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Cretaceous fore-arc basalts from the Tonga arc: Geochemistry and implications for the tectonic history of the SW Pacific

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ABSTRACT

The Tonga fore-arc preserves a complex history of subduction initiation, back-arc basin formation and arc volcanism which has extended from the Cretaceous to the present. In this paper, we discuss the geochemistry of a Cretaceous basalt/dolerite/gabbro suite recovered in two dredges from the Tonga fore-arc at ~19°S. The geochemistry of the Tonga fore-arc suite is unlike that of the uniformly depleted MORB basalts of the subducting Pacific Plate and therefore is unlikely to be accreted from Pacific Cretaceous crust. The ~102 Ma age obtained for one Tongan fore-arc dolerite is contemporaneous with a major phase of Cretaceous subduction-related volcanism, recorded both in detrital zircon age populations and associated volcanics from New Caledonia and New Zealand. We believe that the Tonga fore-arc basalts are a remnant of a hypothesized, once extensive Cretaceous back-arc basin, called the East New Caledonia Basin, which we propose to have existed from ~102 to 50 Ma. The allochthonous Poya Terrane of New Caledonia is geochemically very similar to the Tonga fore-arc basalts and represents a younger (~84–55 Ma) remnant of the same basin. Subduction-related Cretaceous volcanics from the SW Pacific, representing both arc and back-arc settings, all appear to have similar Zr/Nb values, suggesting a common mantle component in their petrogenesis. The Tonga fore-arc basalts are also similar to fore-arc basalts recovered from the Izu-Bonin-Mariana fore-arc, but unlike these basalts they are not associated with subduction initiation.

1. Introduction

Basement terranes exposed in modern fore-arcs have the potential to preserve the tectono-magmatic record of long-lived subduction systems (Meffre et al., 2012; Stern et al., 2012). Modern fore-arcs are widely believed to be modern analogues of many ophiolite rock assemblages, thus a better understanding of fore-arc geology and tectonic history will contribute to a better understanding of not only ophiolite formation and their tectonic significance but also the overall global tectonic cycle (Stern et al., 2012). The SW Pacific is characterized by continental ridges, back-arc basins and remnant volcanic arcs formed by Mesozoic subduction, Cretaceous rifting and Cenozoic subduction (Bache et al., 2012; A.J. Crawford et al., 2003; Schellart et al., 2006; Sdrolias et al., 2003). The Tonga fore-arc, therefore, may preserve aspects of this complex evolutionary history. Indeed, Meffre et al. (2012) demonstrate via U–Pb dating of zircons that the Tonga fore-arc is composed of a number of different components ranging in age from Cretaceous to the Pliocene. A significant aspect of the data set presented by Meffre et al. (2012) is a mid-Cretaceous age (~102 Ma) from a dolerite recovered from the fore-arc at ~19°S and ~6000 m water depth. In this paper, we present the geochemistry of rocks recovered along with this dolerite sample. We suggest that the geochemistry of these rocks reveals that they represent a coherent tholeiitic back-arc basin association similar to the Cretaceous aged allochthonous Poya Terrane of New Caledonia. We propose that both the Tonga fore-arc and Poya Terrane tholeiitic rocks are possible remnants of a hypothesized once extensive Cretaceous back-arc basin referred to as the East New Caledonia Basin (Eissen et al., 1998).

2. Geological setting

Tonga is recognised as a type example of an extension-dominated non-accretionary convergent margin (Clift and MacLeod, 1999; Clift et al., 1998; Lonsdale, 1986; MacLeod, 1994; Tappin, 1994; Tappin

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et al., 1994; Wright et al., 2000; Fig. 1). The Tonga fore-arc from 14° to 26°S may be subdivided latitudinally into three major blocks, based on morphology, structure, and sediment geometry (Tappin, 1994; Wright et al., 2000):

(i) a northern block (north of ~18° 30′S, Fig. 1) lies in the deepest water, and includes small islands formed by Tofua volcanic arc volcanoes that penetrate a relatively thin sedimentary section with no preferential regional dip;
(ii) a central block (~18° 30′ to 22°S, Fig. 1) is composed of numerous small islands with a sedimentary section dipping mainly towards the east, and the Tofua volcanic arc lying on the western margin of this part of the fore-arc;
(iii) and a southern block (~22° to 26°S, Fig. 1) is entirely submarine with shallow water depths, a sedimentary section dipping westward towards the Lau Basin, and the Tofua volcanic arc against the western margin of the forearc.

During the 1996 voyage of the RV Melville rock samples were recovered by dredging of the Tonga forearc at ~19°S, located within the central block (Fig. 2; Table 1). In this area, the fore-arc displays a typical 'equilibrium' bathymetric profile and morphology resulting from tectonic erosion (Lonsdale, 1986; Raitt et al., 1955; Wright et al., 2000). A new seamount collision is developing north of the dredge locations as the Capricorn seamount enters the trench (Fig. 2). Lonsdale (1986) and Clift et al. (1998) have suggested that in contrast to the rest of the trench which is dominated by tectonic erosion, a small accretionary prism exists west of the Capricorn seamount. The trench axis here comprises a series of en echelon basins, developed as grabens on the subducting plate as it enters the trench. Locally, what is morphologically the trench axis is structurally the axis of a graben in the Pacific Plate, and the plate boundary is actually within the landward slope (Bloomer and Fisher, 1987; Hilde, 1983; Lonsdale, 1986).

The landward trench slopes in this area are steep, with prominent structural highs in the middle and lower landward slopes. These structural highs commonly define the trench slope break at about 4000 m water depth and appear to be fault blocks (Wright et al., 2000). The fore-arc in this area is dominated by strong normal faulting, as evidenced by the many large, trench-parallel scarps, most of which must have accommodated large-scale subsidence of the fore-arc and a gradual, regional tilt of fault blocks towards the trench axis (Wright et al., 2000).

During the Boomerang Leg 8 cruise of the RV Melville (May to June 1996), four dredges were conducted on the Tonga fore-arc at ~19°S (Fig. 2, Table 1). The dredges 99 and 100 recovered basalts, dolerites and gabbros from ~6000 to 7000 m water depth. The basalts include aphyric to sparsely porphyritic glassy pillow fragments as well as more massive interior parts of pillow lavas. Glass has been completely replaced by secondary minerals due to seafloor weathering; however plagioclase and clinopyroxene microphenocrysts remain relatively unaltered. Olivine when present is mostly completely altered. The dolerites are relatively fresh compared to the altered lavas. The gabbroic rocks are relatively fresh, mostly isotropic equigranular gabbros with minor amounts of orthopyroxene. A dolerite from dredge 100 (sample 100-1-40, Table 2) was found to contain interstitial zircons which gave a U–Pb crystallization age of 102.4 ± 4.5 Ma (Meffre et al., 2012). Although it was only possible to date this single sample, we consider that the rocks recovered from dredges 99 and 100 are all most likely sampled from the same basement unit, both due to the close proximity of the two dredges and the geochemical coherence of the rocks taken as a group (as discussed below).

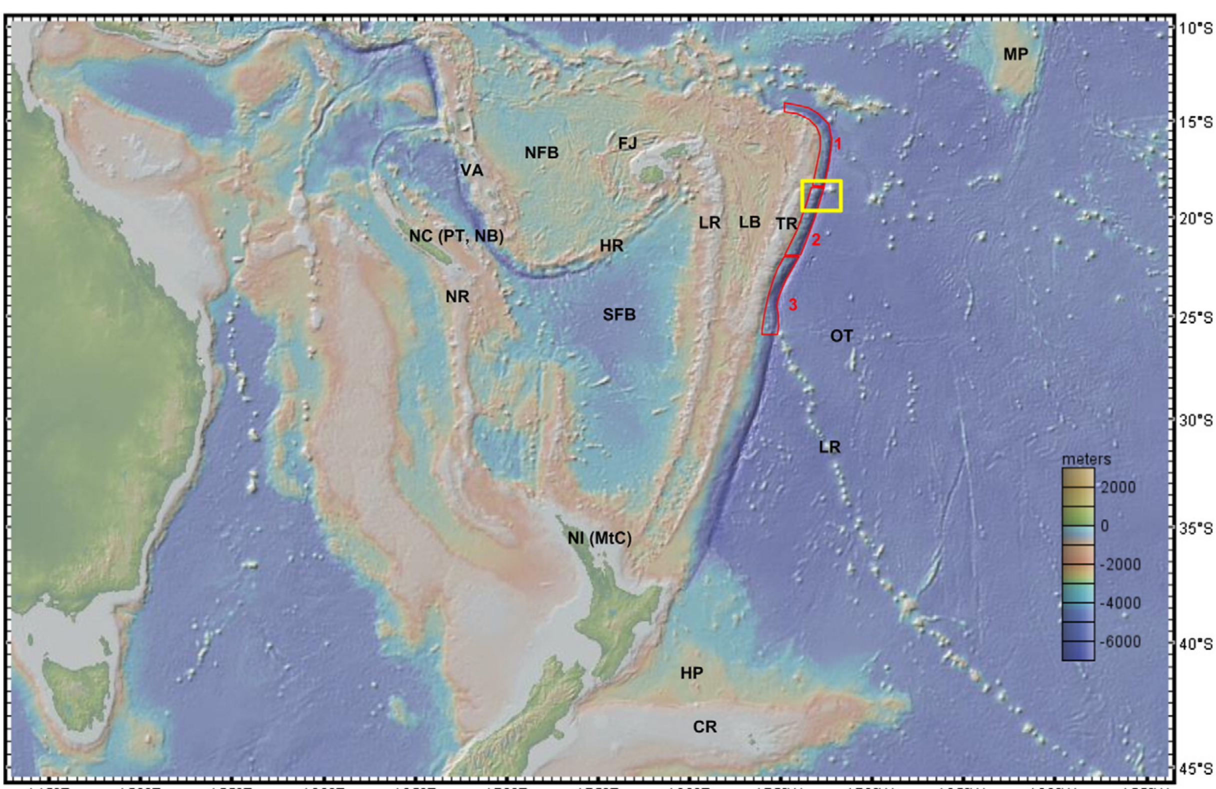

Fig. 1. Regional bathymetry of the SW Pacific showing the location of the Tonga fore-arc and trench (bathymetry created using geomap app; Ryan et al., 2009, http://www.geomapapp.org). Yellow square outlines the area of Fig. 2. Red polygons numbered 1 to 3 refer to the distinct structural blocks of the Tonga fore-arc and trench as defined by Wright et al. (2000) (see text for discussion). Bold text show the relative positions of geographical entities mentioned in the text as follows: NFB = Northern Lau Basin; VA = Vanuatu Arc; FJ = Fiji; HR = Hunter Ridge; NC (PT, NB) = New Caledonia and the Poya Terrane and Noumea Basin (for a more detailed location of the Poya Terrane and Noumea Basin, the reader is referred to Nicholson et al., 2011); NR = Norfolk Ridge; SFB = South Fiji Basin; LR = Lau Ridge; LB = Lau Basin; TR = Tonga Ridge: NI (MtC) = Northland, North Island New Zealand and the Mount Carmel Terrane (for a more detailed location of the Mt Camel Terrane the reader is referred to Nicholson et al., 2008); HP = Hikurangi Plateau; CR = Chatham Rise; LR = Louisville Ridge; OT = Osbourn Trough; MP = Manihiki Plateau (web & print).