

RV Sonne cruise SO-229

Final report | Schlussbericht

01.07.2013, Townsville (Australia) to
26.07.2013, Nouméa (New Caledonia)



*Volcanism, hydrothermal activity
and vent biology
in the Coriolis Troughs,
New Hebrides Island Arc*

GEFÖRDERT VOM



Bundesministerium
für Bildung
und Forschung

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I Kurze Darstellung

I.1 Aufgabenstellung

Im Rahmen des Projekts SO229 COVOLVE sollten die petrologisch-geochemische Entwicklung der Kruste eines Inselbogens am Beispiel der Neuen Hebriden sowie die vulkano-tektonische Bildung eines Backarc-Rifts und die dort vorkommenden hydrothermalen Prozesse untersucht werden. Das erste wesentliche Ziel der Ausfahrt war eine detaillierte Untersuchung und Beprobung des Nifonea Vulkans im Vate Trough und die Untersuchung der dort vermuteten hydrothermalen Aktivität. Die drei Becken der Coriolis Troughs hinter dem Inselbogen der Neuen Hebriden sind relativ jung und erst etwa 20 km breit, zeigen aber schon verbreitet Anzeichen von vulkanischer Aktivität, über die allerdings wenig bekannt war. Drei australische bzw. japanische Ausfahrten in die Region zeigten hydrothermale Plumes in der Wassersäule, allerdings war wenig über die Austrittsstellen der Fluide bekannt. Aus anderen Backarc-Regionen der Erde sind hydrothermale Vents mit hohen Konzentrationen wichtiger Metalle wie Cu, Au, Ag, und Sb bekannt, so dass bestimmt werden sollte, ob auch im Vate Trough solch hohe Konzentrationen auftreten. Weiterhin sollten die steilen Flanken des Vate und des Futuna Trough stratigraphisch beprobt werden, um die Zusammensetzung der Gesteine in den obersten Bereichen der Inselbogenkruste zu untersuchen. Damit können Aussagen über die Bildung und Entwicklung von Subduktionszonen und ihre Auswirkungen auf die Bildung von Magmen in der Erde sowie für die Entstehung der Erdkruste gewonnen werden. Als letzter Punkt in der Aufgabenstellung sollte die vulkanische und hydrothermale Aktivität in der großen submarinen Caldera des Epi Vulkan untersucht werden, um die vulkanischen Prozess und das Gefahrenpotential zu bestimmen sowie um etwaige Bildungen von metallischen Erzlagerstätten zu finden.

I.2 Voraussetzungen

Das Projekt entstand aus der vorherigen Zusammenarbeit der drei Arbeitsgruppen mit ähnlichen wissenschaftlichen Fragestellungen, z.B. im Rahmen des DFG SPP 1144 "Vom Mantel zum Ozean" sowie mehrerer Ausfahrten in das Gebiet des Tonga-Kermadec Inselbogens. Die Arbeitsgruppe Endogene Geodynamik des GeoZentrums Nordbayern hat langjährige Erfahrung in der petrologischen und geochemischen Untersuchung magmatischer Gesteine, insbesondere auch an Subduktionszonen und hat bereits mehrere erfolgreiche Ausfahrten mit den Forschungsschiffen SONNE, METEOR und POSEIDON organisiert und durchgeführt. Die Arbeitsgruppe von Dr. U. Schwarz-Schampera an der Bundesanstalt für Geowissenschaften und Rohstoffe in Hannover beschäftigt sich seit rund zwanzig Jahren mit der Bildung von Sulfiden und anderen Mineralen an hydrothermalen Vents in verschiedenen submarinen vulkanischen Milieus. Die Arbeitsgruppe von Prof. Dr.

Andrea Koschinsky untersucht seit ca. 15 Jahren an der Jacobs Universität in Bremen die Zusammensetzung von hydrothermalen Fluiden und deren Wechselwirkung mit dem Ozean und den Organismen an den hydrothermalen Austritten.

Die technischen Fortschritte der letzten 20 Jahre erlauben eine immer bessere Untersuchung der Tiefsee, speziell auch zur kleinräumigen Beobachtung und Beprobung von Gesteinen, Fluiden oder Organismen. Insofern konnte das ROV Kiel 6000 mit großem Erfolg eingesetzt werden und mehrere neue Fluidaustritte wurden gefunden und beprobt. Weiterhin ist auch der TV-Greifer des alten FS SONNE ein hervorragendes Gerät zur punktuellen Beprobung des Meeresbodens und auch dieses Gerät war eine wesentliche Voraussetzung für den Erfolg des Beprobungsprogramms. Die wichtigste Voraussetzung für den Erfolg des Projekts war allerdings die hervorragend eingespielte Mannschaft des FS SONNE, die die wissenschaftliche Beobachtung und Probenahme unterstützte und ermöglichte.

I.3 Planung und Ablauf des Vorhabens

Der Ablauf des Vorhabens erfolgte wie im Projektantrag beschrieben mit einer gemeinsamen Ausfahrt mit dem FS SONNE und nachfolgenden Arbeiten in den Heimatlabors der drei Arbeitsgruppen sowie der assoziierten Wissenschaftler. Die ersten Untersuchungen und die Probenahme erfolgten zwischen dem 1.7.2013 und 26.7.2013 während der Ausfahrt SO229 mit dem Forschungsschiff SONNE. Leider verkürzte sich die Zeit der Ausfahrt um fünf Arbeitstage, weil FS SONNE zunächst keine Genehmigung zum Einlaufen in den Hafen von Townsville erhielt und daher statt am 27.6. erst am 1.7.2013 auslaufen konnte. Auch spielte das Wetter während der Ausfahrt nicht immer mit und bei starkem Wind und Seegang konnten im südlichen Teil des Arbeitsgebietes an einigen Tagen die Geräte nicht wie geplant eingesetzt werden. Trotzdem wurden im Verlauf der Ausfahrt alle wesentlichen Ziele der Beprobung angesteuert und hervorragendes Probenmaterial gesammelt. Es traten keine technischen Probleme mit den Geräten auf und sowohl das ROV als auch der TV Greifer und die CTD wurden häufig eingesetzt und erbrachten sehr viele hervorragende Proben von Gesteinen, Fluiden, Meerwasser und Organismen.

Die Arbeiten nach Ende der Fahrt verliefen ebenfalls problemlos und wurden weitgehend von der Postdoktorandin Dr. S. Lima am GeoZentrum Nordbayern in Erlangen sowie von den Mitarbeitern Dr. K. Schmidt an der Jacobs Universität Bremen und MSc F. Häckel an der BGR in Hannover durchgeführt. Die Proben wurden dabei mineralogisch und geochemisch untersucht und eine Vielzahl von verschiedenen Daten erstellt, die größtenteils noch interpretiert werden müssen. Im Rahmen der Kooperation mit anderen Arbeitsgruppen wurde das tektonische Umfeld des Nifonea Vulkans und der hydrothermalen Vents genauer untersucht (AG Hannington), die Li, Sr und B Isotopenzusammensetzung der Fluide und Gesteine bestimmt (AG Kasemann) sowie die Organismen bestimmt (AG Tunnicliffe).

Inzwischen sind zwei Manuskripte bei internationalen Zeitschriften eingereicht und drei weitere sind in einem relativ fortgeschrittenen Stadium. Für drei weitere wurden die Daten erhoben und die Gerüste für die Artikel sind definiert. Insofern bewerten wir den Ablauf des Projekts sehr positiv und hoffen, dass in 2016 ein Großteil der Ergebnisse zur Publikation eingereicht werden kann.

I.4 Wissenschaftlicher Stand

I.4.1 Dynamik des Erdmantels und Bildung von Magmen an Subduktionszonen

In den letzten zehn Jahren sind besonders die Subduktionszonen in den Fokus der internationalen geowissenschaftlichen Forschung gerückt und große Fortschritte wurden im Verständnis der tektonischen und magmatischen Prozesse und der Dynamik dieser Plattengrenzen erzielt [z.B. Stern, 2002; Tatsumi and Stern, 2006; van Keken et al., 2011]. Speziell die Untersuchung von Inselbögen mit Backarc-Becken ermöglichte neue Einsichten in die Fließprozesse des Mantels, den Eintrag von ozeanischer Kruste und Sedimenten, die Aufschmelzprozesse und globale Massenbilanzen [z.B. Bebout, 2007; Hacker, 2008; Martinez and Taylor, 2002; Taylor and Martinez, 2003; Wiens et al., 2008]. Allerdings sind nach wie vor grundlegende Prozesse nicht verstanden. Dazu gehören beispielsweise die Entstehung der ausgeprägten negativen Nb-Ta Anomalien in den Subduktionsmagmen und ihre Beziehung zu residualen Mineralen oder Aufschmelz- und Anreicherungsprozessen [Baier et al., 2008; Kelemen et al., 1994; McCulloch and Gamble, 1991; Woodhead et al., 1993]. Auch die Entwicklung von Inselbögen ist nicht geklärt und viele Autoren nehmen an, daß es eine systematische Variation der Gesteine gibt, die von Boniniten über Tholeiite bis hin zu kalkalkalischen Magmen reicht [z.B. Ishizuka et al., 2011]. Allerdings basiert dieses Modell hauptsächlich auf Untersuchungen im Izu-Bonin-Marianen Inselbogen, während Untersuchungen an Querschnitten fossiler Inselbögen keine Boninite zeigen [Greene et al., 2006; O Jagoutz et al., 2011]. Weiterhin ist unklar, ob sich Inselbögen tatsächlich mit zunehmendem Alter chemisch entwickeln, so daß mehr kalkalkalische und felsische Magmen in einer verdickten Kruste produziert werden [O E Jagoutz, 2010; Tatsumi and Suzuki, 2009]. Ein neues Modell des Lau-Valu Fa Backarcs geht davon aus, daß in einem frühen Stadium des Backarc Riftings keine adiabatische Aufschmelzung des hydratisierten Mantelkeils existiert, sondern daß umgekehrt die Aufschmelzung dieses hydratisierten Mantelkeil die Backarc Schmelzzone dominiert [Dunn and Martinez, 2011]. Damit verändert sich vermutlich nicht nur die Magmenzusammensetzung im Backarc, sondern aufgrund der Änderung von Viskosität und Volatilgehalt der Laven auch die Porosität der oberen Kruste [Jacobs et al., 2007], was direkten Einfluß auf die hydrothermale Aktivität haben sollte. Die Verteilung von Vulkanen entlang von Subduktionszonen wird durch Magmadiapire unter dem Inselbogen erklärt, wodurch der sehr schnelle Aufstieg der Schmelzen aus der metasomatisch überprägten begründet werden kann [Hall and Kincaid,

2001; *Tamura et al.*, 2002]. Allerdings ist unklar, wie sich solche Diapire bilden können und bisherige Modelle sehen eine bestimmte Tiefe des Fluidausstoßes aus der subduzierten Platte vor, die durch Stabilitätsgrenzen von wasserhaltigen Mineralen und den P-T-Bedingungen bestimmt wird [z.B. *Grove et al.*, 2009; *Tatsumi and Eggins*, 1995]. Andererseits modellieren *England* und *Katz* [2010] eine Magmenbildung bestimmt durch die Lage der Isothermen im Mantelkeil, wobei sich die gebildete Schmelze einen Aufstiegs weg durch den Mantel schafft, der dann von allen Magmen benutzt wird. Bislang wurden diese Modelle aber noch nicht auf viele Inselbögen übertragen und es ist nicht klar, inwieweit die dynamische Entwicklung von Vulkanen mit Riftingprozessen nahe der Inselbogenfront mit diesen Modellen erklärt werden kann. Viele der offenen Fragen zur Bildung der Magmen und der tektonischen Entwicklung von Inselbögen können nur mit weiteren detaillierten Untersuchungen an Gesteinen von aktiven Inselbögen beantwortet werden. Geriftete Inselbögen wie die südlichen Neuen Hebriden bieten die Möglichkeit, tiefe Bereiche der Kruste zu beproben und damit Einblicke in die zeitliche Entwicklung des Inselbogenmagmatismus zu gewinnen.

I.4.2 Bildung von hydrothermalen Lagerstätten an Subduktionszonen

Nach der Entdeckung submarin-hydrothermaler Prozesse an mittelozeanischen Rückensystemen verschob sich das wissenschaftliche Interesse seit Mitte der 90er Jahre vermehrt auf den Hydrothermalismus im Bereich von Back-arc Becken [*Fouquet et al.*, 1991; *Fouquet et al.*, 1993]. Die hier anzutreffenden Mineralisationen können als moderne Analoga zu vielen goldreichen Sulfidlagerstätten an Land angesehen werden [*de Ronde et al.*, 2005; *Ishibashi and Urabe*, 1995; *Stoffers et al.*, 2006]. In den vergangenen Jahren wurden zunehmend die flachmarinen Vulkanbauten entlang vulkanischer Fronten von Inselbögen in die Untersuchungen zum Hydrothermalismus einbezogen. Die Vermutung, dass dieses Milieu ein flachmarines Äquivalent landgebundener, epithermalen Goldlagerstätten repräsentiert, fand im Neu-Irland Inselbogen seine Bestätigung [*Herzig and Hannington*, 2000; *Herzig et al.*, 1998; *Petersen et al.*, 2002] und konnte auch im Tonga-Inselbogen erstmals nachvollzogen werden [*Schwarz-Schampera et al.*, 2003], [*Stoffers et al.*, 2006]. Die Untersuchungen haben gezeigt, dass sich der aktive Hydrothermalismus an Inselbogensystemen im Vergleich zu mittelozeanischen Rücken unterscheidet. Dazu gehören vor allem Merkmale wie die Ausgangsgesteine, der Mineralisations- und Alterationstyp sowie die Quelle der hydrothermalen Fluide. Analogschlüsse aus der terrestrischen Lagerstättenforschung und Untersuchungen an der Sulfid- und Alterationsmineralparagenese flachmariner Vorkommen in Inselbögen legen den Schluss nahe, dass die Freisetzung volatiler Elemente aus subduzierten Platten (H_2O , CO_2 , Fl , Cl , S), deren Einflussnahme auf petrogenetische Prozesse, Gesteinsdifferenziation und nachhaltige magmatische Aktivität die Freisetzung metallreicher, magmatischer Volatile ermöglichen. Der

Eintrag fluid-mobiler Elemente (z.B., As, Sb, B, Cl, S, Pb) in die Subduktionszone [Hawkesworth *et al.*, 1993; Noll *et al.*, 1996] und deren weitgehende Inkompatibilität während der fortschreitenden Differenziation weisen auf die Beteiligung dieser Elemente an der Bildung einer magmatisch-hydrothermalen fluiden Phase hin. Diese Lösungen besitzen deutlich andere Fluidparameter (z.B. niedriger pH-Wert, oxidierender, hoher Sulfidisierungsgrad) als Fluide deren Zusammensetzung weitgehend auf der Modifikation von Meerwasser beruht. Tatsächlich bedingen höher differenzierte Inselbogenvulkane (z.B. Andesite, Dazite) nach bisherigem Kenntnisstand einen variablen Chemismus der Ventfluide [de Ronde *et al.*, 2001; McMurtry *et al.*, 1993; Tsunogai *et al.*, 1994], der ursächlich auf der Freisetzung magmatischer Volatile beruht. Prinzipiell begünstigen die Fluidparameter in diesem Bildungsbereich den Transport von Elementen wie Au, Ag, As, Sb, Hg, Te, Ti.

Die Vergesellschaftung von großen subaerischen Sulfidlagerstätten mit submarin gebildeten Laven mit typischer Subduktionszusammensetzung weist darauf hin, daß sich Fe-Cu-Zn-Pb-Ag-Au Lagerstätten an aktiven Vulkansystemen von Inselbögen und Backarc-Becken bilden [Galley *et al.*, 2007; Hedenquist and Lowenstern, 1994; Izasa *et al.*, 1999; Stix *et al.*, 2003]. Bislang wurden allerdings nur relativ wenige solcher submariner Hydrothermalquellen eingehend untersucht, bei denen sowohl magmatische Gesteine, Präzipitate und Fluide des gleichen Vorkommens beprobt und analysiert wurden [de Ronde *et al.*, 2005; de Ronde *et al.*, 2011; Hedenquist *et al.*, 1993]. Fluiddaten von Hydrothermalquellen in Backarc-Becken und von Inselbogenvulkanen zeigen deutliche Anreicherungen von Pb, Ba, Au, Sn, Sb und anderen Elementen gegenüber Fluiden von Mittelozeanischen Rücken [de Ronde *et al.*, 2011; K Yang and Scott, 2006]. Diese Elemente stammen teilweise aus der Lösung von Gesteinen in der Kruste und teilweise aus den Magmen und werden mit Gasen in die Fluide transportiert [K Yang and Scott, 2006], wobei jedoch der jeweilige Anteil der Prozesse nicht bekannt ist. Insofern ist eine Untersuchung des gesamten vulkanischen Systems an Hydrothermalquellen wichtig, um die Transport- und Fraktionierungsprozesse von Volatilen, Fluiden und Metallen zu bestimmen.

I.5 Zusammenarbeit mit anderen Stellen.

Zusätzlich zu den drei Arbeitsgruppen der Antragsteller arbeiten in dem Projekt Prof. Dr. M. Hannington (Univ. Ottawa, Kanada/GEOMAR KIEL) zum tektonischen Setting sowie Prof. Dr. V. Tunnicliffe (Univ. of Victoria, Kanada) zu den Faunen der hydrothermalen Vents. Proben der Fluide und von Gesteinen wurden außerdem von Prof. Dr. S. Kasemann (MARUM, Univ. Bremen) genommen, um die Isotopenverhältnisse von Li, Sr und B in den Hydrothermalsystemen zu bestimmen.

II Eingehende Darstellung

II.1 Verwendung der Zuwendung und der erzielten Ergebnisse im Einzelnen

II.1.1 Erzielte Ergebnisse während der Ausfahrt

Ein wesentliches Ergebnis der Ausfahrt war der Fund und die Beprobung von hydrothermalen Quellen in der Epi Caldera sowie die Beprobung von verschiedenen submarinen Vulkanen in der Caldera, darunter eines 2004 aktiven Vulkans. Die Laven zeigen sehr variable Zusammensetzung und deuten auf eine umfangreiche fraktionierte Kristallisation in einer flachen Magmenkammer hin. Die hydrothermale Aktivität ist weit verbreitet, aber diffus und die Fluide sind relative kühl, d.h. nur wenige °C wärmer als das Bodenwasser. Offenbar sind die Fluidaustritte gebunden an Störungen am Rand der Caldera. Mineralisationen bestehen aus Fe-Oxiden und-Hydroxiden und eine hydrothermale Fauna tritt vereinzelt auf. Die einzelnen kleinen Vulkankegel in der Epi Caldera weisen sehr unterschiedliche Zusammensetzungen von basaltischen bis rhyolitischen Laven auf, wobei die jüngsten Eruptionen sehr SiO₂-reich sind.

Der Nifonea Vulkan im Vate Trough besteht aus einen Zentralvulkan mit einer großen, halbkreisförmigen Caldera sowie zwei vulkanischen Riftzonen, die nach Norden und Süden in das Becken des Vate Trough verlaufen. Diese Strukturen wurden beprobt und detaillierte Untersuchungen mit dem ROV in der Caldera zeigten, dass hier die jüngste vulkanische Aktivität vorkommt. Die Caldera zeigt verbreitete hydrothermale Aktivität und es wurden mehrere z.T. kochende Systeme gefunden, an denen Fluidproben genommen wurden. Hydrothermale Fauna ist verbreitet und es wurden alle beobachteten Spezies beprobt, um die vorkommenden Arten mit denen von Hydrothermalfeldern weiter östlich bzw. weiter westlich zu vergleichen.

II.1.2 Erzielte Ergebnisse nach der Ausfahrt

Many of the results of the project exist already in manuscript form and thus we present the abstracts here and refer to the attached manuscripts for more details.

II.1.2.1 Petrology and Geochemistry (AG Haase, GZN Erlangen)

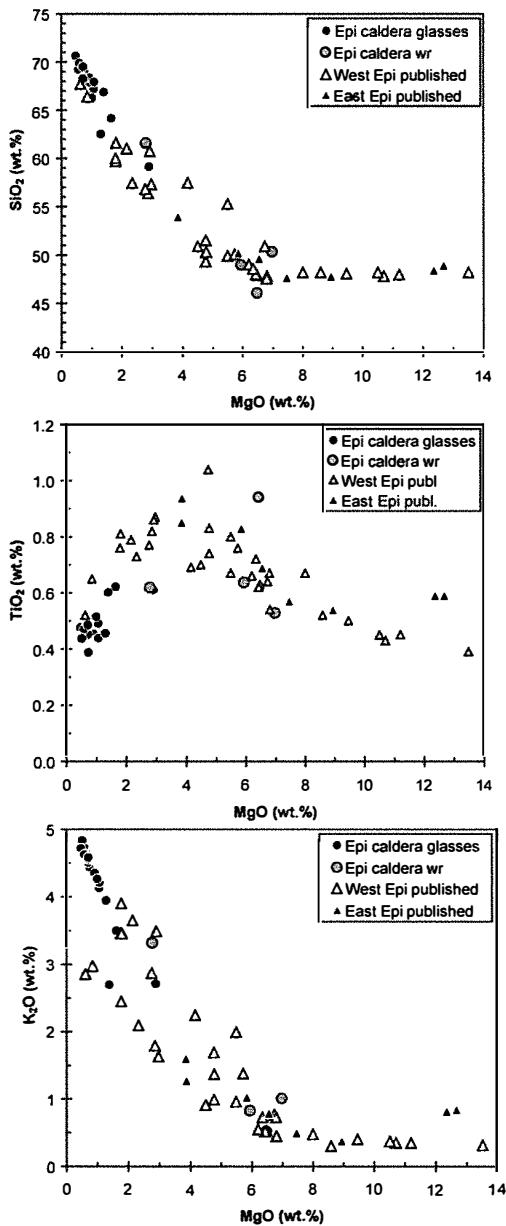
Volcanism of Nifonea Ridge and Vate Trough (see manuscript Lima et al.)

Backarc basin basalts are compositionally similar to lavas erupted along mid-ocean ridges but are variably enriched by the addition of a “subduction component”. In the SW Pacific, such enrichment is not limited to the most mobile elements suggesting the involvement of different mantle sources in the origin of the magmas. These include the depleted mantle and sources contaminated by mantle-plumes, influx of fertile mantle due to opening of slab windows, or contribution of low-degree melts. Volcanism at the Vate Trough (New Hebrides) is presently focused at the Nifonea volcano, which erupts lavas with a unique chemistry.

These are the product of extensive fractional crystallization accompanied by minor contamination with vent fluids within a shallow magma chamber (< 1 km) of magmas derived from a depleted mantle source slightly metasomatised by sediment that mixed with an enriched mantle source (2–4% E-MORB). The contribution of variable enriched sources is a viable mechanism to explain the absence of a negative Nb anomaly in this group and is supported by the transitional chemistry of lavas recovered at the caldera rim but is apparently contradicted by the homogeneous isotopic signature of the caldera glasses. We thus propose that stagnation and extensive fractionation of these magmas at shallow crustal levels promoted efficient homogenization. The chemical and isotopic signature of the caldera lavas, which erupted under vapor- oversaturated conditions, contrasts with the more depleted composition of lavas erupting under vapor-undersaturated conditions, along the rift system. Given the small but increasing contribution of the enriched source with time, we proposed that sampling of small size heterogeneities is responsible for the construction of the large Nifonea volcano. Contrarily to what is suggested in previous studies, the restricted spatial distribution of these enriched lavas precludes their genetic relation with major tectonic / magmatic processes.

Epi caldera volcanism

Whereas the western part of Epi consists of older raised submarine and younger subaerial volcanic structures [Barsdell and Berry, 1990], the eastern part represents a large submarine caldera that was volcanically active in 2004. Seven seamounts exist in the caldera rising 100 to 250 m above the caldera floor. Most of these structures were sampled during SO229 in order to study the complex history of the volcanism and understand the formation of the caldera. Mapping and ROV dives showed that Epi B is not a volcanic structure but rather formed tectonically whereas the other seamounts are volcanic cones. The most recent eruptions occurred at Epi A/Cioan in 2004 and we observed green water discolouration above this structure indicating strong hydrothermal activity. The glasses analysed so far from the Epi caldera are significantly more evolved than the lavas from the island and their composition ranges from dacites to rhyolites with 58 to 71 wt% SiO₂ (Fig. 2.1). The glasses lie on a continuation of the major element trends formed by the published lavas. Four bulk rock samples form the Epi caldera have been analysed so far and they also resemble the published values. Olivine and clinopyroxene apparently fractionate in magmas with more than 7 wt% MgO whereas plagioclase begins to crystallize in melts with less than 7 wt% MgO. Magnetite and Ti-magnetite fractionate in magmas with less than 7 to 5 wt% and there appears to be a range of different melt compositions crystallizing oxides, possibly due to variations in redox state. Interestingly, the Epi samples lie on two separate trends of K₂O at MgO contents below 6 wt.% (Fig. 2.1) suggesting different fractionation processes. Thus, the



lavas from Epi caldera closely resemble those from the subaerial part implying similar mantle sources and melting processes. In general, the caldera magmas appear to be more evolved than the lavas from the island which may indicate a shallow crustal magma reservoir where the magmas stagnate for long periods of time thus having dacitic to rhyolitic composition. This shallow magma chamber then probably collapsed during a large eruption giving rise to the caldera.

The trace element data of the Epi caldera samples are relatively homogeneous implying similar magma sources for all lavas in the caldera but significant fractional crystallization processes. For example, the Ba/Nb are between 120 and 200 whereas the (Ce/Yb)_N range from 2.0 to 5.5 reflecting fractionation of clinopyroxene. This is supported by the variable Sc contents in the lavas and olivine fractionation is indicated by decreasing Ni concentrations with decreasing MgO.

Figure 2.1. Major element composition of the Epi caldera samples compared to published data from Epi Island (Barsdell and Berry, 1990).

Vate Trough profile

During ROV dive 72 we sampled exposed lava formations along the western rift flank of Vate Trough between 2000 m and 1500 m water depth (Fig. 2.2). In order to study the stratigraphy of the uppermost part of the New Hebrides island arc we tried to recover only lava flow samples that were in situ. All recovered samples are basaltic but MgO contents range between 10.6 and 4.5 wt.% thus indicating significant variations in terms of crystal fractionation and accumulation. The K/Ti ratios vary between 0.18 and 0.68 and interestingly, with one exception at 1980 m depth the most enriched basalts occur between 1900 and 1750 m depth (Fig. 2.2). The clearest variation can be observed in HFSE where most samples form the profile have Zr/Y < 3 similar to the active island arc front lavas but between 1880 and

1780 m depth we recovered lavas with significantly higher Zr/Y >3. Importantly, some of these samples also have high Nb/La around 1 indicating that during some times the arc volcanoes erupted melts that did not show the typical Nb depletion. This has important implications because it indicates that the mantle is replaced relatively fast and that the Nb depletion may not be due to prior depletion of the source but due to another process.

Petrology and geochemistry of the lavas in the Futuna Trough

The Futuna is the southernmost through of the Coriolis Throughs. It is a fault-bounded NNE-trending basin that is 25-30 km wide, 75 km long and locally more than 3.6 km deep [Neef and McCulloch, 2001]. According to the K-Ar ages published by Monjaret et al. [1991], the

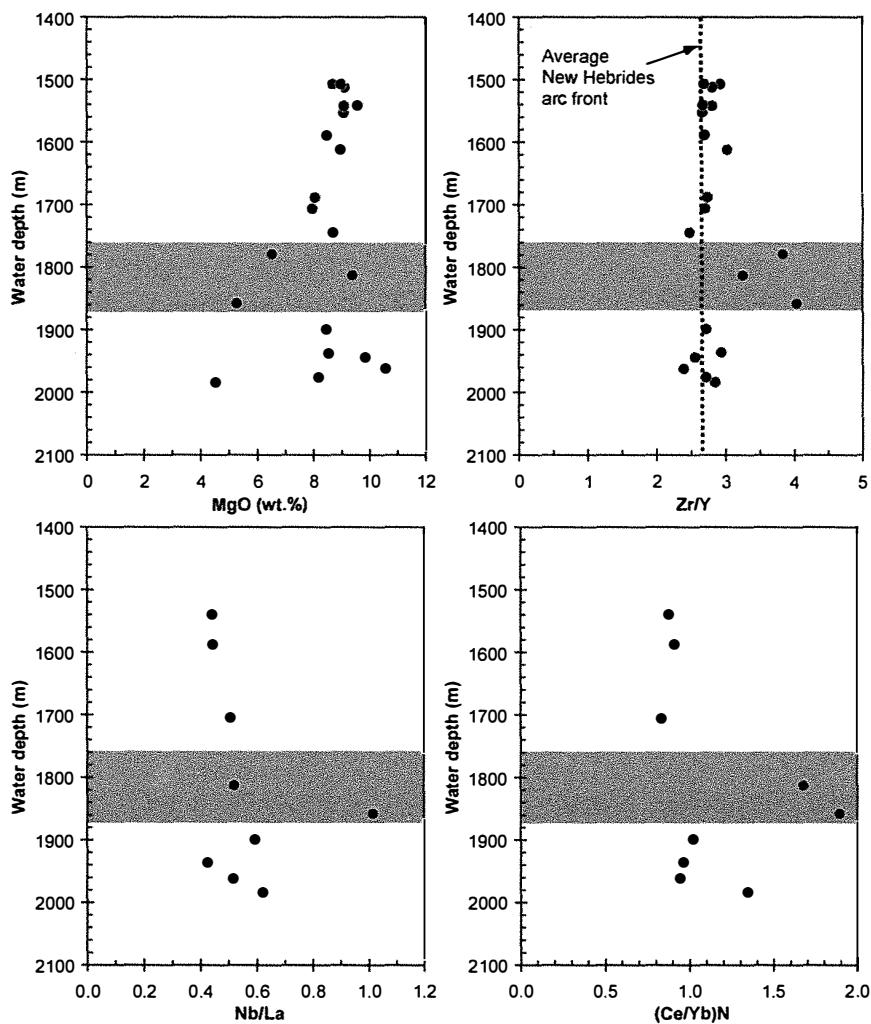


Figure 2.2. Variation of the lava compositions along the stratigraphic profile at the western Vate Trough rift flank.

volcanic activity began at 6.5-6.1 Ma and progressed towards the north. These authors further suggest that this first stage of volcanism is coeval with the building of the arc.

Samples can be divided into two groups: 1) the old island crust sampled during two ROV profiles (039ROV/044ROV) and; 2) the submarine volcanoes (045-TVG, 046-TVG/087TVG, 050-TVG, all aligned NE-SW, and 048-TVG, located near the eastern wall of the trough). The study of these two groups will allow the characterization of magma sources and to trace the evolution of the magmatism with time. It is aimed to recognize potential relations between the submarine volcanoes and magmatism in the neighboring islands (Tanna and Anatom to the west and Futuna to the east of the trough).

Methods and analytical techniques

A total of 23 volcanic glass and 55 whole-rock samples from the Futuna Trough were selected and prepared for chemical analyses. Major elements in glasses were analyzed on single glass chips using a JEOL JXA-8200 Superprobe electron microprobe and minerals' major chemistry was determined in 13 samples using the same microprobe. Major elements and some trace elements (V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, and Ba) were measured on fused glass beads on a Philips PW 2400 XRF spectrometer. Whole-rock trace elements were measured by Thermo X-Series 2 ICP-MS. All the analytical work was performed at GeoZentrum Nordbayern (Friedrich-Alexander Universität) in Erlangen.

Petrography and mineral compositions

Group 1: old island arc crust

Mineral major compositions were determined in 11 samples along the profile and the petrography of selected samples is shown in Figure 2.3. These are composed mainly by Pl + Cpx + Opx + Sp. Olivine ($Fo = 80.2\text{--}89.3$), surrounded by pyroxenes, is scarce and was only observed in sample 044ROV23. Its rare occurrence and the fact that the grains are fragmented may indicate a xenocrystic origin for this phase. Phenocrysts occur both as isolated grains and as mono- or polymimetic aggregates. The majority of Pl grains present normal or oscillatory zoning, with sieve texture. Anorthite contents within the same sample are highly variable (e.g. $An_{56.0\text{--}94.3}$ in sample 039ROV13). Pyroxenes present simple (reverse or normal), oscillatory, and sectorial zoning. In most of the samples Cpx predominates over Opx. Cpx is augite with rare occurrence of pigeonite (in the matrix and rims of augite) and subcalcic augite ($Wo < 25\%$). Opx is always enstatite. Opaque minerals include TiO_2 -magnetite (more abundant) and magnesiochromite. The latter occurs only as microphenocrysts in samples 044-ROV-02 and 044-ROV-23 whereas TiO_2 -magnetite may also occur as inclusions in Pl, Opx and Cpx and small matrix grains.

The occurrence of resorbed rims and growth zones, the common sieve texture of Pl,

and the occurrence of reverse and sectorial zoning are strong indicators of open-system processes. The degree of alteration of some samples and precipitation of calcite and celadonite within vesicles indicates that the samples were affected by late-stage low-temperature hydrothermal alteration. Indeed, in some samples LOI values reach up to 8 wt.%.

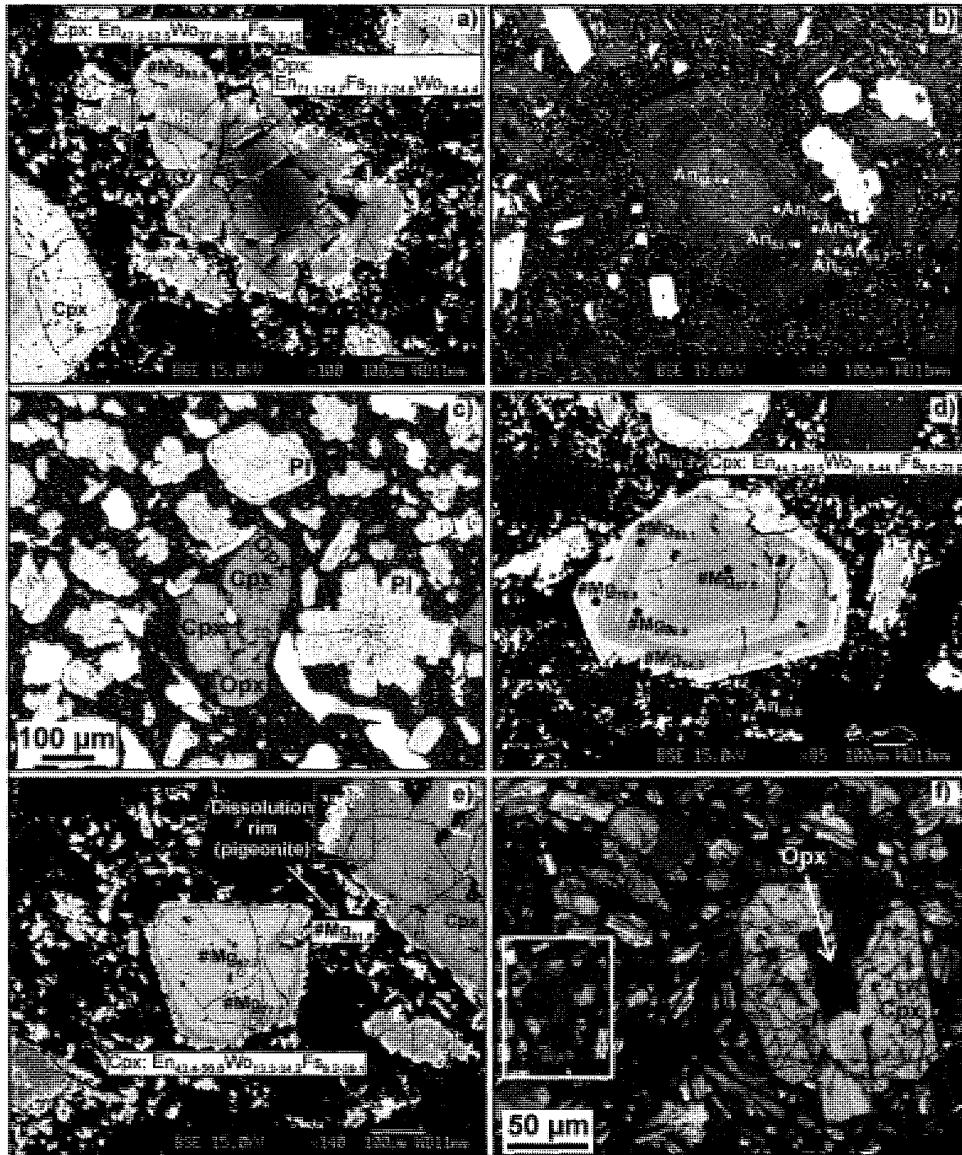


Figure 2.3. Some petrographic aspects of group 1 samples from old crust: a) fragmented OI surrounded by Opx in sample 044ROV23. A reverse zoned Cpx also occurs (rectangle); b) oscillatory zoned PI in sample 044ROV20; c) sieve texture of PI in sample 039ROV02; d) oscillatory zoned Cpx in sample 044ROV23; e) formation of pigeonite rims around Cpx in sample 044ROV23; f) altered Cpx with an Opx core in sample 044ROV23. Inside the rectangle occurs again OI surrounded by disaggregated Opx + Cpx. Photos a-b) and d-e) are in backscattered, photo c) was taken under transmitted light, and photo f) was taken under polarized light.

Group 2: volcanic cones

Mineral major compositions were determined only in two samples belonging to two different cones (045 and 050). These are composed by OI + PI + Cpx + Sp (Fig. 2.4). Fo contents of OI in cone 045 ranges between 75.2 and 83.7 whereas in cone 050 Fo varies from 86.2 to

89.2. The higher Fo contents of olivine from cone 050 (near the values observed in mantle olivine Fo > 88; e.g. [Eggins, 1993]) compared to olivine from cone 045 may be related to the proximity of this cone to the subduction trench. Pl is commonly oscillatory zoned, although one reversed zoned grain was analyzed in cone 050. As in group 1, anorthite contents are quite variable ranging from An_{65.0-93.7} in cone 045 and between An_{67.1-87.9} in cone 050. Augite presents a very limited composition in cone 045 with Mg# = 82.6–84.6 but this is larger in cone 050 (Mg#=70.7–88.1) where the grains may present oscillatory or reverse zoning. Spinel (s.s.) and TiO₂-magnetite occur as inclusions in Pl and augite in cone 045 whereas in cone 050 the opaque mineral is magnesiocromite.

Overall, these samples are fresher than group 1 samples but re-equilibration textures such as resorbed rims are common.

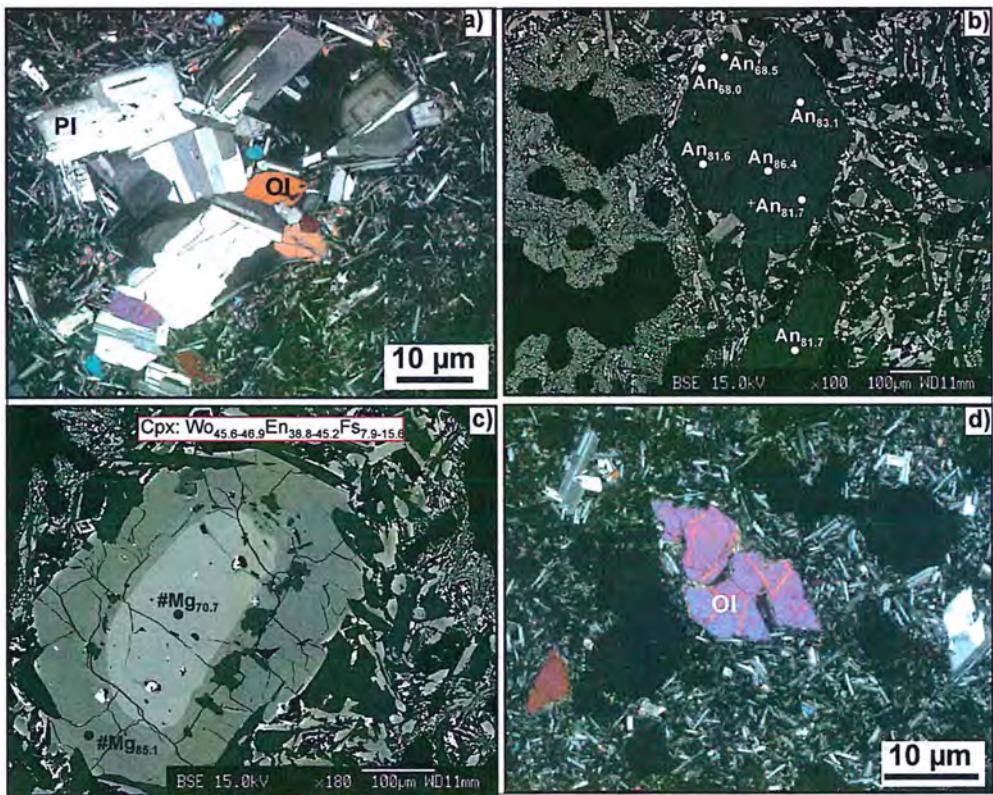


Figure 2.4. Some petrographic aspects of samples from the volcanic cones: a) poly-mineral aggregate in cone 045. Pl is oscillatory zoned; b) oscillatory zoning of Pl in cone 050; c) reversed zoned Cpx with a resorbed growth front in cone 050; d) partial resorption of OI in cone 050. Photos a) and d) were taken under polarized light and photos b-c) are in backscattered.

Chemical composition of the lavas

Of the three studied areas (Epi, Nifonea and Futuna), Futuna shows the largest compositional variability. Overall, the samples from group 1 show a trend from low- to medium-K (basaltic andesites to trachybasalts whereas group 2 shows a variation from predominantly low-K basalts to andesites.

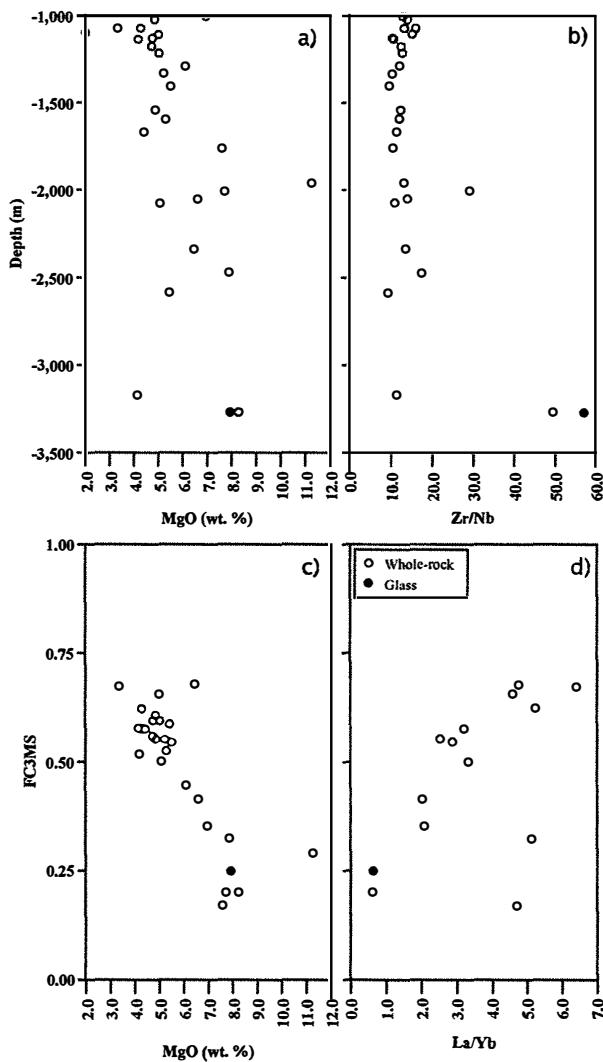


Figure 2.5. Futuna old crust chemical variation with: a-b) depth; c-d) FC3MS (as defined by Yang and Zhou 2013).

Group 1: old island arc crust

Glass and whole-rock chemical data shows substantial variations in major elements. Samples with LOI > 3 wt. % were not considered. They are characterized by 48.28–60.09 wt. % SiO₂, 13.82–20.06 wt. % Al₂O₃, 6.28–11.04 wt. % Fe₂O₃^T, 3.34–11.27 wt. % MgO, 7.06–12.16 wt. % CaO, 1.77–3.34 wt. % Na₂O and, 0.12–1.45 wt. % K₂O. In spite of this variation, no chemical trends are observed with decreasing depth (Fig. 2.5a-b). Normalization to the primitive-mantle confirms enrichment in all incompatible elements (Fig. 2.6a). These rocks show positive anomalies of U and Sr and a negative Nb-Ta anomaly, all consistent with a subduction-environment. Chondrite-normalized REE profiles are flat (LaN/YbN = 1.45–4.61) to slightly enriched in LREE over HREE and the Eu anomaly is negligible (absent to slightly negative) (Fig. 2.6b). Sample 039-ROV-01 (collected on the bottom of the profile at 3271 m deep) presents a distinct normalized profile, similar to N-MORB (red line in Fig. 2.6). The crustal profile shows a small variation in Zr/Nb (Fig. 2.5b), which may indicate derivation from a common mantle component [e.g. Falloon *et al.*, 2014]. Sample 039ROV01, however, has a significantly higher value. The low Zr/Nb values (9.4–29.3) and the flat chondrite-normalized REE patterns suggest derivation from an undepleted source (Zr/Nb and Ti/Zr ratios are similar to primitive mantle [Hofmann, 1988]) and the observed linear correlation between Nb and Zr exclude generation by different degrees of partial melting of the same source [Kamber and Collerson, 2000].

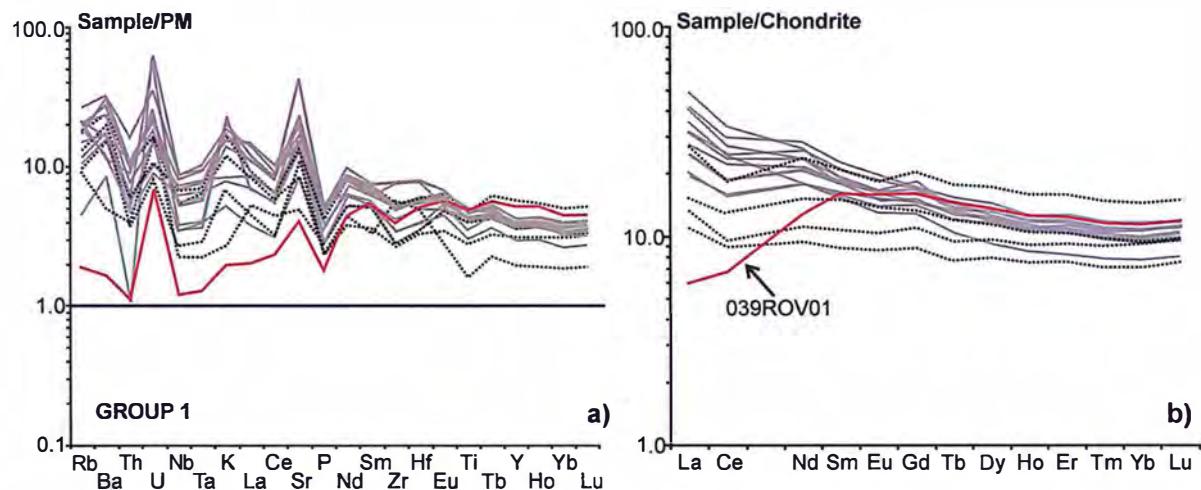


Figure 2.6. Normalized patterns for Futuna old crust (group 1): a) primitive-mantle; b) chondrite. Primitive mantle and chondrite from Sun and McDonough (1989).

As seen in Fig. 2.7a-b, no fractionation trends are observed thus, the data was not corrected for fractionation of olivine. The negative correlation between FC3MS [as defined by Z-F Yang and Zhou, 2013] and MgO (Fig. 2.5c) and the positive correlation between this parameter and La/Yb (Fig. 2.5d) may indicate derivation from a pyroxenitic rather than a peridotitic melt. This can explain the low MgO contents of these rocks (<10 %) without arguing for fractionation [e.g. Z-F Yang and Zhou, 2013] and the overall low Ni (mostly < 50 ppm) and Cr (mostly <100 ppm) contents. This, however, requires further investigation of the

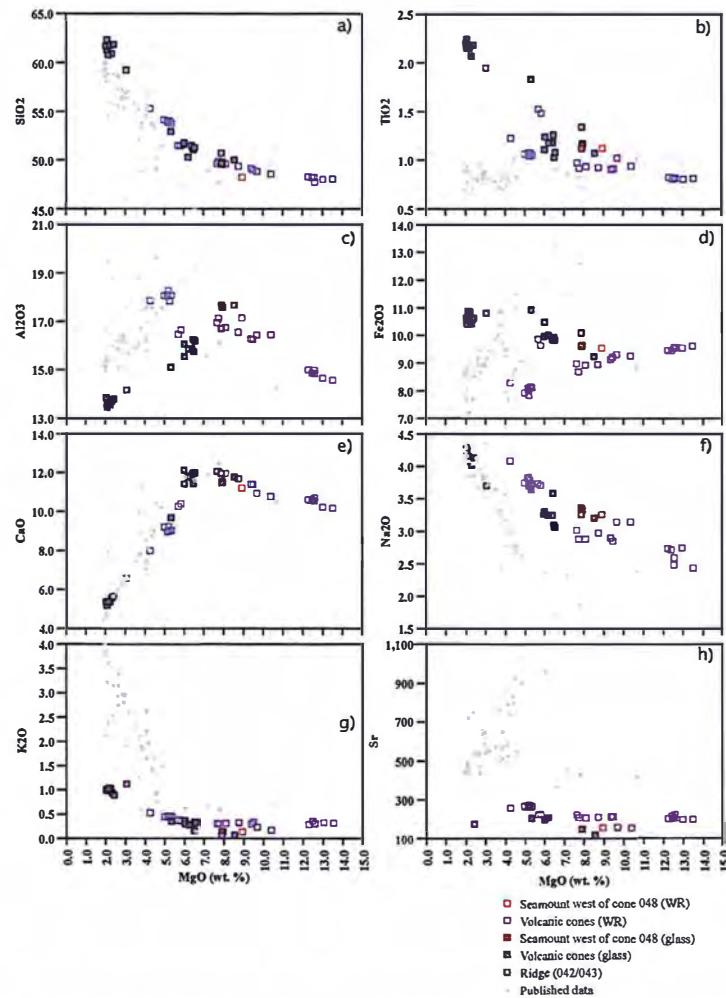


Figure 2.7. Selected variation diagrams showing the chemistry of group 2 samples. Published data from the neighboring islands are shown for comparison (Dupuy et al. 1982; Marcelot et al. 1983; Robin et al. 1994; Métrich et al. 2011).

genetic relationship between the sampled rocks, namely by determining precise Ar/Ar ages (in progress) and Sr-Nd-Pb isotopic data.

Group 2: volcanic cones

Four out of the five volcanic cones sampled are located at the western part of the Futuna

Trough and aligned NE-SW. The samples collected from one of the middle cones (051-TVG) are intensely weathered and thus were not used for analysis. Overall, whole-rock data is slightly less evolved than glass analyzed in the same sample. An increase in SiO₂ content from 47.72 wt. % (whole-rock) to 62.33 wt. % (glass) is accompanied by a decrease in MgO from 13.51 wt. % (whole-rock) to 2.03 wt. % (glass) (Fig. 2.7a). Considering the entire dataset and including data from the neighboring islands [Dupuy et al., 1982; Marcelot et al., 1983; Métrich et al., 2011; Robin et al., 1994], fractionation of olivine seems to be the most important process in the evolution of magmas until MgO contents of approximately 6 wt. % are achieved. Fractionation of minor clinopyroxene may also account for the relatively low increase in SiO₂ (around 2.5 wt. %) compared to the considerable decrease in MgO (around 6.5 wt. %) (Fig. 2.7a). At MgO ≈ 6 wt. % an abrupt increase in SiO₂ and some incompatible elements, like K₂O, Y, Zr, Nb, and Ba, and an abrupt decrease in CaO are observed (Fig. 2.7). Fractionation of Fe-Ti oxides could explain the increase in SiO₂ but this is not consistent with Fe₂O₃ and TiO₂ trends (Fig. 2.7b, d). On the other hand, fractionation of plagioclase would consume significant amounts of SiO₂ and minor Sr. This behavior can then be explained either by fractionation of SiO₂-undersaturated phases, like feldspathoids (not observed so far in the thin-sections) or by the occurrence of another mechanism other than simple fractionation in the genesis of these rocks. The latter could also explain the distinct trends observed in TiO₂, Al₂O₃, and Fe₂O₃^T (Figs. 2.7b-d) and the considerable more evolved composition of glass relative to whole-rock data. The neighboring islands (Tanna and Ambrym to the west and Futuna to the east) were characterized by similar SiO₂, MgO, and CaO contents but tend to be enriched in Al₂O₃, K₂O, Rb, Sr and depleted in Na₂O, TiO₂, Cr, and Ni compared to the submarine volcanism.

Comparison between cones

Cone 050-TVG, located at the SW end of the chain, is characterized by a considerable variation in MgO contents (7.7–13.5 wt.%; n = 14 samples). On the other hand, the range in MgO is quite limited in the other two cones, ranging between 4.3–5.4 wt. % (n = 8 samples) in cone 046/087-TVG and being equal to 5.7 wt. % (n = 2 samples) in cone 045-TVG, located at NE end. The composition of these two cones is similar thus, an evolution towards NE (with increasing distance to the trench), is inferred. The major composition of the fifth cone (048-VSR) falls within the compositional range of cone 050-TVG. However, this is characterized by lower K₂O and Nb contents and slightly more depleted LREE. Primitive-mantle normalized values show similar patterns to group 1 although presenting lower enrichment in all elements compared to primitive-mantle. The cone 048 is also slightly depleted in Th and Nb-Ta compared to this reservoir (Fig. 2.8). Chondrite-normalized patterns support the similarity between the cones nearest to the trough flanks (050 to the

west and 048 to the east) and between volcanoes 046/087 and 045 (Fig. 2.8). The first are characterized by HREE enrichment relatively to LREE ($\text{La/YbCN} < 1$) whereas the later are characterized by flat REE-normalized patterns ($\text{La/YbCN} = 1.06\text{--}1.15$) and slightly higher REE content. The Eu anomaly is negligible in both subgroups although slightly negative in the second.

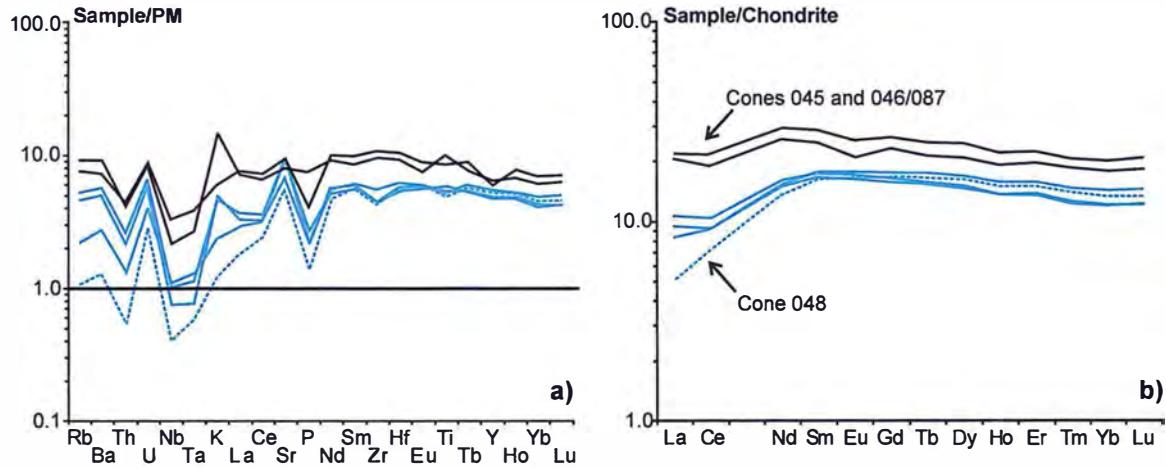


Figure 2.8. Normalized patterns for the submarine volcanic cones in Futuna (group 2): a) primitive-mantle; b) chondrite. Primitive mantle and chondrite from Sun and McDonough (1989).

II.1.2.2 Hydrothermal precipitates (AG Schwarz-Schampera BGR Hannover)

Hydrothermal activity is known from many back-arc regions and is typically associated with young volcanism along these extensional structures. Venting of hydrothermal fluids was found at 1900 m water depth in the large submarine caldera of Nifonea volcano in Vate Trough, a back-arc basin east of the New Hebrides island arc. Focused discharge of hot fluids up to 368° forms of up to 4 m high sulfide chimneys that are located directly on lavas. The chimneys emanate jets of steam indicating phase separation ("boiling") as well as black smoke and almost clear fluids. Lack of hydrothermal alteration of host rocks and of significant amounts of hydrothermal debris indicates a young age of the hydrothermal system. The sulfide mineral assemblage in all recovered chimneys comprises pyrite, marcasite, sphalerite/wurtzite, and chalcopyrite. One chimney is characterized by abundant galena and reveals minor amounts of Cu-As-Sb sulfosalts of the tennantite-tetrahedrite solid solution series as well as amorphous As sulfides on its outer surface. Pyrrhotite occurs as inclusions in pyrite and (iso-)cubanite is sometimes intergrown with chalcopyrite. The common gangue minerals are anhydrite and barite. Ore textures differ within individual chimneys and range from a dense intergrowth of sulfides like chalcopyrite and galena to sulfide zonations reflecting temperature gradients and evolving fluid temperatures with time and monomineralic massive aggregates. The geochemical composition of the sulfide chimneys reveals significant contents of highly volatile elements including As, Se, Sb, Tl, and In. The

hydrothermal fluids indicate that sub-critical phase separation is frequent but sulfide textures and compositions suggest either a non-continuous influence of boiling on sulfide precipitation within the individual chimneys or variable depths of phase separation below the seafloor. The high contents of elements like As, Se, and Tl, the occurrence of complex sulfosalts and As sulfides, the argillic alteration mineral assemblage, and the low Fe contents of sphalerite possibly reflect an input of magmatic volatiles into the Nifonea hydrothermal system. The S isotopic composition of sulfides, sulfates and native sulfur does not indicate disproportionation of magmatic SO₂ in the hydrothermal system so that an input of magmatic volatiles is not supported.

II.1.2.3 Hydrothermal fluids (AG Koschinsky Jacobs Univ. Bremen)

The active, high-temperature hydrothermal vent field “Nifonea” is located in a water depth of 1860 m – 1875 m within a caldera structure in the Vate Trough, an extensional rift in the New Hebrides island arc. Discovered in 2010, the first comprehensive study including high temperature fluid sampling has been carried out in 2013. Clear colourless to black smoke fluids emanate from several sites with temperatures up to 368°C, the hottest measured so far in the W Pacific. The water depth of the Nifonea vent field corresponds to a pressure of 188–189 bars, and this places the hottest fluids into the two-phase field of NaCl-H₂O, close to the 2-phase boundary of seawater. The lowest calculated endmember salinity of 27 mM Cl proves venting of an almost pure vapour phase fluid at the prevailing p-T conditions. The geochemical fluid signature including only slightly elevated Li/Cl and Rb/Cl ratios relative to seawater suggests only limited, non-equilibrium water-rock interaction with quick fluid passage in the subseafloor. Phase separation, vapour phase segregation, two-component fluid mixing, and sulphide precipitation are the processes determining the individual composition of vent fluids sampled at different chimney orifices. Subcritical phase separation likely occurs very shallow <200m in the sub-seafloor. While concentrations of alkali and alkali earth elements are low and generally follow Cl concentrations, the concentrations of Fe (0.7 mM to 7 mM), As (10 µM to 21 µM), and REY (55 nM to 180 nM) are among the highest so far reported from submarine hydrothermal fluids. This study provides the most comprehensive dataset for trace metals and metalloids in hydrothermal systems, including Co, Ag, Ge, Cd, Ga, Se, Sb, Tl, Sn, W, In. The element/Cl ratios of most metals and metalloids are highest in the most Cl-depleted fluids with <30 mM Cl (REY>B>As, Si, Ge>Al>Cu, Zn, Co, Pb, Tl), relative to the more Cl-enriched fluids with ~270 mM Cl, while Fe/Cl ratios are similar. The remarkable enrichment of some of these elements may reflect to varying degrees higher concentrations in the enriched basaltic to andesitic Nifonea rocks (proven for REY), a preferential mobilization from grain boundaries (Fe, REY, As, ...), preferential fractionation into the vapour phase (As), and a generally increased

solubility in low-salinity, low-density vapours at the specific physico-chemical conditions. A direct contribution of metals such as As from magmatic degassing cannot be satisfactorily shown.

Previous phases of magmatic-hydrothermal activity in the Nifonea caldera are indicated by the specific fluid composition at one vent site with elevated SO₄, Al, Si, and Ge concentrations and low metal concentrations, suggesting interaction with rocks affected by argillitic alteration. The Nifonea vent field represents a very young, early stage hydrothermal system that is thermally linked to recent magmatic activity. It resembles vent sites previously discovered in Mid-Ocean Ridge settings at the East Pacific Rise between 9°N and 10°N, where fluids with similar fingerprints of limited water-rock interaction and phase separation were observed shortly after magmatic events in 1991 and 2005/6.

II.1.2.4 Tectonic setting of hydrothermal venting (AG Hannington GEOMAR Kiel)

The Coriolis Troughs of the New Hebrides subduction zone are among the youngest backarc rifts in the world. They are 100 km in length and only 25–45 km wide, reaching depths of > 3 km despite their close proximity to the arc front (~50 km). The narrow, deep graben morphology is characteristic of magma-deficient arc rifts in the early stages of backarc extension, where the rate of extension and subsidence exceeds the magmatic input. Unexpectedly, the youngest graben, the Vate Trough, contains a centrally-located 1000 m tall and 14 km wide shield volcano with a large, 5 × 8 km wide summit caldera and lava lake. The caldera is host to extensive diffuse hydrothermal venting and several clusters of black smoker chimneys with the highest recorded temperatures in the SW Pacific. The focusing of voluminous basaltic eruptions into an otherwise magma-deficient backarc is linked to strong left-lateral transtension caused by segmentation and clockwise rotation of the southern portion of the arc following collision with d'Entrecasteaux ridge. The Nifonea axial volcano has a volume of ~126 km³, reflecting very high extrusion rates, given its young age (<3 m.y.). The summit caldera hosts the first large lava lake described from a submarine backarc setting in the SW Pacific. By comparison with eruption rates at large axial volcanoes on the mid-ocean ridges, the 46×10^6 m³ of jumbled sheet flows in the caldera could have been erupted in under 26 h. High-temperature hydrothermal venting and an “event plume” were associated with the effusive sheet flow eruptions. We suggest that upper plate stresses can result in dramatic variability in magma supply and hydrothermal activity at the earliest stages of arc rifting and could explain the wide range of melt compositions, volcanic styles and mineral deposit types found in nascent backarc rifts.

II.1.2.5 Li, Sr and B isotope ratios (AG Kasemann Univ. Bremen)

We report strontium (Sr), lithium (Li), and boron (B) concentrations and isotopic data of hydrothermal fluids. The aim is to characterize the processes and water-rock interaction at the Nifonea vent field influencing the emanating fluids in the subsurface. Sr and Li isotopes are good proxies for the water/rock ratio during water-rock interaction in the hydrothermal circulation, whereas B isotopes help to identify the host-rock composition as well as processes like phase separation and segregation.

To evaluate the water-rock interaction and calculate water/rock ratios for the emanating fluids, several basement rocks, sampled on the same cruise, were also analyzed for their isotopic compositions.

Methods

Before isotope analysis Li, B and Sr were separated from their sample matrix using different separation methods. To prepare the rock samples for chemical separation of Li and Sr, the rock chips were pulverized and afterwards digested using a mixture of HF, HNO₃ and H₂O₂. To prepare of the vent fluids for Sr and Li column separations the fluids were dried.

For Sr isotope analysis 300 ng Sr was loaded onto the columns. The chromatographic separation was done with Sr spec as resin using a modified method described by Pin and Bassin [1992]. The separated Sr fraction was than loaded together with an tantalum emitter onto rhenium filaments and measured with TIMS (thermal ionization mass spectrometry). For Li isotope analysis at least 100ng Li was loaded onto the column. Li was separated from its sample matrix using a two-step column separation modified after Moriguti and Nakamura [1998]. Separated Li fractions were checked for their purity and measured on a Neptune MC-ICP-MS (Multicollector inductively coupled plasma mass spectrometer). Boron in fluids was purified using a sublimation technique modified after Wang et al. (2010) whereas Boron in rocks was separated differently. First rock powders were digested using an alkali carbonate fusion method. Afterwards the B in the melted samples was purified using a two-step column separation method modified after Tonarini et al. [1997] and Romer et al. [2014]. Boron isotope ratios from fluids and rocks were measured on MC-ICP-MS.

Both Li and B isotope ratios were measured using the standard-sample-bracketing method. For Li L-SVEC was used as bracketing standard and for B NBS-951. Isotope data for Li- and B-isotopes are reported in delta notation relative to a standard material and expressed in per mill (‰).

$$\delta^{7Li} [\text{‰}] = \left[\frac{\left(\frac{^{6}Li}{^{7}Li} \right)_{\text{sample}}}{\left(\frac{^{6}Li}{^{7}Li} \right)_{L-SVEC}} - 1 \right] \cdot 1000 \quad (1)$$

$$\delta^{11}B [\text{‰}] = \left[\frac{\left(\frac{11}{10}B\right)_{\text{sample}}}{\left(\frac{11}{10}B\right)_{\text{NBS-951}}} - 1 \right] \cdot 1000 \quad (2)$$

To validate and verify the chemical separation and digestion techniques used in this study, in each series of samples international reference materials were separated and measured as well. Results for these reference materials are within analytical uncertainty in agreement with literature values.

Results

Filtered CTD water column samples show typical isotopic compositions for seawater in all analyzed isotopic systems. Smoker Fluids are generally depleted in Li and Sr whereas B is enriched compared to seawater. Calculated endmember Li and Sr concentrations range from 2.1 to 31.1 mM and 11 to 53 µM, respectively. Measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the hydrothermal fluids have lower ratios compared to seawater. Also Li and B isotopic compositions differ from seawater. Both isotopic systems are depleted in their light isotopes in the vent fluids. The calculated endmember isotopic compositions vary from 10 to 18‰ for $\delta^7\text{Li}$, 17.3 to 22‰ for $\delta^{11}\text{B}$, and 0.7063 to 7079 for $^{87}\text{Sr}/^{86}\text{Sr}$.

Analyzed isotopic ratios for different rocks from Nifonea, Vate Trough and Futuna range between 0.70308 to 0.704165 for $^{87}\text{Sr}/^{86}\text{Sr}$, 2.5 to 8.4‰ for $\delta^7\text{Li}$, and -0.5 to +10.4‰ for $\delta^{11}\text{B}$.

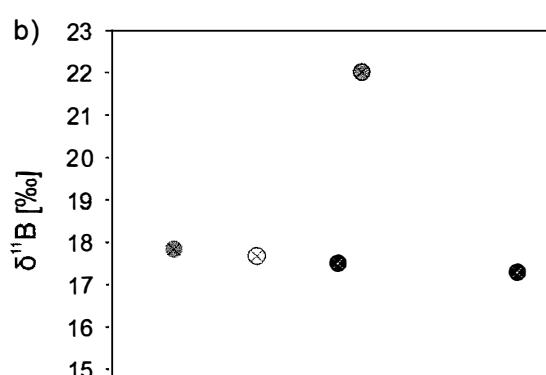
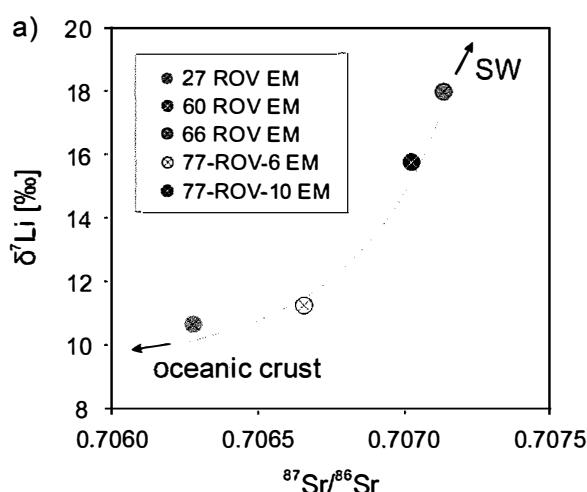


Figure 2.9: Correlation between endmember $^{87}\text{Sr}/^{86}\text{Sr}$ ratios versus a) $\delta^7\text{Li}$ show a mixing trend between seawater (SW) and the composition of rocks in the oceanic crust. Figure b) shows the relationship between $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{11}\text{B}$.

Discussion

Although $\delta^7\text{Li}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are significantly different from the seawater values, both isotope systems have relatively high values in the Nifonea vent fluids compared to other hydrothermal systems located in arc and back-arc settings in the Western Pacific. $\delta^7\text{Li}$ values are characteristically in a range between 3 to 10‰ [Chan et al., 1994; Foustoukos et al., 2004]. But because Sr and Li isotope ratios correlate (Fig. 2.9a) it can be assumed that the data of the Nifonea vent fluids indicate a low water rock interaction with high water/rock ratios during hydrothermal circulation. Indeed, water/rock ratios (W/R ratio) calculated with Sr isotope ratios show values between 22

and 73, where the highest W/R ratio was calculated for the 60-ROV endmember and the lowest for 66-ROV. There are several possible explanations for these findings but some can be already excluded because of the high temperatures during the venting of the fluids. Thus the high values for Li and Sr isotope ratios can be explained by either the reaction with highly altered rocks or by a shallow hydrothermal circulation. Many elements in highly altered rocks could be already leached during former reaction with hot hydrothermal fluids which leads to a depletion in highly mobile elements like Li. If the hot fluids react with those altered rocks not much Li or Sr can be leached and thus their isotopic composition changes only slightly.

In contrast, B concentration range from 1012 to 1565 µM and are highly enriched compared to seawater. Depleted chloride concentrations in the fluids indicate phase separation processes in the fluids. Since boron is slightly volatile, it can partition into the vapour phase during phase separation. If these concentrated gases mix again with hydrothermal fluids in the subsurface, B and other volatile compounds get concentrated in the emanating fluids. However, variations in B concentrations and $\delta^{11}\text{B}$ values (17 to 22 ‰) match within analytical uncertainty with other arc related hydrothermal systems in the western Pacific [Yamaoka *et al.*, 2015]. This implies that there is no significant isotope fractionation of B during phase separation and segregation.

In conclusion these results show that Sr and Li isotope ratios in the vent fluids from Nifonea volcano are a good indicator for water-rock interaction during hydrothermal circulation. Both isotopic systems show high water/rock ratios during hydrothermal circulation. Although B is enriched in the vent fluids due to phase separation, $\delta^{11}\text{B}$ values are in accordance with other arc/back-arc basin fluids from the Western Pacific and reflect the strong arc influence of this setting.

II.1.2.6 Biological Collections and Faunal Assessment

V. Tunnicliffe, J. Rose (University of Victoria, Canada), A. Metaxas (Dalhousie University, Canada)

Collections

Jonathan Rose joined the SONNE cruise and returned biological collections to U Vic. The majority of specimens came from nine ROV grabs and suctions plus two TV grabs at Nifonea. Additional fauna was picked from rocks collected by both ROV and TV grabs.

Verena Tunnicliffe sorted the collections and assessed the animals present by consulting the literature and several taxonomic experts. The table below represents the current taxonomic assessment of the material returned. There is much work to be done yet – many species have still to be sent to experts for examination. Some interesting observations include:

- i) Overall, the fauna has many similarities to the nearest known vents: Lau Basin. For example, the mussel species appears to be the same as are the alvinellid polychaetes,

barnacle and likely several other species. Yet, many Lau species are not present, instead are replaced by species known from Manus Basin or from the Kermadec Arc. Still other species may be new. Thus, Vanuatu may prove to be an interesting "confluence" of biogeographic areas.

- ii) The shrimp is a new species currently under description; specimens from this cruise are incorporated into the publication that is currently under review: Komai and Tsuchida, New records of Alvinocarididae (Crustacea: Decapoda: Caridea) from the western Pacific hydrothermal vents, with descriptions of three new genera and three new species, Journal of Natural History. Other specimens of *Chorocaris* sp. nov. come from Manus Basin.
- iii) There are two species of tubeworm present. Dr. Eve Southward examined them to determine that they are similar to species recently published from Brothers Caldera in the Kermadec Arc. However, there are some differences that may warrant a redescription of the species.
- iv) The "hairy snails" (*Alviniconconcha hessleri*) were confirmed by molecular analysis (S. Johnson, MBARI) and will appear in a publication on this species.
- v) Three species (a squat lobster and two limpets) are not in the published literature although undescribed specimens may lie with specialists.

We have accessioned the specimens into the Univ. Victoria collection and are dispersing specimens to specialists for examination. The mussels will be used in a student project to examine reproduction and growth.

First taxonomic assessment of fauna collected on SO-229 by V. Tunnicliffe

Taxon	Group	Species	Status	#	Comments	Field Collection
Arthropoda	Brachyura	unk		1	orange male 2cm	019-05-01
Mollusca	Gastropoda	unk		3	neogastropod	019-05-04
Chordata	Pisces	eel	unk	1		019-05-05
Mollusca	Bivalvia	<i>Bathymodiolus</i> <i>brevior</i>	cf ok	1	small	019-05-06, -01
Mollusca	Gastropoda	<i>Lepetodrilus schrolli</i>	check	50	v. small	027-08-01
Polychaeta	Ampharetidae	<i>Amphysamytha</i> sp		20		027-08-01
Polychaeta	Siboglinidae	<i>Lamellibrachia cf juni</i>	sure	30	to Southward	027-08-01
Mollusca	Bivalvia	<i>Bathymodiolus</i> <i>brevior</i>	cf ok	2		027-08-03
Arthropoda	Anomura	<i>Munidopsis</i> sp		1	not <i>lauensis</i> or <i>kermadeci</i>	027-09-02
Mollusca	Gastropoda	cf <i>Shinkailepas</i>	unsure	3		027-09-02

Arthropoda	Anomura	<i>Paralomis hirtella</i>	sure	2	minor diffs	062-01
Mollusca	Gastropoda	<i>Lepetodrilus schrolli</i>	check	<50	on crabs	062-01
Arthropoda	Anomura	<i>Munidopsis</i> sp		21	not lauensis or kermadec	062-02
Arthropoda	Brachyura	<i>Austinograea alayseae</i>		1		062-03
Cnidaria	Actinaria	anemone unk		2		062-03
Mollusca	Bivalvia	<i>Bathymodiolus</i> cf <i>brevior</i>	re-exam	1		062-03
Mollusca	Bivalvia	<i>Bathymodiolus</i> cf <i>brevior</i>	re-exam	16	v. Small	062-03
Polychaeta	Maldanidae	<i>Nicomache</i> sp		1	partial specimen	062-03
Polychaeta	Nereidae	<i>Nereis</i> sp		1	partial specimen	062-03
Polychaeta	Polynoidae	<i>Branchinotogluma</i> cf <i>trifucus</i>		1		062-03
Mollusca	Bivalvia	<i>Bathymodiolus</i> cf <i>brevior</i>		11		077-01-01
Mollusca	Bivalvia	<i>Bathymodiolus</i> cf <i>brevior</i>		2		077-01-02
Arthropoda	Anomura	<i>Munidopsis</i> unk		2	not lauensis or kermadec	077-01-04
Arthropoda	Cirripedia	<i>Eochionelasmus ohtai</i>	sure	14		077-01-04
Mollusca	Gastropoda	<i>Lepetodrilus schrolli</i>	check	lots	<i>Lepetodrilus</i> -	077-01-04
Mollusca	Gastropoda	provannid		11		077-01-04
Polychaeta	Ampharetidae	<i>Amphysamytha</i> sp		1		077-01-04
Polychaeta	Polynoidae	unk		4		077-01-04
Mollusca	Gastropoda	<i>Alviniconcha hessleri</i>	sure	1		077-11-
Polychaeta	Alvinellidae	<i>Paralvinella fijiensis</i>	sure	10		077-11-1
Polychaeta	Alvinellidae	<i>Paralvinella fijiensis</i>	sure	1		077-11-1

Imagery

Vent and non-vent biological assemblages have been assessed qualitatively from video imagery for 3 dives on Epi Caldera (SO229-006-ROV01, SO229-013-ROV02, SO229-019-ROV03) and 6 dives on Nifonea (SO229-027-ROV04, SO229-060-ROV07, SO229-066-ROV08, SO229-072-ROV09, SO229-077-ROV10, SO229-083-ROV11). Overall, few fauna were present on Epi caldera. During dive SO229-006-ROV01, the substratum was mostly mud showing occasional white staining, and the fauna consisted of sparse gorgonian sea whips, crinoids, anemones and sponges. The substratum was mostly fine on the other two dives on Epi, except in a few locations where pebbles and boulders were present. Fauna was mostly absent during SO229-013-ROV02, except of some barnacles, sponges and

snails in the very end of the transect. Few dead shells and live mussels were present in dive SO229-019-ROV03.

The fauna was more abundant and diverse on Nifonea than Epi caldera. In the regions of visible hydrothermal flow near chimneys, intermingled beds of mussels and barnacles reached almost 100% cover. Dense patches of skinny tubeworms were interspersed with those beds. Galatheid and brachyuran crabs were relatively abundant amongst these beds and shrimp on chimney walls (the shrimp). These assemblages formed distinct boundaries, with increasing distance from the chimneys and as the influence of the fluids waned. Away from the vents, the non-vent fauna was slightly more abundant than on Epi and consisted mainly of stalked sponges, soft corals and anemones. Almost no fauna (vent or non-vent) were present during dives SO229-072-ROV09 and SO229-083-ROV11.

II.2 Wichtigste Positionen des zahlenmäßigen Nachweises

- Miete des Kiel 6000 ROV für die Ausfahrt
- TVL-E13 Stelle für Dr. Selma Lima, GZN Univ. Erlangen-Nürnberg
- 0.5 TVL-E13 Stelle für Dr. K. Schmidt, Jacobs Univ. Bremen
- 0.5 TVL-E13 Stelle für MSc F. Häckel, BGR Hannover

II.3 Notwendigkeit und Angemessenheit der geleisteten Arbeit

Alle Arbeiten in dem Projekt waren notwendig und sind weitestgehend im Projektantrag beschrieben. Insofern sind die Maßnahmen angemessen und auch die Kosten für die jeweiligen Arbeitsschritte sind vorher im Antrag dargelegt worden.

II.4 Voraussichtlicher Nutzen, insbesondere der Verwertbarkeit des Ergebnisses im Sinne des fortgeschriebenen Verwertungsplans

Die wissenschaftlichen Ansätzen und Zielen des Projekts COVOLVE liefert essentielle Beiträge zu laufenden internationalen und nationalen Programmen der Meeres- und Polarforschung. Inselbögen sind „Brennpunkte im Nutzungs- und Gefährdungspotential der Erde“ und Thema des gleichnamigen Schwerpunktes der Forschungsperspektiven „Geotechnologien“. Die bisher erzielten Ergebnisse von COVOLVE zeigen, dass sich sulfidische Erzlagerstätten häufig in Back-arc Rifts bilden und eine große Variation in ihrer Zusammensetzung aufweisen. Die beobachteten Anreicherungen von Elementen wie Gold, Silber, Kupfer, Selen und Arsen sind offenbar typisch für Lagerstätten im Zusammenhang mit jungen, relativ gasreichen Vulkaniten. Die Untersuchungen ergeben wichtige Beiträge für die zukünftige Versorgung der Bevölkerung mit mineralischen Rohstoffen sowie für die Kenntnis der geochemischen und strukturellen Prozesse, die zu Anreicherungen von polymetallischen

Sulfiden führen. Diese sind unerlässlich, um nachhaltig die Versorgung der Gesellschaft mit Industrie- und Hochtechnologiemetallen sicherzustellen. Damit hat COVOLVE umwelt- und gesellschaftswissenschaftliche wie auch politische Relevanz und wird wichtige Beiträge sowohl zur meeresswissenschaftlichen Grundlagenforschung als auch zur angewandten Forschung leisten. Auf diese Weise trägt das Projekt auch zum Programm FoNa (Forschung für nachhaltige Entwicklung) des BMBF bei, insbesondere zu den Themen „Ressourcen und Nachhaltigkeit“ und „System Erde“.

II.5 Während der Durchführung des Vorhabens dem ZE bekannt gewordenen Fortschritte auf dem Gebiet des Vorhabens bei anderen Stellen

Nicht relevant

II.6 Erfolgte oder geplante Veröffentlichungen des Ergebnisses nach Nr. 6.

MSc Arbeiten

Gress, M.U. (2014). Vate Trough - The evolution of the Vanuatu Island Arc crust. Masterarbeit Friedrich-Alexander-Universität Erlangen-Nürnberg, 52 S.

Konferenzbeiträge

Beier, C., Lima, S., Haase, K. (2014). Magmatism in the southern New Hebrides arc-Coriolis backarc. Goldschmidt 2014 Conference, Sacramento, USA.

Anderson, M.O., Hannington, M.D., Haase, K., Schwarz-Schampera, U. and McConachy, T. (2014). Insights into magmatic-hydrothermal processes in the newly-discovered seafloor massive sulfide deposits of the New Hebrides arc-backarc, SW Pacific. In: AGU Annual Fall Meeting, San Francisco, California, USA.

Lima, S.M., Haase, K.M., Beier, C. (2014) Tracing the evolution of island-arc volcanism in the Tanna-Futuna transect (New Hebrides). In: AGU Annual Fall Meeting, San Francisco, California, USA.

Anderson, M.O., Hannington, M.D., Haase, K., Schwarz-Schampera, U. and McConachy, T. (2015) Geological controls on hydrothermal venting at the Nifonea Volcano, Vate Trough, Vanuatu. In: 13. SGA Biannual Meeting 2015, 24.-28.08.2015, Nancy, France.

Haase, K.M., Lima, S.M., Gress, M.U., Beier, C. (2015) Crust formation in the New Hebrides Arc. Goldschmidt 2015 Conference, Prag, Czech Republic.

Nasemann P, Gault-Ringold M, Rolison J, Stirling C, Koschinsky A, Sander S (2015) Iron Isotope Fractionation in a Hydrothermal Plume Above the Nifonea Vent Field, Vanuatu. Goldschmidt 2015 Conference, Prag, Czech Republic.

Eingereichte Manuskripte

Anderson, M.O., Hannington, M.D., Haase, K., Schwarz-Schampera, U., Augustin, N. and McConachy, T. (eingereicht Sept. 2015). Tectonic focusing of voluminous basaltic eruptions in magma-deficient backarc rifts. *Earth and Planetary Science Letters*.

Lima, S.M., Haase, K.M., Beier, C., Regelouos, M., Brandl, P.A., Hauff, F., and Krumm, S. (eingereicht Nov. 2015). Magmatic evolution and source variations at the Nifonea Ridge (New Hebrides Island Arc). *Journal of Petrology*.

Manuskripte in Vorbereitung

Schmidt, K., Garbe-Schönberg, D., Hannington, M., Anderson, M., Bühring, B., Haase, K., Haruel, C., Lupton, J., Koschinsky, A. (in prep.). Fluid geochemistry of an early-stage hydrothermal system in the New Hebrides Island Arc (Vanuatu, SW Pacific): the Nifonea vent field. *Geochimica et Cosmochimica Acta*

Häckel, F., Schwarz-Schampera, U., Haase, K.M., Hannington, M. (in prep.). Mineralogy and chemical composition of hydrothermal sulfides from the Nifonea backarc volcano, Vanuatu, New Hebrides Arc. *Mineralium Deposita*

Haase, K.M., Anderson, M., Garbe-Schönberg, D., Beier, C., Brandl, P., Lima, S.M., Schwarz-Schampera, U, Hannington, M., Allen, K.M., Haruel, C., (in prep.). Relationship between volcanic and hydrothermal activity in the submarine caldera of Nifonea Volcano, Vate Trough backarc basin, Vanuatu. *Geochemistry Geophysics Geosystems*.

III Kurzgefasster Erfolgskontrollbericht

III.1 Beitrag des Ergebnisses zu den förderpolitischen Zielen

Die Ergebnisse des Projekts tragen zu einem besseren Verständnis einerseits der tektonischen und magmatischen Prozesse an einer Subduktionszone und andererseits der Anreicherungsprozesse von Metallen und der Lagerstättenbildung bei. Die Dynamik insbesondere der Subduktion im Vanuatu Inselbogen zeigt sich in der Häufigkeit der Erdbeben und Vulkanausbrüche in diesem Gebiet, die ein Gefahrenpotential für die Bevölkerung Vanuatus und benachbarter Staaten darstellt. Insofern fällt diese Forschung in den Bereich der Untersuchung der Küsten- und Meeresforschung im Rahmen des FoNa. Die Beteiligung von Wissenschaftlern aus Vanuatu und deren späterer Fortbildung in Deutschland und ihre Einbeziehung in die Untersuchungen wurde in Vanuatu mit großem Interesse verfolgt. Die Studien an den hydrothermalen Prozessen der heißen und kühleren Vents im Gebiet von Vanuatu verbessern das Verständnis der Interaktionen zwischen Magmenkörpern, vulkanischen Eruptionen, Entgasung, Fluidzusammensetzung und der Auswirkungen auf die Konzentrationen in Sulfiden und anderer Minerale in einzelnen Fuidaustritten. Dieses Verständnis ist eine Grundlage für die verbesserte und nachhaltige Nutzung von ähnlichen Lagerstätten auf den Kontinenten und in den Ozeanen, wie sie im Rahmen von FoNa vorgesehen ist.

III.2 Wissenschaftliche Ergebnisse des Vorhabens

Die wichtigsten Ergebnisse des Projektes zum jetzigen Stadium sehen wie folgt aus:

1. Im Hauptgebiet der Arbeiten am submarinen Nifonea Vulkan im Vate Trough treten Anzeichen von sehr jungen Lavaströmen neben hydrothermaler Aktivität mit sehr heißen Fluiden auf. Offenbar löste die Intrusion eines Gangs und die Eruption von Laven eine starke hydrothermale Zirkulation aus, die immer noch kochende Fluide erzeugt. Die Zusammensetzung der Fluide weist ebenfalls einige Besonderheiten auf wie z.B. relativ niedrige pH Werte und Cl Konzentrationen aber dagegen hohe Konzentrationen von As und Fe. Diese weisen möglicherweise auf einen hohen Anteil an einer magmatischen Volatilkomponente hin, können allerdings auch größtenteils die Dampfphase nach der Phasentrennung repräsentieren.
2. Die Petrologie und geoschemische Zusammensetzung der Laven des Nifonea Vulkans und des Vate Trough zeigen eine große Variation von an inkompatiblen Elementen verarmten bis angereicherten Zusammensetzungen und einer Entwicklung zu zunehmenden angereicherten Magmen. Die jüngsten Laven in der Caldera zeigen die höchsten Konzentrationen der inkompatiblen Elemente und die

höchsten Sr und Pb Isotopenverhältnisse. Darin spiegelt sich die zunehmende Aufschmelzung von angereichertem Material im Mantel wider, die zu der Fokussierung des Vulkanismus im Vate Trough und der Bildung des Nifonea Vulcans geführt hat. Die Magmen, die unter der Nifonea Caldera aufsteigen, verweilen offenbar relativ lange in einer flachen Magmenkammer in etwa 1 km Tiefe und entgasen dort. Die aufsteigenden Gase und volatilen Komponenten tragen vermutlich zur hydrothermalen Aktivität bei und liefern wichtige Anteile der Metalle für die Sulfidbildung.

3. Ein 500 m hohes Krustenprofil wurde an der westlichen Riftflanke des Vate Trough mit dem ROV beprobt, um die Entwicklung der Inselbogenkruste zu bestimmen. Die Laven zeigen drei Bereiche mit unterschiedlicher Zusammensetzung der Gesteine, wobei der unterste und oberste aus verarmten Laven mit deutlicher Subduktionssignatur besteht und der mittlere aus relativ angereicherten Gesteinen. Der mittlere, etwa 100 m mächtige Bereich der Abfolge besteht aus angereicherten Laven mit einer OIB-ähnlichen Zusammensetzung. Diese Abfolge zeigt, dass der Mantelkeil rasche Wechsel der Zusammensetzung erfährt und offenbar Einstrom von sehr angereichertem Material erfolgt.
4. Die Proben von fünf verschiedenen Hoch-T Fluidaustritten bestehen überwiegend aus Sulfiden, deren mineralogische und chemische Zusammensetzung untersucht wurde. Dabei zeigen sich sehr hohe Gehalte an As und z.T. das Vorkommen von As-Sulfiden, die die Zusammensetzung der Fluide widerspiegeln. Trotzdem sind die Au Gehalte in den Sulfiden niedrig (<2 ppm), während die Ag Gehalte zumindest in einem Raucher relativ hoch sind (200-560 ppm). Eisenoxid und -hydroxidkrusten und -schlote wurden beprobt an mehreren jungen bzw. aktiven Vulkanen und dieses Material zeigt erhebliche Variationen in der Zusammensetzung. Offenbar ändert sich die Zusammensetzung dieser Ablagerungen abhängig von der Temperatur der Fluide und der Zusammensetzung der Ausgangsgesteine, wobei die Parameter noch genauer bestimmt werden sollen. Zudem soll geprüft werden, inwieweit sich solche Ablagerungen für die Exploration von Sulfidlagerstätten eignen.
5. Obwohl die beprobten Schwarzen Raucher sehr dicht beieinander liegen, zeigen die Fluide z.T. deutliche Unterschiede in der Zusammensetzung. Der Einfluss einer Phasentrennung ist in den heißen Fluiden zu beobachten und zeigt sich in der niedrigen Salinität und in den Gehalten an Metallen. Damit unterscheiden sich die Fluide deutlich von denen anderer Backarc Bereiche im Südpazifik.

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Erfolgskontrollbericht

Die Ergebnisse des Projektes SO229 COVOLVE tragen zu einem Verständnis der magmatischen und tektonischen Prozesse bei der Bildung der Erdkruste an Subduktionszonen bei, sowie zu dem Verständnis der Entstehung von Lagerstätten von ökonomisch relevanten Metallen wie Kupfer, Silber, Zink, Gold und Selen. Ein Verständnis der Prozesse in der Erde ist eine Grundlage für die verbesserte und nachhaltige Nutzung von ähnlichen Lagerstätten auf den Kontinenten und in den Ozeanen, wie sie im Rahmen von FoNa vorgesehen ist. Die Ergebnisse zeigen, dass sich die Kruste an ozeanischen Inselbögen nach komplexeren Mustern entwickeln als es aktuelle Modelle beschreiben. Zum Beispiel zeigen viele Laven in der Kruste sowohl des inselbogens als auch des Backarcs an inkompatiblen Elementen angereicherte Zusammensetzungen ohne negative Nb-Ta Anomalie und deuten damit an, dass der Mantel an der Subduktionszone nicht an diesen Elementen verarmt ist. Weiterhin finden wir weitgehend mafische Gesteine in der gesamten Abfolge der oberen Kruste am Vanuatu Inselbogen anstatt einer Entwicklung hin zu mehr felsischen Zusammensetzungen. Die Zusammensetzung der Fluide und der Sulfide deutet auf eine Beteiligung von magmatischen Fluiden, allerdings führt diese nicht zu einer Anreicherung von Au und Cu wie ursprünglich vermutet, sondern es finden sich hohe Konzentrationen von As in den relativ sauren Fluiden. Diese Anreicherung zeigt sich auch in den Vent-Präzipitaten mit dem Auftreten von As-Sulfiden. Eine genauere Untersuchung der Zusammenhänge zwischen magmatischer Entgasung und den Quellen der hydrothermalen Fluide ist noch in Gang. Die Zahl und Qualität der Proben wird noch anschließende Arbeiten erfordern und es werde noch einige weitere Publikationen erwartet, da der Umfang der gesammelten Daten sehr groß ist. Wir gehen davon aus, dass die Arbeiten noch bis 2017 andauern, bevor die wesentlichsten Arbeiten publiziert sind.

Alle im Antrag geplanten Arbeiten wurden erfolgreich durchgeführt und haben wichtige Ergebnisse gebracht. Der Ausgaben- und Zeitplan wurde eingehalten.

Document Control Sheet

1. ISBN or ISSN 0012821X	2. type of document (e.g. report, publication) Journal article, accepted Earth and Planetary Science Letters
3. title Tectonic focusing of voluminous basaltic eruptions in magma-deficient backarc rifts	
4. author(s) (family name, first name(s)) Anderson, M.O., Hannington, M.D., Haase, K.M., Schwarz-Schampera, U., Augustin, N., McConachy, T.F.	5. end of project
	6. publication date
	7. form of publication
8. performing organization(s) (name, address) Department of Earth Sciences, University of Ottawa, 75 Laurier Ave E, Ottawa, Ontario, K1N 6N5, Canada	9. originator's report no.
	10. reference no.
	11. no. of pages
12. sponsoring agency (name, address) Bundesministerium für Bildung und Forschung (BMBF) 53170 Bonn	13. no. of references
	14. no. of tables 0
	15. no. of figures 10
16. supplementary notes	
17. presented at (title, place, date)	
18. abstract <p>The Coriolis Troughs of the New Hebrides subduction zone are among the youngest backarc rifts in the world. They are 100 km in length and only 25–45 km wide, reaching depths of > 3 km despite their close proximity to the arc front (~50 km). The narrow, deep graben morphology is characteristic of magma-deficient arc rifts in the early stages of backarc extension, where the rate of extension and subsidence exceeds the magmatic input. Unexpectedly, the youngest graben, the Vate Trough, contains a centrally-located 1000 m tall and 14 km wide shield volcano with a large, 5 × 8 km wide summit caldera and lava lake. The caldera is host to extensive diffuse hydrothermal venting and several clusters of black smoker chimneys with the highest recorded temperatures in the SW Pacific. The focusing of voluminous basaltic eruptions into an otherwise magma-deficient backarc is linked to strong left-lateral transtension caused by segmentation and clockwise rotation of the southern portion of the arc following collision with d'Entrecasteaux ridge. The Nifonea axial volcano has a volume of ~126 km³, reflecting very high extrusion rates, given its young age (<3 m.y.). The summit caldera hosts the first large lava lake described from a submarine backarc setting in the SW Pacific. By comparison with eruption rates at large axial volcanoes on the mid-ocean ridges, the 46×10^6 m³ of jumbled sheet flows in the caldera could have been erupted in under 26 h. High-temperature hydrothermal venting and an “event plume” were associated with the effusive sheet flow eruptions. We suggest that upper plate stresses can result in dramatic variability in magma supply and hydrothermal activity at the earliest stages of arc rifting and could explain the wide range of melt compositions, volcanic styles and mineral deposit types found in nascent backarc rifts.</p>	
19. keywords	
20. publisher Elsevier	21. price

Document Control Sheet

1. ISBN or ISSN 0022-3530	2. type of document (e.g. report, publication) Journal article, submitted to Journal of Petrology
3. title Magmatic evolution and source variations at the Nifone Ridge (New Hebrides Island Arc)	
4. author(s) (family name, first name(s)) Lima, S.M., Haase, K.M., Beier, C., Regelous, M., Brandl, P.A., Hauff, F., and Krumm, S.	5. end of project
	6. publication date
	7. form of publication
8. performing organization(s) (name, address) GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany	9. originator's report no.
	10. reference no.
	11. no. of pages
12. sponsoring agency (name, address) Bundesministerium für Bildung und Forschung (BMBF) 53170 Bonn	13. no. of references
	14. no. of tables 5
	15. no. of figures 14
16. supplementary notes	
17. presented at (title, place, date)	
18. abstract <p>Backarc basin basalts are compositionally similar to lavas erupted along mid-ocean ridges but are variably enriched by the addition of a "subduction component". In the SW Pacific, such enrichment is not limited to the most mobile elements suggesting the involvement of different mantle sources in the origin of the magmas. These include the depleted mantle and sources contaminated by mantle-plumes, influx of fertile mantle due to opening of slab windows, or contribution of low-degree melts. Volcanism at the Vate Trough (New Hebrides) is presently focused at the Nifonea volcano, which erupts lavas with a unique chemistry. These are the product of extensive fractional crystallization accompanied by minor contamination with vent fluids within a shallow magma chamber (< 1 km) of magmas derived from a depleted mantle source slightly metasomatised by sediment that mixed with an enriched mantle source (2–4% E-MORB). The contribution of variable enriched sources is a viable mechanism to explain the absence of a negative Nb anomaly in this group and is supported by the transitional chemistry of lavas recovered at the caldera rim but is apparently contradicted by the homogeneous isotopic signature of the caldera glasses. We thus propose that stagnation and extensive fractionation of these magmas at shallow crustal levels promoted efficient homogenization. The chemical and isotopic signature of the caldera lavas, which erupted under vapor-oversaturated conditions, contrasts with the more depleted composition of lavas erupting under vapor-undersaturated conditions, along the rift system. Given the small but increasing contribution of the enriched source with time, we proposed that sampling of small size heterogeneities is responsible for the construction of the large Nifonea volcano. Contrarily to what is suggested in previous studies, the restricted spatial distribution of these enriched lavas precludes their genetic relation with major tectonic / magmatic processes.</p>	
19. keywords	
20. publisher Oxford Univ. Press	21. price

Document Control Sheet

1. ISBN or ISSN 1525-2027	2. type of document (e.g. report, publication) Journal article, in prep. for Geochemistry, Geophysics, Geosystems
3. title Relationship between magmatic and hydrothermal processes in the submarine caldera of Nifonea Volcano, Vate Trough backarc basin, Vanuatu	
4. author(s) (family name, first name(s)) K.M. Haase, S.M. Lima, C. Beier, P. Brandl, M. Hannington, M. Anderson, D. Garbe-Schönberg, U. Schwarz-Schampera, C. Kleint ⁶ , K.M. Allen, C. Haruel	5. end of project
	6. publication date
	7. form of publication
8. performing organization(s) (name, address) GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany	9. originator's report no.
	10. reference no.
	11. no. of pages
12. sponsoring agency (name, address) Bundesministerium für Bildung und Forschung (BMBF) 53170 Bonn	13. no. of references
	14. no. of tables 1
	15. no. of figures 11
16. supplementary notes	
17. presented at (title, place, date)	
18. abstract We report on new observations and geochemical data of volcanic glasses from the Nifonea Volcano, a central volcano in the Vate Trough backarc rift basin of the Vanuatu Island Arc. Boiling hydrothermal vents occur on very young lavas in the large Nifonea caldera and it appears that the recent intrusion of a dike along the SW rift and the eruption of lavas in the caldera yield the thermal energy for the venting. Lavas in the caldera are more evolved than those on the older outer parts of the volcano and indicate the presence of a shallow (about 1 km depth) magma reservoir beneath the caldera. The caldera glasses are depleted in S and H ₂ O implying degassing of the shallow magma reservoir whereas increasing Cl/K suggest assimilation-fractional crystallization processes. The primitive Nifonea basalts have similar V/Sc and Zn/Fe ratios to other backarc glasses and MORB indicating similar oxygen fugacity in their mantle sources. Fractionation of magnetite in melts with less than 4 wt.% MgO has no effect on chalcophile elements in the Nifonea magmas possibly indicating sulfide formation and fractionation.	
19. keywords	
20. publisher American Geophysical Union	21. price

Document Control Sheet

1. ISBN or ISSN 0016-7037	2. type of document (e.g. report, publication) Journal article, in prep. <i>Geochimica et Cosmochimica Acta</i>
3. title Boiling vapour-type fluids from the Nifonea vent field (New Hebrides Island Arc, Vanuatu, SW Pacific): Geochemistry of an early-stage hydrothermal system	
4. author(s) (family name, first name(s)) Schmidt, K., Garbe-Schönberg, D., Hannington, M., Anderson, M., Bühring, B., Haase, K., Haruel, C., Lupton, J., Koschinsky, A.	5. end of project 6. publication date
	7. form of publication
8. performing organization(s) (name, address) Department of Physics and Earth Sciences, Jacobs University Bremen gGmbH, Campus Ring 1, D-28759 Bremen, Germany	9. originator's report no. 10. reference no.
	11. no. of pages
12. sponsoring agency (name, address) Bundesministerium für Bildung und Forschung (BMBF) 53170 Bonn	13. no. of references 14. no. of tables 1
	15. no. of figures 8
16. supplementary notes	
17. presented at (title, place, date)	
18. abstract <p>The active, high-temperature hydrothermal vent field "Nifonea" is located in a water depth of about 1870 m within a caldera structure in the Vate Trough, an extensional rift in the New Hebrides island arc. Here we report results from the first comprehensive study including high temperature fluid sampling in 2013. Clear to black smoke fluids emanate from several sites with temperatures up to 368°C, the hottest measured so far in the W Pacific. The water depth of the Nifonea vent field corresponds to a pressure of 188-189 bars, and this places the hottest fluids within the two-phase field of NaCl-H₂O, close to the 2-phase boundary of seawater. Boiling could be visually observed. The lowest calculated endmember chlorinity of 27 mM Cl represents an almost pure vapour phase fluid resulting from subcritical phase separation. The geochemical fluid signature including only slightly elevated Li/Cl and Rb/Cl ratios relative to seawater suggests only limited, non-equilibrium water-rock interaction with quick fluid passage through the sub-seafloor. Subcritical phase separation <200m within the sub-seafloor, vapour phase segregation, two-component fluid mixing, and sulphide precipitation are the processes determining the individual compositions of vent fluids sampled at different chimney orifices. While concentrations of Li and other alkali and alkali earth elements are low and generally follow Cl concentrations, the concentrations of Fe (0.7 mM to 7 mM), As (10 µM to 21 µM), REY (55 nM to 180 nM) and Fe/H₂S are among the highest reported so far from submarine hydrothermal fluids. The element/Cl ratios of most metals and metalloids are highest in the most Cl-depleted fluids with <30 mM Cl (REY>B>As, Si, Ge>Al>Cu, Zn, Co, Pb, Ti) relative to the more Cl-enriched fluids with ~270 mM Cl, while Fe/Cl ratios are similar. The remarkable enrichment of some of these elements are a consequence of leaching at high water-to-rock ratios and reflect elevated concentrations in the enriched basaltic to andesitic Nifonea rocks (proven for REY), a preferential mobilization from grain boundaries (Fe, REY, As), preferential fractionation into the vapour phase (B, As), and a generally increased solubility in low-salinity, low-density vapours at the specific physico-chemical conditions. A direct contribution of metals such as As from magmatic degassing cannot be satisfactorily shown. Brine or fluids with "evolved" seawater signatures were not found. Previous magmatic-hydrothermal activity in the Nifonea caldera is indicated by the specific fluid composition at one vent site with elevated SO₄, Al, Si, Ge, and low metal concentrations, suggesting interaction with rocks affected by argillic alteration. The Nifonea vent field represents a very young, early stage hydrothermal system that is thermally linked to recent magmatic activity. It resembles vent sites previously discovered in Mid-Ocean Ridge settings on the East Pacific Rise between 9°N and 10°N where fluids with similar fingerprints of limited water-rock interaction and phase separation were observed shortly after magmatic events in 1991 and 2005/6.</p>	
19. keywords	
20. publisher Elsevier	21. price

Document Control Sheet

1. ISBN or ISSN 0026-4598	2. type of document (e.g. report, publication) Journal article, in prep. Mineralium Deposita
3. title Mineralogy and chemical composition of hydrothermal sulfides from the Nifonea backarc volcano, Vanuatu, New Hebrides Arc	
4. author(s) (family name, first name(s)) Häckel, F., Schwarz-Schampera, U., Haase, K.M., Hannington, M., Anderson, M., McConachy, T.	5. end of project 6. publication date
	7. form of publication
8. performing organization(s) (name, address) Bundesanstalt für Geowissenschaften und Rohstoffe Stilleweg 2, D-30655 Hannover, Germany	9. originator's report no. 10. reference no.
	11. no. of pages
12. sponsoring agency (name, address) Bundesministerium für Bildung und Forschung (BMBF) 53170 Bonn	13. no. of references 14. no. of tables 1
	15. no. of figures 9
16. supplementary notes	
17. presented at (title, place, date)	
18. abstract <p>Hydrothermal activity is known from many back-arc regions and is typically associated with young volcanism along these extensional structures. Venting of hydrothermal fluids was found at 1900 m water depth in the large submarine caldera of Nifonea volcano in Vate Trough, a back-arc basin east of the New Hebrides island arc. Focused discharge of hot fluids up to 368° forms of up to 4 m high sulfide chimneys that are located directly on lavas. The chimneys emanate jets of steam indicating phase separation ("boiling") as well as black smoke and almost clear fluids. Lack of hydrothermal alteration of host rocks and of significant amounts of hydrothermal debris indicates a young age of the hydrothermal system. The sulfide mineral assemblage in all recovered chimneys comprises pyrite, marcasite, sphalerite/wurtzite, and chalcopyrite. One chimney is characterized by abundant galena and reveals minor amounts of Cu-As-Sb sulfosalts of the tennantite-tetrahedrite solid solution series as well as amorphous As sulfides on its outer surface. Pyrrhotite occurs as inclusions in pyrite and (iso-)cubanite is sometimes intergrown with chalcopyrite. The common gangue minerals are anhydrite and barite. Ore textures differ within individual chimneys and range from a dense intergrowth of sulfides like chalcopyrite and galena to sulfide zonations reflecting temperature gradients and evolving fluid temperatures with time and monomineralic massive aggregates. The geochemical composition of the sulfide chimneys reveals significant contents of highly volatile elements including As, Se, Sb, Tl, and In. The hydrothermal fluids indicate that sub-critical phase separation is frequent but sulfide textures and compositions suggest either a non-continuous influence of boiling on sulfide precipitation within the individual chimneys or variable depths of phase separation below the seafloor. The high contents of elements like As, Se, and Tl, the occurrence of complex sulfosalts and As sulfides, the argillic alteration mineral assemblage, and the low Fe contents of sphalerite possibly reflect an input of magmatic volatiles into the Nifonea hydrothermal system. The S isotopic composition of sulfides, sulfates and native sulfur does not indicate disproportionation of magmatic SO₂ in the hydrothermal system.</p>	
19. keywords	
20. publisher Springer	21. price