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A geochemical study of off-axis seamount lavas at the Valu Fa Ridge: Constraints on magma genesis and slab contributions in the southern Tonga subduction zone

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ABSTRACT

New geochemical data are presented for fresh lavas from off-axis seamounts east and west of the Valu Fa Ridge and from seamounts south of the propagating rift tip of the Valu Fa Ridge. Most seamount lavas are basaltic and thus more primitive than the mostly andesitic to dacitic lavas from the adjacent Valu Fa Ridge. Slight differences in fluid-mobile element ratios and in Sr isotope ratios suggest small-scale heterogeneities of the slab component in this region with an apparently higher sedimentary input into the off-axis seamount lavas than into the island arc magmas. Off-axis volcanoes near back-arc basin spreading centres thus resemble off-axis seamounts adjacent to mid-oceanic ridges which also show more extreme compositions than the well-homogenized mid-ocean ridge basalts. The geochemical variations support a diapiric ascent of the hydrated or partially molten mantle leading to separate magma supply systems for the different volcanic structures. The mantle wedge between the Valu Fa Ridge and the island arc appears to be uniformly depleted in fluid-immobile incompatible elements compared to average depleted mid-ocean ridge basalts whereas lavas from seamounts west of the Valu Fa Ridge show less depletion in agreement with a depletion event of the whole mantle wedge in the backarc melting zone. Seamount lavas south of the Valu Fa Ridge propagating rift resemble the Valu Fa lavas indicating an increased magma production caused by the influx of water into the mantle.

1. Introduction

Off-axis volcanoes are common in the vicinity of mid-ocean ridges and also occur near back-arc spreading centres. The development of volcanoes near spreading centres provides insight into underlying mantle, melt ascent and into the distribution of mantle sources in the upper mantle. Geochemical studies have shown that there are significant differences in the sources and in the melting processes between mid-ocean ridges and neighbouring off-axis volcanoes (Batiza et al., 1990; Niu et al., 2002). Frequently, the seamount lavas have more extreme compositions in terms of incompatible elements and radiogenic isotopes and thus imply the presence of depleted and/or enriched mantle sources beneath the spreading axis. Individual off-axis seamounts represent small melt volumes lacking steady-state magma chambers and thus the magmas are not necessarily well mixed whereas the petrology and geochemistry of axial lavas indicates extensive crystal fractionation and mixing processes within crustal magma chambers located beneath the ridge (Batiza, 1989; Batiza et al., 1990; Sinton and Detrick, 1992; Perfit and Chadwick, 1998). Seamount lavas are in most cases also more primitive than mid-ocean ridge basalts (MORB) reflecting the differences in the amount of fractionation. Consequently, comparative geochemical studies of MORB and associated off-axis lavas provide important information on melting conditions and sub-axial mantle flow processes. In subduction systems the input of slab components appears to increase with the proximity to the island arc and studies in the Lau Basin show that the influence of the subducting slab can be traced up to 60 km behind the active island arc (Pearce et al., 1995). Thus, off-axis seamounts along the Lau back-arc spreading centre provide insights into the influx of the slab component into the mantle wedge. Furthermore, the highly depleted high field strength element composition of the Tonga-Kermadec arc lavas has been attributed to depletion of the mantle wedge source at the Lau backarc spreading centre and the off-axis seamounts thus should also form from depleted sources.

Here we present new geochemical data of samples from nine off-axis seamounts and several locations south of the Valu Fa Ridge and compare these with the active Valu Fa Ridge axis to study the variations in petrogenesis and slab contributions normal to the ridge.

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On the basis of the small-scale chemical and isotopic heterogeneities we suggest that magma supply occurs in diapirs from the slab to the volcanic structures.

2. Geological setting

Within the triangular shaped Lau Basin three major active spreading ridges exist: the Central Lau Spreading Centre (CLSC), the Eastern Lau Spreading Centre (ELSC), and the Valu Fa Ridge (Fig. 1). The Lau Basin back-arc opened in the past 5-5.5 Ma by successive southward propagation of seafloor spreading centres (Hawkins, 1995). It is one of the fastest spreading back-arcs with full spreading rates between 90 mm/a at 18°S and 65 mm/a at 21°S (Taylor et al., 1996). Subduction rates of the 100-140 Ma old Pacific Plate along the Tonga Trench varies between 240 mm/a in the north and 165 mm/a in the south (Bevis et al., 1995). The southernmost part of the Lau Basin, south of 21°20′S is referred to as the Valu Fa Ridge (e.g. Jenner et al., 1987) which is propagating southward into the Miocene island arc crust at about 22°45′S (Taylor et al., 1996). The Valu Fa spreading centre extends for at least 165 km, is 5-6 km wide with ridge flanks rising about 600 m above the surrounding seafloor and only 40 km away from Ata Island, an active volcano in the Tofua island arc. Geophysical studies (e.g. Taylor et al., 1996) show that the Valu Fa Ridge is divided into three ridge sections, i.e. the southern, central and northern Valu Fa Ridge (SVFR, CVFR, NVFR) which are bounded by overlapping spreading centres. Seismic data indicate that the CFVR is underlain by a robust axial magma chamber between 22°10′ and 22°30′S which lies at 3.2 km depth and is 2-3 km wide (Collier and Sinha, 1990). This magma lens appears to be present beneath both limbs of the overlapping spreading centre at 22°10′S and beneath the overlap basin. Well-defined seismic reflectors and a large reflective coefficient as well as the flattened top of this magma lens are probably related to a low-density, highly viscous siliceous melt. A discontinuity in the seismic record towards the CVFR probably reflects thinning of the crystal mush zone and could imply that the overlapping spreading centre between CVFR and NVFR is currently the side of enhanced magmatism (Day et al., 2001).

The detailed bathymetric map of the Valu Fa Ridge between 22° and 23°S, recorded during cruise SO167 shows several seamounts situated on both sides of the ridge axis as well as south of the ridge tip (Fig. 1). The samples presented in this study come from two regions. The first group of samples were recovered on off-axis seamounts about 5 to 30 km east and west of the Valu Fa Ridge between 22°00 and 22°20′S. The second group consists of volcanic rocks sampled on seamounts south of the Valu Fa Ridge. Three of the sampled off-axis seamounts occur close to the overlapping spreading centre at 22°10′S and have been named S1-S3 (e.g. Collier and Sinha, 1992). Their shape, the generally fresh appearance of the lavas with little or no FeMn-oxy-hydroxide staining and the presence of U-excesses in some lavas (Loock, 1992) suggests that these seamounts formed by off-axis volcanism rather than by tectonic processes. Little is known about the seamounts further distant from the Valu Fa Ridge and some of them

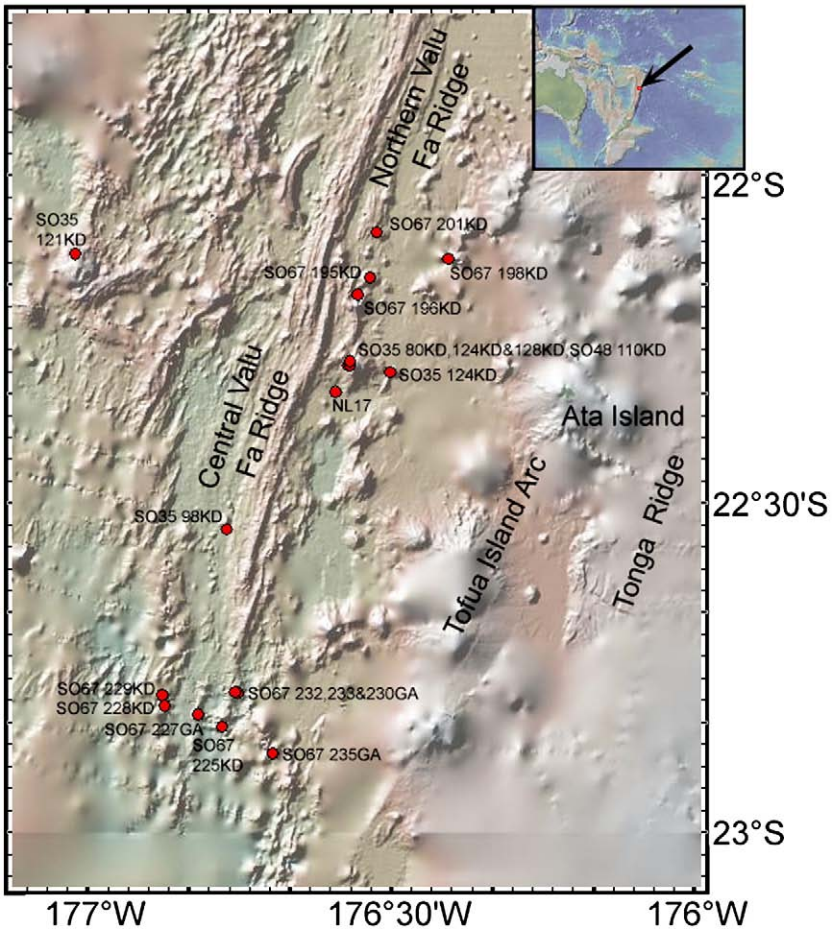

Fig. 1. Bathymetric map of the southern Lau Basin showing the location of the sampling sites on the different off-axis seamounts and the seamounts south of the propagating rift tip of the Valu Fa Ridge.