and McDonough, 1989. The samples are grouped to determine the enrichment groups. The white stars and black stars are the maximum and minimum H_2O/Ce values respectively for each basin. The smaller, gray symbols at Nb/Ce = 0.06 are the segment average H_2O/Ce values. A) Mariana Trough. The three spreading segments are Northern Mariana Trough (NMT, 19-22°N), Central Mariana Trough (CMT, 17-19°N), and Southern Mariana Trough (SMT, 15-17°N). B) East Scotia Ridge. The spreading segments are E2, E3, E4, E5, E6, E9 (Fretzdorff et al., 2002). C) Manus Basin. The four spreading segments are Eastern Rifts (ER), Southern Rifts (SR), Manus Spreading Center (MSC), and Eastern Transform Zone (ETZ). D) Lau Basin. The six spreading segments are Eastern Lau Spreading Center (ELSC), Intermediate Lau Spreading Segment (ILSC), Central Lau Spreading Segment (CLSC), Peggy Ridge (PR), Fonualei Spreading Center (FSC), and Mangatolu Triple Junction (MTJ). E) North Fiji Basin. The two spreading segments are the Triple Junction (TJ) and the N15 Spreading Ridge.

Figure 3.6 Plot of temperature vs. pressure for the five back-arc basins. The H_2O -isopleths, identified by black lines with the H_2O wt.% of the melt in the circle, are from Hermann and Spandler (2008). The wet solidus, defined by Hermann and Spandler (2008), is constrained by experiments up to 3.5 GPa (solid line) and extrapolated to greater pressures (dashed line). The H_2O/Ce thermometer is calibrated at 4.0 GPa and samples are extrapolated along the H_2O -isopleths to intersect the slab surface temperature (Syracuse et al., 2010) at pressures of fluid release. The yellow symbols are the back-arc basin spreading segment PT values at 4 GPa. **A)** Mariana Trough. The black square is the PT arc values from Cooper et al., 2012 at 4 GPa, and the two gray squares are the projected temperatures from Cooper et al. (2012) and the recalculated temperature using Agrigan data from Kelley and Cottrell, 2012, projected to a depth of h , the depth from volcano to slab surface as determine by Syracuse et al. (2010). **B)** East Scotia Ridge. The arc PT value (black cross) is from the D80 thermal models (Syracuse et al., 2010). The blue cross is the projected SST for the E9 segment, the only segment cool enough to intersect the SST at depth. **C)** Manus Basin. The arc PT value (black circle) is from the D80 thermal models (Syracuse et al., 2010). The gray circle is the projected temperature to a depth of h , the depth from volcano to slab surface as determine by Syracuse et al. (2010). **D)** Lau Basin. The arc PT value (black diamond) is from Cooper et al., 2012. **E)** North Fiji Basin. The arc PT value (black elongated square) is from the D80 thermal models (Syracuse et al., 2010). The gray elongated square is the projected temperature to a depth of h , the depth from volcano to slab surface as determine by Syracuse et al. (2010).

Figure 3.7 Plot of the H_2O/Ce estimates for the slab fluid and associated temperatures (horizontal lines) from the H_2O/Ce geothermometer (Plank et al., 2009; Cooper et al., 2012). The black symbols are the arc temperatures from Cooper et al., 2012 and the purple symbol for South Sandwich Arc is the temperature from the D80 thermal model (Syracuse et al., 2010) and the pink symbols for New Britain Arc and Vanuatu Arc are calculated using whole rock trace element data and assume H_2O content from 4.0 wt.% (Woodhead et al., 1998; Raos and Crawford, 2004). Data from the back-arc basins constrains the temperature range, where the blue symbols are the minimum temperature constraints from the sample with the highest H_2O/Ce value, the purple symbols are the averages calculated from the segment averages, and the green symbols are the maximum temperature constraints from the sample with the lowest H_2O/Ce value.

Figure 3.8 Schematic of two possible scenarios for the slab-surface temperature with depth. **A)** The solid line is the slab surface profile modeled from the D80 thermal models (Syracuse et al., 2010) and the dashed line is a hypothetical extension of the slab surface at depths greater than 8 GPa. **B)** Thermal variation within the subducting plate where the plate edges are warmer than the center of the plate, allowing for thermal variation without a corresponding depth change.

Figure 3.9 **A)** Plot of distance from the arc (km) vs. temperature (°C) at 4 GPa for the arc, located at 0 km, and the back-arc basin segments with increasing distance from the arc. The $\text{H}_2\text{O}/\text{Ce}$ geothermometer from Plank et al. (2009) has 50°C error bars. **B)** Plot of distance from the arc (km) vs. temperature (°C) at projected depths for the arc at 0 km and the back-arc basin segments with increasing distance from the arc. The $\text{H}_2\text{O}/\text{Ce}$ geothermometer from Plank et al. (2009) has 50°C error bars. The arc samples are projected to the depth of volcano to slab surface as determined by Syracuse et al., 2010. The ESR E9 segment is projected to a depth of 4.5 GPa, and the rest of the back-arc basin samples are projected to a depth of 8 GPa.

Figure 3.10 Plot of latitude or longitude vs. temperature at 4 GPa, showing along strike variations for the five back-arc basins. The spreading segments are the same abbreviations and symbol design as in Figure 4. The near-arc trend in the Lau Basin is circled in red.

Figure 3.11 Schematic back-arc basin cartoon, with the back-arc slab fluid released at depth and entering the back-arc basin melt region from below. The gray curved arrows represent arc slab-derived fluids and the stippled curved arrows represent back-arc slab-derived fluids released at depth. The black arrows represent mantle flow, including 3D motion (toroidal flow). The thin black arrows show slab motion.

APPENDICES

A. LASER ABLATION ICP-MS

Part 1: Sample Exchange Time Delay:

During the process of sample analysis by laser ablation ICP-MS (LA-ICP-MS), three spots are typically collected on unknown glass sample chips. Upon analysis of this collected laser data, a mismatch between spots on unknown samples was observed. The first spot (spot 1) always had lower concentrations for rare earth elements (REE) and the difference between concentrations for spot 1 and spots 2 and 3 was greater for the light REE (LREE). The observed lack of correlation between spots was found to be present only in the first analyzed sample after sample mounts were switched and the sample chamber was exposed to the ambient atmosphere. Several tests were performed to determine both the cause of the spot disparity and arrive at an appropriate solution to avoid the lack of correlation between spots on future analyzes. As noted, the first spot also has lower REE concentrations, and preventing the lower concentrations observed in spot 1 will also be significantly important for samples such as melt inclusions, in which only one spot can be analyzed.

The first test involved multiple steps starting with three runs of the standards in the “normal” order and one run of the standards in the “reverse” order, as the standards are typically analyzed in a set order and could be influencing the data analysis. The next step was three separate tests to test three different variables including (1) the number of times the laser was purged, (2) the wait time between sample mount changes, and (3) the “warmness” of the laser. Each test had a normal run that analyzed the standards and 3 spots each on four unknowns. Test 1 consisted of

a normal run then a sample mount switch followed by one purge of the laser system, a 15 minute wait time, and reanalysis of the four unknowns and then another sample mount switch followed by one purge, no wait time, and reanalysis of the four unknowns (Figure A1). Test 2 consisted of a normal run then a sample mount switch followed by two purges of the laser system, a 15 minute wait time, and reanalysis of the four unknowns and then another sample mount switch followed by two purges, no wait time, and reanalysis of the four unknowns (Figure A1). Test 3, shown in Figure A2, consisted of a normal run then a sample mount switch followed by two purges of the laser system, a 15 minute wait time, 5 minute laser warm-up time, and reanalysis of the four unknowns and then another sample mount switch followed by two purges, a 15 minute wait time, 10 minute laser warm-up time, and reanalysis of the four unknowns.

Upon analysis of these tests, the analysis order of the standards had no impact on the observed concentrations or sample spot disparity. The number of purges performed on the laser system and the length of time for laser warm-up appeared to be insignificant compared to the amount of time spent waiting between sample mount changes post-purge. The samples analyzed following a 15 minute wait time had no disparity between spots on the first sample analyzed, while the samples analyzed following no wait time had a noticeable disparity between spot 1 and spots 2 and 3.

Further tests were performed to determine the amount of time required to wait before continuing sample analysis after changing sample mounts. All tests had two purges of the laser system following sample mount change before analysis continued and the first test had a two minute wait time, while the second test had a five minute

wait time and the third test had a ten minute wait time. The analysis of these tests (see Figure A3) showed that the ideal sample wait time was 10 minutes (Figure A3c) as both the two minute (Figure A3a) and five minute (Figure A3b) wait times had noticeable differences between spot 1 and spots 2 and 3, although spot 1 was closer to spots 2 and 3 after a five minute wait time rather than a two minute wait time.

Part 2: Laser Tuning Tests:

A complication that arises during tuning is that NIST 612 is heterogeneous and does not ablate evenly. Six additional natural glass samples (NLD-65-01-01, RC2806 16D-1g, EN026 10D-3g, RC2806 4D-3g, RC2806 40D-9g, Kilauea glass) were analyzed for comparison of count rates to the known tuning benchmark count rates on NIST 612. The six natural glass samples, while ablating consistently, have the problem of crystal inclusions, not exposed at the surface. The results of three analyzes are shown in Table A1 and RC2806 40D-9g has the highest sensitivity on ^{139}La out of all the natural glass samples. The counts on ^{139}La for RC2806 40D-9g are similar to the counts observed on NIST 612, providing a similar tuning reference range with similar sensitivity but a more reliable ablation pattern.

Part 3: Laser Conditions Tests:

The three main laser properties which affect the count rate and sensitivity of laser ablation ICP-MS are spot size (μm), repeat rate (Hz), and laser energy (%). Spot size ranges from 5 – 160 μm , repeat rate ranges from 1 – 20 Hz, and laser energy ranges from 50 – 100%. The three laser properties affect count rate and can vary

between different standards. While the count rate on the standards will change as properties change, ideal laser settings will maintain a constant relationship between standards. Providing constraints on the behavior of each of the laser properties will determine the range of conditions under which the laser can be used, while maintaining accuracy as the ratio between samples remains constant. During data reduction, samples are normalized to CaO, which removes the variation in signal, providing a constant reference in which to analyze the effects of the three laser properties.

Each of the three laser properties were tested individually and were focused on the three USGS standards (BIR-1g, BHVO-2g, BCR-2g). The first test (Figure A4a) analyzed each USGS standard with the following spot sizes: 5 μm , 8 μm , 12 μm , 16 μm , 20 μm , 30 μm , 40 μm , 60 μm , 80 μm , 100 μm , and 120 μm . Looking at a low abundant element such as U normalized to CaO, the ratio between BIR-1g, BHVO-2g, and BCR-2g is found to be largely unchanged above 20 μm . The second test analyzed the USGS glasses with the following settings for repeat rate: 1 Hz, 2 Hz, 4 Hz, 5 Hz, 10 Hz, and 20 Hz. As shown in Figure A4b, a repeat rate of 5 Hz or greater is found to provide a constant ratio between BIR-1g, BHVO-2g, and BCR-2g for U normalized to CaO. The third test also analyzed the USGS standards while increasing the laser energy from 0% to 100% in 5% increments. Again, looking at U normalized to CaO in Figure A4c, it is determined that U is not detected until the laser energy reaches 50%, after which the ratio is largely unchanged above 50%.

Analysis of the three USGS glass standards provided constraints on the accuracy of results under varying conditions. This provides good constraints for

typical glass analyzes, but for analysis of materials such as melt inclusions, where there is little material available for ablation, the length of time the material is ablated must be maximized. However, that requires a better understanding of how the laser properties interact and jointly affect count rate, sensitivity, and laser drilling rate (i.e., the length of time it takes to drill through a sample). This round of testing was conducted in two parts focusing on interaction between spot size, repeat rate, and laser energy and finally the effect these properties had drilling rate.

Table A2 and Figure A5 show the results from three tests in which (1) the spot size was changed while keeping repeat rate and laser energy constant, (2) the repeat rate was changed while keeping spot size and laser energy constant, and (3) the laser energy was changed while keeping spot size and repeat rate constant. These tests showed that the laser energy output (mJ) increased with both increasing spot size (μm) and repeat rate (Hz). When changing the laser energy (%) from 50% to 80%, the laser energy output (mJ) increased, but further increases in laser energy (%) had little change on the laser energy output (mJ). Overall, increasing each of the settings will increase the laser energy output (mJ), thus increasing the amount of material ablated and increased sensitivity.

The second part of the testing focused on what effect each of the three laser properties had on the laser drilling rate ($\mu\text{m/s}$), shown in Table A3. The first test determined the effect of a changing spot size on drilling rate, in which it was observed, in Figure A6a, that the drilling rate remained relatively constant at $\sim 2 \mu\text{m/s}$ over the entire range of spot sizes (5 – 160 μm). The second test looked at the effect of a changing repeat rate on drilling rate and found that the drilling rate increased from ~ 1

$\mu\text{m/s}$ at 5 Hz to $\sim 4 \mu\text{m/s}$ at 20 Hz, shown in Figure A6b. Finally, Figure A6c shows the third test, which looked at the effect of increasing the laser energy (%) on the drilling rate, and found a very minimal change from $\sim 2 \mu\text{m/s}$ at 55% energy to $\sim 3 \mu\text{m/s}$ at 80% energy. Therefore, to decrease the laser drilling rate, the best option is to decrease the repeat rate from the default of 10 Hz to 5 Hz, which decreased the drilling rate by 50% or from $\sim 2 \mu\text{m/s}$ to $\sim 1 \mu\text{m/s}$.

Part 4: Data Normalization Tests:

Data reduction in LasyBoy requires normalizing the laser data to major element data, typically either CaO or TiO_2 . Comparison of data reductions by CaO and TiO_2 showed that CaO content is the better normalizing value. Ca is a major element and as such is consistent within the mantle and Ti varies in the mantle and as such may not be an ideal consistent measurement for calibration. Using CaO normalized laser data, the experimental major element laser data (specifically SiO_2) was found to be closer to accepted microprobe data and the LREE pattern is smoother (see Figure A7 for REE comparison between Ti and Ca normalization for three samples).

Table A1: Count rates of NIST 612 standard and natural basaltic glass samples

	NIST 612	NLD-65- 01-01	RC2806 16D-1g	EN026 10D-3g	RC2806 4D-3g	RC2806 40D-9g	Kilauea glass
First Analysis – April 6, 2010							
⁷ Li	2869	1067	997	1197	1187	1049	1237
⁹ Be	334	14	14	15	26	28	25
⁵² Cr	49027	269746	294204	366471	284522	314897	319337
⁶⁰ Ni	9374	32660	48832	34135	35446	36401	25253
⁸⁸ Sr	47827	175732	198396	259561	825912	721017	724507
⁸⁹ Y	15754	40243	36363	32262	37920	33288	33424
⁹⁰ Zr	7626	33688	32488	46820	82257	90550	94990
¹³⁷ Ba	4005	3016	3010	33769	99347	85903	41859
¹³⁹ La	21476	3439	3222	12784	34234	45605	25291
¹⁴⁰ Ce	37507	15412	14978	50942	111678	149395	105418
²⁰⁸ Pb	29452	843	763	1776	2791	2889	2605
²³² Th	16985	124	152	927	2598	3893	1343
²³⁸ U	49958	69	107	601	1534	2614	1200
Second Analysis – September 14, 2012							
⁷ Li	52078	5554	5348	6426	6674	6884	6203
⁹ Be	5976	39	60	86	133	176	153
⁵² Cr	174466	542619	613839	770776	650313	788923	659227
⁶⁰ Ni	36015	58834	95874	64291	74140	82639	44180
⁸⁸ Sr	342646	274772	352834	482777	1674636	1581178	1374783
⁸⁹ Y	127985	71876	78998	70976	93310	83261	76247
⁹⁰ Zr	57743	56178	63717	95731	187518	211582	195854
¹³⁷ Ba	26263	4164	4440	53910	174947	160715	66355
¹³⁹ La	137997	4763	5013	21495	62367	86917	41671
¹⁴⁰ Ce	197254	18588	18829	67461	161958	230038	135904
²⁰⁸ Pb	183809	947	721	2256	4153	4958	3581
²³² Th	131759	283	347	1850	5768	8886	2730
²³⁸ U	271051	193	195	946	2588	4477	1790
Third Analysis – September 25, 2012							
⁷ Li	2632	1042	984	1061	1185	1130	1231
⁹ Be	336	5	3	11	15	17	23
⁵² Cr	14562	70636	61864	94532	86722	99816	112432
⁶⁰ Ni	6789	11322	12529	10879	12519	12912	10579
⁸⁸ Sr	24389	37967	37368	60866	228797	203464	273018
⁸⁹ Y	10808	11712	9129	10238	14308	12292	17623
⁹⁰ Zr	5236	9795	8242	14872	31642	33516	48427
¹³⁷ Ba	1750	503	457	6448	22318	19627	12115
¹³⁹ La	11249	779	553	3133	9998	13029	9403
¹⁴⁰ Ce	14419	2595	2164	9057	24004	31905	27698
²⁰⁸ Pb	6713	77	55	145	311	346	357
²³² Th	6719	21	23	157	545	827	403
²³⁸ U	11698	13	7	63	209	364	179

Table A2: Effect of spot size, repeat rate, and laser energy on the laser energy output

Spot Size	Repeat Rate	Laser Energy	Laser Energy Output	Laser Fluence
μm	Hz	%	mJ	J/cm^2
Variable Spot Size (μm)				
5	10	60	0.001	7.29
8	10	60	0.006	11.46
12	10	60	0.013	11.36
16	10	60	0.023	11.30
20	10	60	0.035	11.39
30	10	60	0.079	11.42
40	10	60	0.143	11.39
60	10	60	0.326	11.54
80	10	60	0.546	10.86
95	10	60	0.955	13.48
120	10	60	1.09	9.65
140	10	60	1.63	10.61
160	10	60	1.94	9.63
Variable Repeat Rate (Hz)				
60	1	60	0.291	10.29
60	2	60	0.299	10.56
60	4	60	0.318	11.23
60	5	60	0.304	10.75
60	10	60	0.323	11.43
60	20	60	0.353	12.47
Variable Laser Energy (%)				
60	10	50	0.122	4.33
60	10	55	0.242	8.55
60	10	60	0.285	10.06
60	10	65	0.412	14.57
60	10	70	0.486	17.17
60	10	75	0.497	17.57
60	10	80	0.497	17.57
60	10	85	0.497	17.57
60	10	90	0.497	17.57
60	10	95	0.497	17.57
60	10	100	0.497	17.57

Table A3: Effects of spot size, repeat rate, and laser energy on laser drilling rate

Spot Size	Repeat Rate	Laser Energy	Laser Energy Output	Laser Fluence	Sample Thickness	Time to Drill Through Sample	Drilling Rate
μm	Hz	%	mJ	J/cm ²	μm	s	μm/s
Variable Spot Size (μm)							
60	10	60	0.311	10.98	48	22	2.18
40	10	60	0.139	11.09	48	21	2.29
30	10	60	0.077	10.94	48	25	1.92
20	10	60	0.034	10.92	48	22	2.18
16	10	60	0.022	10.97	48	25	1.92
12	10	60	0.012	10.88	48	22	2.18
60	10	60	0.310	10.96	91	38	2.39
60	10	60	0.312	11.05	64	32	2.00
60	10	60	0.313	11.09	59	22	2.68
40	10	60	0.138	10.98	59	23	2.57
30	10	60	0.078	11.07	59	25	2.36
20	10	60	0.035	11.05	59	25	2.36
16	10	60	0.024	11.56	59	26	2.27
16	10	60	0.022	11.06	59	26	2.27
12	10	60	0.013	11.20	59	25	2.36
60	10	60	0.321	11.35	98	54	1.81
40	10	60	0.137	10.92	98	54	1.81
40	10	60	0.140	11.16	98	50	1.96
30	10	60	0.078	10.97	98	55	1.78
20	10	60	0.035	11.08	98	55	1.78
16	10	60	0.023	11.16	98	54	1.81
12	10	60	0.013	10.90	98	55	1.78
40	10	60	0.140	11.19	95	42	2.26
40	10	60	0.140	11.12	102	48	2.13
AVERAGE					71	34	2.08
Variable Repeat Rate (Hz)							
20	1	60	0.033	10.61	59	> 60	
20	2	60	0.033	10.36	59	> 60	
20	4	60	0.033	10.61	59	> 60	
20	5	60	0.034	10.75	59	53.5	1.10
20	10	60	0.036	11.33	59	26.5	2.23
20	20	60	0.039	12.32	59	14.2	4.15

Table A3: *cont.* Effects of spot size, repeat rate, and laser energy on laser drilling rate

Spot Size	Repeat Rate	Laser Energy	Laser Energy Output	Laser Fluence	Sample Thickness	Time to Drill Through Sample	Drilling Rate
μm	Hz	%	mJ	J/cm^2	μm	s	$\mu\text{m}/\text{s}$
Variable Laser Energy (%)							
20	10	50	0.013	4.09	59	> 60	
20	10	55	0.021	6.76	59	31	1.90
20	10	60	0.027	8.68	59	29	2.03
20	10	65	0.046	14.51	59	25	2.36
20	10	70	0.045	14.58	59	24	2.46
20	10	75	0.055	17.57	59	21	2.81
20	10	80	0.055	17.57	59	19	3.11

Figure A1: Rare earth element plots testing sample delay time. **A)** Plot showing the observed problem of disagreement between three spots on the same sample. **B)** The sample chamber was purged two times and had a sample delay time of 15 minutes post-purge. **C)** The sample chamber was purged two times and with no sample delay time.

Figure A2: Rare earth element plots testing laser warmness time. **A)** Plot showing a laser warm-up time of 5 minutes, with the sample chamber purged two times and a sample delay time of 15 minutes post-purge. **B)** Plot showing a laser warm-up time of 10 minutes, with the sample chamber purged two times and a sample delay time of 15 minutes post-purge.

Figure A3: Rare earth element plots testing the length of sample delay time. **A)** Plot showing a sample delay time of 2 minutes and the sample chamber was purged two times. **B)** Plot showing a sample delay time of 5 minutes and the sample chamber was purged two times. **C)** Plot showing a sample delay time of 10 minutes and the sample chamber was purged two times.

Figure A4: Plots of laser properties vs. normalized intensity for three USGS standards. **A)** Plot of spot size (μm) vs. normalized intensity of U to CaO, showing relatively consistent ratio between the three USGS standards for spot sizes $> 20 \mu\text{m}$. **B)** Plot of repeat rate (Hz) vs. normalized intensity of U to CaO, showing relatively consistent ratio between the three USGS standards for repeat rate $> 5 \text{ Hz}$. **C)** Plot of laser energy (%) vs. normalized intensity of U to CaO, showing relatively consistent ratio between the three USGS standards for laser energy $> 50\%$.

Figure A5: Plots of laser properties vs. laser energy output (mJ). **A)** Plot of spot size (μm) vs. laser energy output. Increasing spot size from 5 - 160 μm corresponded to an exponential increase in laser energy output. **B)** Plot of repeat rate (Hz) vs. laser energy output, where repeat rate ranged from 5 - 20 Hz. The increase in repeat rate corresponded to a small increase in laser energy output. **C)** Plot of laser energy (%) vs. laser energy output, where laser energy ranged from 50 to 100% energy. Laser energy output increased to increases in laser energy from 50 - 70% and then leveled out from 70 - 100% laser energy.

Figure A6: Plots of laser properties vs. laser drilling rate ($\mu\text{m/s}$). **A)** Plot of spot size (μm) vs. drilling rate, where spot size ranged from 12 - 60 μm and showed a consistent drilling rate of $\sim 2 \mu\text{m/s}$. **B)** Plot of repeat rate (Hz) vs. drilling rate. Repeat rate ranged from 5 - 20 Hz, which corresponded to an increase in drilling rate from $\sim 1 \mu\text{m/s}$ to $\sim 4 \mu\text{m/s}$. **C)** Plot of laser energy (%) vs. drilling rate, where laser energy ranged from 55 to 80% energy. Drilling rate showed a slight increase from $\sim 2 \mu\text{m/s}$ to $\sim 3 \mu\text{m/s}$.

Figure A7: Chondrite normalized rare earth element plot comparing Ca-normalized and Ti-normalized samples, analyzed by laser ablation ICP-MS.

B. ICP-MS MANUAL FOR SOLUTION, LASER ABLATION, AND COLLISION CELL ANALYZES

Section 1: Solution ICP-MS

Solution ICP-MS tuning steps

1. Check cones and glassware. Clean cones with isopropanol at the start of each day.
2. Check argon and chiller.
 - a. Argon pressure on the line must be above 250 psi. If using liquid argon the right hand gauge on the regulator will read zero pressure. If using compressed gas tanks, open two tanks at a time and when the right hand gauge reads 500 psi, open two more tanks by first opening the tank then opening the line. Then close the line to the two old tanks and then close the two tanks.
 - b. Check the chiller water level. If you do not see water flowing, add water from the tap water container stored on top of the chiller.
3. Check instrument configuration (XSeries Default). Attach gray tube and spray chamber. Attach nebulizer gas tube to spray chamber.
4. Check and set pump tubing on peristaltic pump. Uptake tube has colored clips. Drain tube has black and white clips. Stretch the tubes and clip into place. Clamp tubes into place on peristaltic pump. Place sample probe into de-ionized water.
5. Check and fill rinse bottles.
6. Open the argon wall valve. The gauge will initially read above 100 psi but will settle down to 80 psi.
7. Turn on the autosampler.
8. Open the autosampler software (ESI software).
9. Open the rinse valves on the rinse bottles.
10. Check that wash times are appropriately set for the run. Typically rinse times total 120 seconds. Rinse 1 is nitric acid and rinse 2 is de-ionized water.

Initialize autosampler.

11. Open PlasmaLab software and check the configuration and make sure the ICP-MS is in solution mode (XSeries default) with the peristaltic pump and autosampler (Cetac 500) selected as accessories and ACL Script is in "Autosampler and Pump."

12. Switch to the ‘Major’ tab and make sure the nebulizer gas level is set between 0.90 and 1.05.

13. Put the ICP-MS into operate mode by hitting the green “On” button.
14. Once in operate mode, give the ICP-MS 30 minutes to warm up.
15. After the warm up period, make sure you are monitoring ^{115}In , ^{88}Sr , and ^{238}U in the Real Time Display window. To change elements being monitored, click on the element name, then the drop down arrow at right of element name box, and then select new element.

16. Place the autosampler probe in the 250mL bottle of 1ppb Tune A solution.
17. Wait about 60 seconds for the solution to reach the plasma and ICP-MS detector. If there is no change in counts, see the troubleshooting section. Wait until you observe a signal in the Real Time Display (RTD) window in the bottom right section of PlasmaLab. Once you have a signal you can start following the steps list below to increase the signal. Make sure the hexapole bias (-5.0) and pole bias (-2.0) are set for solution ICP-MS. Final settings must

have ^{115}In above 250,000 counts.

18. To increase the signal, start with the XSII stage alignment wizard under the Music Note symbol, which will optimize the horizontal and vertical settings for the torch box, as opening the ICP-MS up to check/change cones could jiggle the torch box position.

19. Next run the XSII XS- 1 ppb KT. This will optimize the settings for the lenses and the nebulizer gas flow.
20. After you have ensured that the counts are maximized on ^{115}In , save the final settings.

21. Select "Template" (1) then "Solution Startup" (2) template. Select the saved settings from the current date (3). Use the pre-set element selection and

standard information. Keep the autosampler probe in the 1ppb Tune A solution. Add the experiment to the queue by clicking the “Q” button (4) by the green “On” and red “Off” buttons. Save the experiment in the “Solution Startup Scans” folder, with the name of “Startup MMDDYY.” Hit append and then okay to the warning message. Once the ICP-MS software has a box that says “Place sample probe into sample. Tune A 1ppb”, click continue.

22. Go to the “Results” tab and then the “Mass Uncorrected” Tab. Check the average sensitivity on ^{115}In and ^{238}U for all 5 runs (> 250,000 counts) and calculate the CeO/Ce ratio (< 2%), Ba^{++}/Ba ratio (< 5%) and check that mass 220 background is less than 0.5. Element stability (% RSD) should be less than 2. If the oxide ratio is too high, retune and turn down the nebulizer gas or increase the sampling depth.

24. Go to the ✓ and select “set up the detector.” Wait until you observe the increased signal from the Tune F solution before starting the wizard.

25. Select X-Cal which determines the proportionality between analogue and pulse count detectors as analogue measures the elements at the half-way point (high concentration elements) and pulse measures the elements reaching the detector (low concentration elements).

26. After using Tune F, rinse the system with 2% nitric acid.
27. Switch between nitric acid and de-ionized water until counts on In and Pb are close to zero (under 100).
28. Run a rock matrix (or appropriate solution of similar type to samples being analyzed) through the ICP-MS for ~2 minutes.
29. Rinse again with de-ionized water.
30. Replace the autosampler probe in the autosampler probe holder. Switch to the ESI software and hit rinse/wash which will flush out the rinse solution holders

on the autosampler.

Starting an Experiment

1. To start an experiment, click the experiment button and select “Create an experiment from an existing one.”

2. Open an experiment from an existing experiment, providing a template for your experiment.
3. Go to “Setup” then “Configuration Editor” and make sure the current date solution settings are selected.

4. Under “Setup” then “Timings” and under “Maximum delay” make sure uptake time is 60s and washout time is 120s.

5. Go to “Setup” then “Analyte” and make sure all the elements you wish to analyze are selected. Typically analyzed elements are Li, Be, K₂O, Sc, TiO₂, V, Cr, Co, Ni, Cu, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U for basaltic rock samples.
6. If you modify the sample list, go to “Setup” then “Acquisition Parameters” tab and make sure to change the number of scans to equal 60s and that the newly added elements have 3 channels selected, not the default of 1.
7. Under “Sample List” will be the appropriate setup for a 10 unknown sample run. The samples are run in blocks of 4 samples bracketed by a drift. The layout (see table below) is a 10 sample run, in which each unknown sample is analyzed twice and within each run of every sample, it is run three times and an average is reported for that sample run.

Blank
Drift
Standard 1
Sample 1
Sample 2
Sample 4
Drift
Sample 4
Sample 5
Sample 6
Sample 7
Drift
Standard 2
Sample 8
Sample 9
Sample 10
Drift
Sample 1
Sample 2
Sample 3
Sample 4
Drift

Standard 3
Sample 5
Sample 6
Sample 7
Drift
Standard 4
Sample 8
Sample 9
Sample 10
Drift
Blank

8. The drift is typically a standard that has a high concentration of all the elements you are analyzing. The drift is placed in a 50mL autosampler tube and placed in the front rack.
9. The remaining standards and samples are placed in 15mL autosampler tubes and in one of the white autosampler racks. The table below shows the order of the samples in the autosampler rack from front (closest to you) to back.

Sample	Row in Rack	Position in Rack
Blank	1	1
Standard 1	1	2
Sample 1	1	3
Sample 2	1	4
Sample 3	1	5
Sample 4	1	6
Sample 5	1	7
Sample 6	1	8
Sample 7	1	9
Standard 2	1	10
Sample 8	1	11
Sample 9	1	12
Sample 10	2	1
Standard 3	2	2
Standard 4	2	3

10. After you have placed all the samples in the rack and on the autosampler, confirm sample location with the information you have filled out on your experiment sample list.
11. The column height for all the samples should be 140mm not 144mm.

12. Once you are ready to start, add the experiment in the queue. Click append and then okay to the warning message. Make sure the experiment starts correctly and the autosampler probe goes to the correct sample.
13. Once finished with the entire experiment file, go to “Results”, then “Numerical Results,” and copy the entire “Mass Uncorrected” data file, including the headers, to an excel file.

Shutting down the ICP-MS

1. Put the ICP-MS into vacuum mode by clicking the “Off” button once. **DO NOT PUT THE ICP-MS INTO SHUTDOWN!!**
2. Once the ICP-MS is in vacuum mode, turn off the autosampler.
3. Shut the rinse valves.
4. Release the pump tubing from the peristaltic pump.
5. Shut the argon wall valve.
6. Make sure you have saved your data and copied it to a flash drive or as an email attachment.
7. Close both software programs.
8. Turn off the computer monitor.

Data Reduction

1. Excel Data Sheet.
 - a. Copy data into ‘Sheet 2’ tab.
 - b. Sort data by column A.
 - c. Want ‘x’ rows.
 - d. Sample IDs need to be separated from their time stamp.
 - i. Copy into Word as unformatted text.
 - ii. Replace spaces between ID and time stamp with tab character.
 - iii. Copy back into excel and sort by time stamp.
2. Open ‘ICPMS All Elements GSO 07’.
 - a. Paste Sample IDs into “Wt. Sheet’ tab.
 - b. Wt. Sheet tab.
 - i. Example calculation is an estimate/average of your samples.
 - ii. Enter in sample weight, bottle weight, and bottle + solution weight.
 - c. Reduction tab.
 - i. Paste data (values only).
 - ii. Watch that elements match.
 - iii. Extra elements get added at end.
 - d. Drift is caused by clogging of cones’ openings by salt precipitation.
 - e. Calibration step (Reduction tab).
 - i. Don’t touch the standard values block.
 - ii. Use three standards and blank to calibrate.
 - iii. Make sure non-bold standards (counts) block matches bold standards (concentration) block.
 - f. Move to calibration curves block.

- i. R value must have 0.999x.
 - ii. Using standards tab, check elements with lower R values.
 - 1. Choose correct standards.
 - 2. Change for individual elements in 'Calib. Standards' block.
 - 3. Note all changes.
- g. Move to compare repeats block.
 - i. % RSD < 4.0.
 - ii. Clean up data by removing a bad run.
- h. Interference block.
 - i. Select the high and low standards.
 - ii. Will calculate the interference and correct data.
 - iii. Eu interference not a problem in MORBs.

ICP-MS Tuning Solutions

1. 10 ppb Tune A
 - a. Fill 1 L bottle half full with Milli-Q H₂O.
 - b. Pipette 1mL of 100 ppm Tune A stock solution into the 1 L bottle.
 - c. Pipette 10mL of 100 ppb Ba standard solution into the 1 L bottle.
 - d. Add 28mL of full strength nitric acid into the 1 L bottle.
 - e. Fill the remainder of the bottle with Milli-Q H₂O, shake, and allow 30 minutes to mix.
2. 1 ppb Tune A
 - a. Fill 1 L bottle half full with Milli-Q H₂O.
 - b. Pipette 0.1mL of 100 ppm Tune A stock solution into the 1 L bottle.
 - c. Pipette 10mL of 100 ppb Ba standard solution into the 1 L bottle.
 - d. Add 28mL of full strength nitric acid into the 1 L bottle.
 - e. Fill the remainder of the bottle with Milli-Q H₂O, shake, and allow 30 minutes to mix.
3. Tune F
 - a. Add 1 mL concentration Tune F.
 - b. Add 28 mL clean (4x) 70% HNO₃.
 - c. Add Milli-Q H₂O to bring bottle weight to 1000g.
 - d. Add a couple drops of 4x HF to stabilize solution.

Troubleshooting

1. If the peristaltic pump is not running while you are in solution mode, open the accessory window. Connect to the peristaltic pump by selecting ∞. Hit play

and then okay.

2. If there is no increase in signal or counts displayed in the Real Time Display once placed in 1ppb Tune A, check that the tubes are tighten down enough on the peristaltic pump. Also check that the spray chamber has a good seal with the gray connector tube by slowly rotating the spray chamber angle and see if the observed counts increase.
3. When changing pump tubing, make sure to carefully heat the pump tubing enough to insert the autosampler probe, spray chamber, or drain tubing into the peristaltic pump tubing without too much trouble. The peristaltic pump rotates clockwise. The colored tubing should have the yellow clip side going to the autosampler probe and the orange clip side going to the spray chamber. The drain tubing should go from the spray chamber to the peristaltic pump and then to the drain.
4. If running extremely sensitive samples, such as Ti, change the pump tubing before every run.
5. Make sure there are no visible bubbles entering the spray chamber.
6. Run a mass calibration (✓) if the sensitivity is lower than normal and suspect the ICP-MS is not sampling the plateau of the peak.
 - a. Use Tune A solution.
 - b. High resolution peak width: 0.3 – 0.4.
 - c. Standard resolution peak width: around 0.7.
 - d. Error should be around zero.
7. If the nebulizer is clogged and the nebulizer spray is pulsing.
 - a. Find a small, never used plastic syringe.
 - b. Affix a short length of stretchy plastic tubing to the nozzle, of a size that will fit snugly over the end of the nozzle and over the ends of the openings on the nebulizer.
 - c. Mix up a small volume (~125mL maximum) of 50% nitric acid and set up a secondary containment tray for the procedure.

- d. Draw up some acid into the syringe and connect it to the sample introduction end of the nebulizer. Gently push acid through until it drips from the spray tip.
 - e. Do the same for the leg that connects to the nebulizer gas, pushing acid through until it drips from the tip.
 - f. Let the nebulizer sit for at least 30 minutes.
 - g. Connect the syringe to the spray trip of the nebulizer and gently push more nitric acid through the nebulizer in the reverse direction and confirm that acid drips from both openings on the nebulizer.
 - h. If acid does not flow through, try increasing the pressure, or switch the syringe to the other openings and try in the normal flow direction.
 - i. When unclogged, flush the nebulizer several times using milli-Q water, following the same approach you did with the nitric acid.
8. If when running a solution, the autosampler has an error saying “Invalid Tray Type”, stop the experiment and make sure that you have selected the appropriate tray in both the ESI software and in PlasmaLab. To change the tray type in ESI, click on the appropriate tray rack and then select tray size (5 x 12 for a 10 unknown sample run).

To change the tray type in PlasmaLab, select the accessories window, connect to the autosampler, and then under the appropriate tray number, select the tray size. Hit okay and then restart the experiment.

Section 2: Laser Ablation ICP-MS

Guidelines before visiting LA-ICP-MS laboratory for first time users

1. Bring detailed sample maps – includes photographs and hand drawings of thin sections or 1” round mounts to enable navigation to selected mineral/glass chip to analyze
2. Take photographs in both reflected and transmitted light to enable proper identification of mineral or glass chip when using the laser as the laser optics only show a small section of the overall sample
3. Photographs will also help identify areas, such as cracks or inclusions that you will wish to avoid when lasering. For example, in the case of cracks, there could be polishing material remaining in the cracks which could contaminate the analysis, or for glasses you wish to avoid crystals, which may not show up as clearly with the laser optics as under a microscope.
4. Know which elements you wish to analyze. Typically analyzed elements are Li, Be, K₂O, Sc, TiO₂, V, Cr, Co, Ni, Cu, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U.
5. Spot size constraints:
 - a. Minerals or glass chips: no smaller than 40µm, preferable at least 60µm. The bigger the spot size, the more data will be collected, which is extremely important for low abundance elements such as uranium.
 - b. Melt inclusions: ideally no smaller than 20µm. For a 20µm spot, the melt inclusion should be at least 25µm in size (length and width) to ensure ability to laser without clipping the host mineral.
6. Thin sections should be at least 30µm thick, while thicker (50µm) provides more material to ablate, resulting in a longer time sample spectrum.
7. Remove carbon coating from samples before arriving by polishing the sample mounts with 0.3µm Alumina polish.

LA-ICP-MS tuning steps

1. Check cones and glassware. Clean cones with isopropanol at the start of each day.
2. Check argon and chiller.
 - a. Argon pressure on the line must be above 250 psi. If using liquid argon the right hand gauge on the regulator will read zero pressure. If using compressed gas tanks, open two tanks at a time and when the right hand gauge reads 500 psi, open two more tanks by first opening the tank then opening the line. Then close the line to the two old tanks and then close the two tanks.
 - b. Check the chiller water level. If you do not see water flowing, add water from the tap water container stored on top of the chiller.
3. Check power supply for laser is on.

4. Open the helium tank and the pressure needs to be above 7 bars.
5. Open the argon wall valve. The gauge will initially read above 100 psi but will settle down to 80 psi.
6. Open the laser software (MeO/laser icon) and the ICP-MS software (PlasmaLab).
7. Go to “Instrument” then “Configurations” and check the configuration and make sure the ICP-MS is in laser mode with no accessories.

8. Under the ‘Tune’ tab, then ‘Add. Gas’ tab, turn helium gas to full.

9. Switch to the laser software, and purge the laser twice.

10. Back in PlasmaLab turn the helium gas back down to zero.

11. Switch back to the ‘Major’ tab and make sure the nebulizer gas level is set between 0.90 and 1.05.

12. Put the ICP-MS into operate mode by hitting the green “On” button.
13. Once in operate mode, slowly turn up the helium gas to full (read out of 760). Click the right arrow for the helium gas, which will increase the level in helium in approximately intervals of three. This should be about one click per every couple seconds and take about two minutes to reach full.
14. After the helium gas is at full, give the ICP-MS 30 minutes to warm up.
15. While the ICP-MS is warming up, go back to the laser software and:
 - a. Turn up the co-axial light until you can see the samples in the viewing window of the software
 - b. Focus the optics using the arrows in the top left of the viewing window
 - c. Set the repeat rate at 10 Hz, the laser energy at 65%, and the spot size at 60µm
 - d. Using the sample map button, make a map of your samples. Change the number of images and then select “make new map.” For a 1” round mount, an 18 image height x length map covers majority of the sample mount.
 - e. If the map does not show up in the sample map window, move around on the 1” mount and the map will fill in on the sample map window.

16. After the warm up period, make sure you are monitoring ^{139}La and ^{88}Sr .

Then in the laser software, select the position button, check "Don't move Z" and then select NIST 612 and select "Move To" button. Close the position box

once you have moved to NIST 612.

17. Focus on NIST 612, then place a line on NIST 612 in a region that has not been previously lasered.

18. Select the line and check that the properties of the line match the properties you have set in the laser software (repeat rate, laser energy, and spot size). The line ablates at 1 $\mu\text{m/s}$.

19. Click run scans. Make sure you have selected the **enable laser** option to actually fire the laser. Then click run.

20. Back in PlasmaLab, wait until you observe a signal in the Real Time Display (RTD) window. Once you have a signal you can start changing settings to increase the signal. Do not touch forward power, cool, and auxiliary. Make sure the hexapole bias (-4.5) and pole bias (-3.0) are set for laser ablation ICP-MS. ^{139}La should be above 100,000 counts. To increase the signal, start with the horizontal and vertical settings for the torch box, as opening the ICP-MS up to check/change cones could jiggle the torch box position.

21. After checking horizontal and vertical positions, adjust the nebulizer gas flow (between 0.85 and 1.05) and the sampling depth (ideally above 60). Then check the additional settings (Lens 1, Lens 2, Lens 3, D1, D2, Extraction, Focus).

22. After you have maximized the counts on ^{139}La , save the final settings.

23. Select “Template” (1) then “Laser Startup” (2) template. Select the saved settings from the current date (3). Use the pre-set element selection and standard information. Place a 60 μm spot (10Hz, 65% energy, 120s dwell time) on NIST 612. Once a spot is placed, add the experiment to the queue by clicking the “Q” button (4) by the green “On” and red “Off” buttons. Save the experiment in the “Laser Startup Scans” folder with the name “Laser Startup MMDDYY”. Hit append and then okay to the warning message. Once the ICP-MS software has a box that says “Place sample probe into sample. NIST 612”, make sure you have the run scans box open in the laser software.

24. Click OK on the “Place sample probe into sample. NIST 612” and then **immediately** click “Run Scans.” The two boxes must be clicked right after each other to tell both the ICP-MS to start collecting data and the laser to start ablating the sample.
25. After the second run of data is collected, check the sensitivity on ^{139}La by going to “Results” then “Numerical Results” then “Mass Uncorrected ICPS”

tab and calculate the ThO/Th ratio ($< 2\%$). Mass 220 measures the background. If the oxide ratio is too high, retune and turn down the nebulizer gas or increase the sampling depth.

Once you have a successful startup scan, print the results by going to the “Reports” tab. Select “Instrument Configuration” and “Mass Uncorrected ICPS” then hit the refresh button and then print.

26. After a successful tuning, in the laser software, use the position button to move to NIST 610 to do a cross calibration. Make sure the laser is focused then set the spot size to 160μm. Do not print an actual spot on NIST 610.
27. Back in PlasmaLab, go to the ✓ and select “set up the detector.” Select X-Cal which determines the proportionality between analogue and pulse count detectors as analogue measures the elements at the half-way point (high concentration elements) and pulse measures the elements reaching the detector

- Thermo PhasmatLab - X Series (Default)**
- File Edit View Tools Window Help
- PhasmatLab
On Off Q Zone
- Set: 0.0 bar Fwd: 0 V Int: 0 V Load: 92 Tune: 163 Exp: 4.1 eV-2 rbar Acc: 6.6 eV-8 rbar Speed: 1000 Hz Load: 0 mA Vacuum: map
- Tune | Configuration Calibration Advanced
- Detector Class Calibration Mass Calibration [Detector monitoring]
- [+] Current device
17/05/2015 10:14:53 AM
• MS calibration
• 100790
• 73609
• 68974
- Measured Measured but uses calculated Calculated Calculated -15.0% Calculated +15.0%
- Factor
- Mass
- Mass Type Factor Used by
1	Calculated	58920	1H
2	Calculated	60643	2H
3	Calculated	61395	3He
4	Calculated	62119	4He
5	Calculated	62895	
6	Calculated	62963	6Li
7	Calculated	64373	7Li
8	Calculated	64375	
9	Measured	66025	9Be
10	Calculated	68257	10B
11	Measured	63419	11B
12	Calculated	67707	12C
13	Calculated	68372	13C
14	Calculated	69028	14N
15	Calculated	69677	15N
16	Calculated	70319	16O
17	Calculated	70952	17O
18	Calculated	71590	18O
19	Calculated	72230	19F
20	Calculated	72913	20Ne
21	Calculated	73619	21Ne
22	Calculated	74257	22Ne
23	Calculated	74898	23Na
24	Calculated	75193	24Mg
25	Measured	72364	24Mg
26	Measured	76915	26Mg
27	Calculated	76935	27Al
28	Calculated	77462	28Si
29	Calculated	78013	29Si
30	Calculated	78596	30Si
31	Calculated	79054	31P
32	Calculated	79624	32S
33	Calculated	80149	33S
34	Calculated	80656	34S
35	Calculated	81179	35Cl
36	Calculated	81663	36S, 36Ar

Starting an Experiment

1. To start an experiment, click the experiment button and select “Create an experiment from an existing one.”

2. Open an experiment from an existing experiment, providing a template for your experiment.
3. Go to “Setup” then “Configuration Editor” and make sure the current date laser settings are selected.

4. Go to “Setup” then “Analyte” and make sure all the elements you wish to analyze are selected. Typically analyzed elements are Li, Be, K₂O, Sc, TiO₂, V, Cr, Co, Ni, Cu, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U for basaltic rock samples.

5. Under “Sample List” the first ~8 samples should be standards. Then you can type in your sample list. Record information such as repeat rate and spot size either in sample name on the sample list or in a notebook.
6. Once you are ready to start, add the experiment to the queue. Save the file in the folder with your name and give the file a name that identifies the nature of the samples and the current date. Click append and then okay to the warning message.
7. Once the ICP-MS software has a box that says “Place sample probe into sample. **Sample Name**”, switch to the laser software and use the position button to navigate to the standard or use the sample map to navigate to your sample. Focus the laser then place a spot. Check the properties on the spot. Make sure they match the laser properties.
8. If you lasering a glass wafer or a melt inclusion, change the repeat rate to 5Hz.
9. Ensure that there is only one spot listed in the scan patterns box.
10. Make sure you have the run scans box open in the laser software. Click OK on the “Place sample probe into sample. **Sample Name**” and then **immediately** click “Run Scans.” The two boxes must be clicked right after each other to tell both the ICP-MS to start collecting data and the laser to start ablating the sample.
11. Switching 1” round sample mounts
 - a. Put laser in **bypass**
 - b. Change out mount, make sure it is flat in the sample holder, and use isopropanol to make sure sample surface is clean
 - c. Once the sample holder is reloaded, purge the laser twice and wait 10 minutes before starting analysis.

12. Check the laser results as you go. Go to “Tools” (1) then “Calculate Results”. Then within the experiment go to “Setup” then “Acquisition Parameters” (2) and remember to log the y axis (3). Make sure you see data here before moving on to the next sample!

13. Once finished with the entire experiment file, copy the entire TRA file, including the headers, to an excel file.

Shutting down the ICP-MS

1. Put the ICP-MS into vacuum mode by clicking the “Off” button once. **DO NOT PUT THE ICP-MS INTO SHUTDOWN!!**
2. Once the ICP-MS is in vacuum mode, go the the “Add. Gas” tab and turn the helium gas to zero.
3. Always close the helium tank.
4. Shut the argon wall valve.
5. Make sure you have saved your data and copied it to a flash drive or as an email attachment.
6. Close both software programs.
7. Turn off the computer monitor.

Troubleshooting

1. If the He gas is left at on in PlasmaLab and the software is left open over night, then the first additional of He will knock out the torch. Shut down PlasmaLab and try adding the He slowly again. It may take a couple tries to successfully add the He to the torch.
2. If the peristaltic pump is running while you are in laser mode, under the “Instrument Configurations” tab, add the peristaltic pump as an accessory. Open the accessory window. Connect to the peristaltic pump by selecting ∞ . Hit stop and then okay. Uncheck the peristaltic pump as an accessory under the

“Instrument Configurations” tab.

3. If you are adding sample names as you go, and then if the experiment comes up with a message stating “Experiment is no longer in the queue” and you still have samples to analysis in that experiment, add the sample names to the list and then click on queue (Q) and hit append then okay. The experiment will now be back in the queue.
4. If you have put the laser into bypass and did not purge the laser before running a spot, the laser will automatically start purging before firing the sample.
5. If you hit “Run Scans” and the laser does not fire, make sure the laser has been enabled.
6. If you have focused the laser and then when you go to fire, the focus changes make sure you place your spot after you focus. The sample spot will reference whichever focus level you have the optics on when you place the spot.
7. If the properties for the spot size are different than the ones set in the laser, the laser will rotate to the appropriate spot size while the ICP-MS is collecting data, taking away from data analysis time.
8. If the lights do not turn on (light interlock), check that the door on the right side of the laser base is fully closed.
9. If there is extremely low sensitivity while tuning, make sure the sample holder is fully seated and flush with the laser.
10. If the helium runs out while analyzing, the torch will be knocked out. This will require a simple change of helium tanks and restart of the ICP-MS.
11. If the argon runs out while you are running, the torch will be knocked out and cause an argon interlock. Take the following steps to fix the problem.
 - a. Abort the experiment and make sure the ICP-MS is properly in vacuum mode.
 - b. PlasmaLab will not show the Real Time Display (RTD).
 - c. Stop the PlasmaLab services.
 - d. Turn off the PC in the ICP-MS.

- e. Unplug the yellow cable and the red/black cable which controls the lens module.
- f. Wait 30 seconds then reconnect the red/black cable and the yellow cable.
- g. Turn the PC back on.
- h. Restart PlasmaLab services.
- i. Under the “Advanced” tab, turn the lens back to on from standby.
- j. RTD should start now.
- k. If there is a problem with data collection and the experiment not starting, put the ICP-MS into vacuum mode, then turn the ICP-MS back on (operate mode), and the experiment should start and collect data now.

Maintenance

1. Changing the Laser Water Filter yearly
 - a. From the task bar at the top of the NWR menu, choose LASER and uncheck the first option, Enable Laser Power Supply. This turns the water pump off. Disconnect the RED hose on the back of the Power Supply. Some water that is already in the lines will drip out but not too much.
 - b. Place this RED hose into a bucket, only about 1 liter of water will come out total.
 - c. Now, recheck the Enable Laser Power Supply and the water pump will turn on for about 1 or 2 seconds and will pump some water into the bucket. The interlock screen will come on because water is not going back into the system.
 - d. Un-check Enable Laser Power Supply and then Re-check it. Some more water will come out. Do this about 10 to 12 times, eventually you will see only air coming out of the hose. Un-check the Enable Laser Power Supply. 95% of the water is now drained.
 - e. The DI Cartridge is inside the Power Supply. Remove the cover (12-16 total screws, 3-4 on each side along the bottom, 3-4 on each side on the back). Remove two screws which hold the cartridge bracket in place. Replace the DI Cartridge.
 - f. Use Teflon thread tape to seal – careful not to over-tighten!
 - g. Plug the RED hose back into the Power Supply. Fill the reservoir with DI water. Re-check the Enable Laser Power Supply, again it will only run about 1 or 2 seconds and stop (interlock screen again comes on because there are a lot of air pockets in the lines). Perform the Un-check and Re-check cycle until the Pump stays on by itself (usually only takes about 4 times). You will also have to top off the DI water each cycle.

Section 3: Collision Cell Solution ICP-MS

Collision Cell Solution ICP-MS tuning steps

1. Check cones and glassware and use the Xt cones (labeled α). Clean cones with isopropanol at the start of each day.
2. Check argon and chiller.
 - a. Argon pressure on the line must be above 250 psi. If using liquid argon the right hand gauge on the regulator will read zero pressure. If using compressed gas tanks, open two tanks at a time and when the right hand gauge reads 500 psi, open two more tanks by first opening the tank then opening the line. Then close the line to the two old tanks and then close the two tanks.
 - b. Check the chiller water level. If you do not see water flowing, add water from the tap water container stored on top of the chiller.
3. Open the He-H compressed gas tank and the pressure must be above 1 bar.
4. Check instrument configuration and make sure it is in CCT mode. Attach gray tube and spray chamber. Attach nebulizer gas tube to spray chamber.
5. Check and set pump tubing on peristaltic pump. Uptake tube has colored clips. Drain tube has black and white clips. Stretch the tubes and clip into place. Clamp tubes into place on peristaltic pump. Place sample probe into de-ionized water.
6. Check and fill rinse bottles.
7. Open the argon wall valve. The gauge will initially read above 100 psi but will settle down to 80 psi.
8. Turn on the autosampler.
9. Open the autosampler software (ESI software).
10. Open the rinse valves on the rinse bottles.
11. Check that wash times are appropriately set for the run. Typically rinse times total 120 seconds. Rinse 1 is nitric acid and rinse 2 is de-ionized water.

Initialize autosampler.

12. Open PlasmaLab software and check the configuration and make sure the ICP-MS is in CCT mode with the peristaltic pump and autosampler (Cetac 500) selected as accessories and ACL Script is in "Autosampler and Pump" mode.

13. Switch to the ‘Major’ tab and make sure the nebulizer gas level is set between 0.90 and 1.05.

14. Put the ICP-MS into operate mode by hitting the green “On” button.
15. Once in operate mode, give the ICP-MS 30 minutes to warm up. While the ICP-MS is warming up, purge the collision cell by going to the “Add. Gas” tab and turning the He-H gas (CCT 1) up to 6.

16. After the warm up period, make sure you are monitoring ^{115}In and ^{78}Se in the Real Time Display window.

17. Turn off the CCT gas and perform normal tuning run.
18. Place the autosampler probe in the 250mL bottle of 10ppb Tune A solution.
19. Wait about 60 seconds for the solution to reach the plasma and ICP-MS detector. If there is no change in counts, see the troubleshooting section. Wait until you observe a signal in the Real Time Display (RTD) window. Once you

have a signal you can start changing settings to increase the signal. Make sure the hexapole bias (-5.0) and pole bias (-2.0) are set for solution ICP-MS. ¹¹⁵In should be above 1.5 million counts.

- To increase the signal, start with the XSII stage alignment wizard under the Music Note symbol, which will optimize the horizontal and vertical settings for the torch box, as opening the ICP-MS up to check/change cones could jiggle the torch box position.

- Next run the XSII XS- 1 ppb KT. This will optimize the settings for the lenses and the nebulizer gas flow.
- After you have ensured that the counts are maximized on ¹¹⁵In, save the final settings.

23. Turn the CCT gas back on to a rate of 3 mL/min and set the Pole Bias to -17.0 and the Hexapole Bias to -20.0. This sets the Kinetic Energy Discrimination.
24. Tune ^{115}In to be $> \sim 250,000$ cps and $^{78}\text{Se} < 20$ cps by adjusting the Focus to be in the range of -5 to -15 and D2 lens to be in the range of -98 to -110. Stability on ^{115}In (% RSD) should be ~ 0.5 .
25. Adjust background ^{78}Se levels by changing the CCT 1 gas flow to between 3-4 mL/min.
26. Run a 2% HCl solution through and make sure ArCl/Cl is $< 2\%$.
27. Run a rock matrix (or appropriate solution of similar type to samples being analyzed) through the ICP-MS for ~ 2 minutes.
28. Rinse again with de-ionized water.
29. Replace the autosampler probe in the autosampler probe holder. Switch to the ESI software and hit rinse/wash which will flush out the rinse solution holders on the autosampler.

Starting an Experiment

1. To start an experiment, click the experiment button and select “Create an experiment from an existing one.”

2. Open an experiment from an existing experiment, providing a template for your experiment.

- Go to “Setup” then “Configuration Editor” and make sure the current date CCT settings are selected.

- Go to “Setup” and under “Timings” make sure the “Maximum Delay” for uptake is 60s and for washout the timing should be equal to the timing you have set the rinse in the ESI software.

- Go to “Setup” then “Analyte” and make sure all the elements you wish to analyze are selected. Typically analyzed elements by collision cell are As and Sb.
- Since you are only analyzing a few elements, go to “Setup” and then “Acquisition Parameters” and change the number of scans to equal 30s and that the newly added elements have 3 channels selected, not the default of 1.
- Under “Sample List” will be the appropriate setup for a 10 unknown sample run. The samples are run in blocks of 4 samples bracketed by a drift. The layout (see table below) is a 10 sample run, in which each unknown sample is analyzed twice and within each run of every sample, it is run three times and an average is reported for that sample run.

Blank
Drift
Standard 1
Sample 1

Sample 2
Sample 4
Drift
Sample 4
Sample 5
Sample 6
Sample 7
Drift
Standard 2
Sample 8
Sample 9
Sample 10
Drift
Sample 1
Sample 2
Sample 3
Sample 4
Drift
Standard 3
Sample 5
Sample 6
Sample 7
Drift
Standard 4
Sample 8
Sample 9
Sample 10
Drift
Blank

8. The drift is typically a standard that has a high concentration of all the elements you are analyzing. The drift is placed in a 50mL autosampler tube and placed in the front rack.
9. The remaining standards and samples are placed in 15mL autosampler tubes and in one of the white autosampler racks. The table below shows the order of the samples in the autosampler rack from front (closest to you) to back.

Sample	Row in Rack	Position in Rack
Blank	1	1
Standard 1	1	2
Sample 1	1	3
Sample 2	1	4
Sample 3	1	5

Sample 4	1	6
Sample 5	1	7
Sample 6	1	8
Sample 7	1	9
Standard 2	1	10
Sample 8	1	11
Sample 9	1	12
Sample 10	2	1
Standard 3	2	2
Standard 4	2	3

10. After you have placed all the samples in the rack and on the autosampler, confirm sample location with the information you have filled out on your experiment sample list.
11. The column height for all the samples should be 140mm not 144mm.
12. Once you are ready to start, add the experiment in the queue. Click append and then okay to the warning message. Make sure the experiment starts correctly and the autosampler probe goes to the correct sample.
13. Once finished with the entire experiment file, go to “Results”, and copy the entire “Mass Uncorrected” data file, including the headers, to an excel file.

Shutting down the ICP-MS

1. Put the ICP-MS into vacuum mode by clicking the “Off” button once. **DO NOT PUT THE ICP-MS INTO SHUTDOWN!!**
2. Once the ICP-MS is in vacuum mode, turn off the autosampler.
3. Shut the rinse valves.
4. Release the pump tubing from the peristaltic pump.
5. Shut the argon wall valve.
6. Make sure you have saved your data and copied it to a flash drive or as an email attachment.
7. Close both software programs.
8. Turn off the computer monitor.

Data Reduction

1. Excel Data Sheet.
 - a. Copy data into ‘Sheet 2’ tab.
 - b. Sort data by column A.
 - c. Want ‘x’ rows.
 - d. Sample IDs need to be separated from their time stamp.
 - i. Copy into Word as unformatted text.
 - ii. Replace spaces between ID and time stamp with tab character.
 - iii. Copy back into excel and sort by time stamp.
2. Open ‘ICPMS All Elements GSO 07’.

- a. Paste Sample IDs into “Wt. Sheet” tab.
- b. Wt. Sheet tab.
 - i. Example calculation is an estimate/average of your samples.
 - ii. Enter in sample weight, bottle weight, and bottle + solution weight.
- c. Reduction tab.
 - i. Paste data (values only).
 - ii. Watch that elements match.
 - iii. Extra elements get added at end.
- d. Drift is caused by clogging of cones’ openings by salt precipitation.
- e. Calibration step (Reduction tab).
 - i. Don’t touch the standard values block.
 - ii. Use three standards and blank to calibrate.
 - iii. Make sure non-bold standards (counts) block matches bold standards (concentration) block.
- f. Move to calibration curves block.
 - i. R value must have 0.999x.
 - ii. Using standards tab, check elements with lower R values.
 1. Choose correct standards.
 2. Change for individual elements in ‘Calib. Standards’ block.
 3. Note all changes.
- g. Move to compare repeats block.
 - i. % RSD < 4.0.
 - ii. Clean up data by removing a bad run.
- h. Interference block.
 - i. Select the high and low standards.
 - ii. Will calculate the interference and correct data.
 - iii. Eu interference not a problem in MORBs.

Troubleshooting

1. If the peristaltic pump is not running while you are in solution mode, open the accessory window. Connect to the peristaltic pump by selecting ∞. Hit play and then okay.

2. If there is no increase in signal or counts displayed in the Real Time Display once placed in 1ppb Tune A, check that the tubes are tighten down enough on the peristaltic pump. Also check that the spray chamber has a good seal with the gray connector tube by slowly rotating the spray chamber angle and see if the observed counts increase.
3. When changing pump tubing, make sure to carefully heat the pump tubing enough to insert the autosampler probe, spray chamber, or drain tubing into the peristaltic pump tubing without too much trouble. The peristaltic pump rotates clockwise. The colored tubing should have the yellow clip side going to the autosampler probe and the orange clip side going to the spray chamber. The drain tubing should go from the spray chamber to the peristaltic pump and then to the drain.
4. If running extremely sensitive samples, such as Ti, change the pump tubing before every run.
5. Make sure there are no visible bubbles entering the spray chamber.
6. Run a mass calibration (✓) if the sensitivity is lower than normal and suspect the ICP-MS is not sampling the plateau of the peak.
 - a. Use Tune A solution.
 - b. High resolution peak width: 0.3 – 0.4.
 - c. Standard resolution peak width: around 0.7.
 - d. Error should be around zero.
7. If the nebulizer is clogged and the nebulizer spray is pulsing.
 - a. Find a small, never used plastic syringe.
 - b. Affix a short length of stretchy plastic tubing to the nozzle, of a size that will fit snugly over the end of the nozzle and over the ends of the openings on the nebulizer.
 - c. Mix up a small volume (~125mL maximum) of 50% nitric acid and set up a secondary containment tray for the procedure.
 - d. Draw up some acid into the syringe and connect it to the sample introduction end of the nebulizer. Gently push acid through until it drips from the spray tip.
 - e. Do the same for the leg that connects to the nebulizer gas, pushing acid through until it drips from the tip.
 - f. Let the nebulizer sit for at least 30 minutes.
 - g. Connect the syringe to the spray trip of the nebulizer and gently push more nitric acid through the nebulizer in the reverse direction and confirm that acid drips from both openings on the nebulizer.
 - h. If acid does not flow through, try increasing the pressure, or switch the syringe to the other openings and try in the normal flow direction.

- i. When unclogged, flush the nebulizer several times using milli-Q water, following the same approach you did with the nitric acid.
8. If when running a solution, the autosampler has an error saying “Invalid Tray Type”, stop the experiment and make sure that you have selected the appropriate tray in both the ESI software and in PlasmaLab. To change the tray type in ESI, click on the appropriate tray rack and then select tray size (5 x 12 for a 10 unknown sample run).

To change the tray type in PlasmaLab, select the accessories window, connect to the autosampler, and then under the appropriate tray number, select the tray size. Hit okay and then restart the experiment.

Section 4: Instrument Troubleshooting

1. If the argon runs out while you are running, the torch will be knocked out and cause an argon interlock. Take the following steps to fix the problem.
 - a. Abort the experiment and make sure the ICP-MS is properly in vacuum mode.
 - b. PlasmaLab will not show the Real Time Display (RTD).
 - c. Stop the PlasmaLab services.
 - d. Turn off the PC in the ICP-MS.
 - e. Unplug the yellow cable and the red/black cable which controls the lens module.
 - f. Wait 30 seconds then reconnect the red/black cable and the yellow cable.
 - g. Turn the PC back on.
 - h. Restart PlasmaLab services.
 - i. Under the “Advanced” tab, turn the lens back to on from standby.
 - j. RTD should start now.
 - k. If there is a problem with data collection and the experiment not starting, put the ICP-MS into vacuum mode, then turn the ICP-MS back on (operate mode), and the experiment should start and collect data now.
2. ICP-MS Communication Issues
 - a. Resetting the lens pcb
 - i. Exit PlasmaLab and close the services (“ms”) icon.
 - ii. Remove the instrument main cover and turn off the embedded computer.
 - iii. The lens pcb is the circuit board on top of the main analyzer on the right hand side and housing underneath the black cover.
 - iv. At the rear are a yellow connector and two blue connectors. Unplug the connectors from **left to right** (i.e. yellow, middle blue, right blue).
 - v. Count to ten and reattach connectors in the reverse order (**right to left**).
 - vi. Turn on the embedded computer and wait a few minutes or until the “coms ok” light illuminates on the vacuum pcb to the right of the front circuit breakers.
 - vii. Reload the PlasmaLab services and then load the main PlasmaLab software.
 - viii. Go to operate mode.
 - b. Power the instrument off and on
 - i. Put the instrument into shutdown mode. Wait a few minutes for the turbo pump to wind down.

- ii. Shut down the main computer.
 - iii. Remove the main instrument cover and turn off the embedded computer.
 - iv. Turn off the instrument circuit breakers. The one labeled instrument electronics is the one essentially needed. The other two are for the RF generator and the peltier power supply.
 - v. Turn on the circuit breaks and wait a handful of seconds.
 - vi. Turn on the embedded computer. Wait a few minutes or until the “coms ok” light illuminates on the vacuum pcb to the right of the front circuit breaks.
 - vii. Turn on the main computer.
 - viii. Open the PlasmaLab services.
 - ix. You will see a message “checking for modules” and “idle”.
 - x. At this point, load the PlasmaLab software and turn on the vacuum pump.
 - xi. When the vacuum reaches 5×10^{-7} mbar, turn to operate mode and check for signal.
- 3. Flashing MS icon
 - a. Right click on the MS icon and acknowledge errors.
 - b. A separate folder will open that has all the error reports.
 - c. The errors are usually related to the torch being knocked out.
- 4. PlasmaLab software freezes
 - a. If you have selected the rounded arrow button to load the currently selected settings
 - i. The entire settings (both Major and Minor tabs) are gray and cannot be selected.
 - 1. Close PlasmaLab and restart the software.
 - 2. If not, restart the entire computer.
 - ii. The torch is knocked out, the He gas was turned on to full (by loading the settings) and was not introduced slowly into the torch.
 - b. If you lose communication with the ICPMS while it is in operate mode, restart the computer.
- 5. Replacing the detector
 - a. Open PlasmaLab and click “Off” and say yes to the message asking to put the instrument into “Shutdown State.”
 - b. Vacuum pump will turn off and you will hear a hissing noise as the high pressure vacuum chamber vents.
 - c. Wait 5 minutes and release the three metal clamps on the high pressure vacuum chamber (large metal box with black top).

- d. If the top does not open, just a screwdriver as a lever on one of the lid catches to separate the lid from the base.
- e. The detector is located on the far left of the high pressure vacuum chamber. Confirm orientation before removing the detector.
- f. Wearing gloves replace the new detector and ensure the “feet” are in the grooves.
- g. Close lid and fasten the three metal clamps.
- h. In PlasmaLab click “On” and say yes to the message asking to put the instrument into “Vacuum Mode.”
- i. PlasmaLab will ask if a new detector has been fitted. Click yes and then enter the serial number and model number, provided with the new detector.
- j. The detector will now outgas overnight (~7 hours).

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