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Volcanic successions in Marquesas eruptive centers: A departure from the Hawaiian model

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ABSTRACT

The temporal evolution and geochemical evolution of Marquesas hotspot volcanoes have often been interpreted with reference to the Hawaiian model, where a tholeiitic shield-building stage is followed by an alkali basaltic post-shield stage, followed after a 0.4 to 2.5 Myr long quiescence period, by a rejuvenated basanitic/nephelinitic stage. Here we discuss geochemical data on 110 Marquesas lavas also dated using the unspiked ^{40}K–^{40}Ar method on separated groundmass (including 45 new ages measured on the southern islands of Hiva Oa, Motane, Tahuata and Fatu Hiva). Sample locations were positioned on detailed geological maps to determine their shield or post-shield position with respect to the caldera collapse event(s), without taking into account their geochemical features. A rather regular decrease of the ages towards SE, consistent with the Pacific plate motion, is observed from Eiao (5.52 Ma) to Fatu Hiva (1.11 Ma), and rejuvenated basanitic volcanism occurs only in Ua Huka (1.15–0.76 Ma). The occurrence of intermediate and evolved lavas is restricted to the post-caldera stage, with the exception of Eiao island. However, many other features of the Marquesas chain are rather atypical with respect to those of Hawaii. Although Marquesas shields are tholeiitic, several of them (Eiao, Tahuata) contain interbedded alkali basaltic and basanitic flows. Moreover, post-shield volcanoes are either alkali basalts (Ua Huka), tholeiites (Hiva Oa, Tahuata, Fatu Hiva) or both (Nuku Hiva). This feature is consistent with the temporal continuity of the two stages and the usually short length of the post-shield period (<0.2 Myr). In a given island, the trace element and isotopic compositions of shield and post-shield lavas overlap, although both display large variations. The sources of alkali basalts and basanites are more enriched than those of the contemporaneous tholeiites. These specific features support the hypothesis of an extremely heterogeneous Marquesas plume. The "weak" character of this plume led to low partial melting degrees, which in turn resulted in the preservation in the basaltic magmas of geochemical features inherited from small-size source heterogeneities.

1. Introduction

The temporal evolution of plume-related oceanic intraplate volcanoes has often been investigated with reference to the classical Hawaiian model, in which four successive growth stages are distinguished (Clague, 1987; Clague and Dalrymple, 1987; Hanano et al., 2010): (1) a small volume (ca. 3%) alkalic pre-shield stage, emplacing mostly submarine alkali basalts and basanites; (2) the main shield-building stage, during which the majority (95–98%) of the volcano is rapidly constructed, culminating in subaerial flows of tholeiitic basalts; (3) the alkalic post-shield phase, during which small volumes (1–2%) of alkali basalts and related intermediate/evolved lavas (hawaiites, mugearites, benmoreites and trachytes) are erupted; and finally (4) the alkalic rejuvenated stage, during which very small volumes $\ll$1%) of basanites, alkali basalts and nephelinites are emplaced after a quiescence period. In the Hawaiian chain, shield tholeiitic basalts are less enriched in incompatible elements and derive from larger melting rates than the post-shield and rejuvenated alkalic lavas; in addition, the mantle sources of the latter are isotopically depleted with respect to those of

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the tholeiites (lower $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$, higher $^{143}Nd/^{144}Nd$: Frey et al., 1990, 2005; Shafer et al., 2005; Fekiacova et al., 2007; Garcia et al., 2010; Hanano et al., 2010).

For Hawaiian volcanoes, the main criterion used for the distinction between the shield-building and post-shield stages is the change from tholeiites to alkali basalts. Indeed, Clague and Dalrymple (1987) stated (their page 7) that "the shield stage usually includes caldera collapse and eruptions of caldera-filling tholeiitic basalt. During the next stage, the alkalic postshield stage, alkalic basalt also may fill the caldera and form a thin cap of alkalic basalt and associated differentiated lava that covers the main shield". They also mentioned (their page 8) that "we have omitted the main caldera-collapse stage of Stearns (1966) from the eruption sequence because it can occur either during the shield stage or near the beginning of the alkalic postshield stage. The lava erupted may therefore be tholeiitic or alkali basalt, or of both types".

Large major, trace element and isotopic variations in Marquesas lavas have been known for decades (Vidal et al., 1984; Duncan et al., 1986; Vidal et al., 1987). They have been interpreted with reference to the shield/post-shield Hawaiian model by several authors (Duncan et al., 1986; Woodhead, 1992; Desonie et al., 1993; Castillo et al., 2007). However, most of these works were based on the pioneer (and hence limited) sampling of Marquesas Islands made during the 1970s by R.A. Duncan (Duncan and McDougall, 1974; Duncan, 1975; McDougall and Duncan, 1980) and R. Brousse (Vidal et al., 1984; Brousse et al., 1990). No geological maps of the islands were available at that time, and therefore the distinction between shield and post-shield lavas was usually made using geochemical criteria. For instance, the observation that the oldest lavas from Nuku Hiva, Ua Pou and Hiva Oa are tholeiitic basalts (Duncan, 1975; Duncan et al., 1986) led Woodhead (1992) to classify hypersthene-normative Marquesas lavas as shield-related and alkali basalts/basanites as post-shield. Later, Castillo et al. (2007) studied samples collected by H. Craig, and used $^{87}Sr/^{86}Sr$ (>0.7041) and $^{143}Nd/^{144}Nd$ (<0.51285) ratios to characterize post-shield lavas, based on the isotopic data of Woodhead (1992) obtained on R.A. Duncan's samples.

A mapping program of the Marquesas archipelago (2001–2009) led us to collect a number of new samples and draw detailed geological maps of the islands. The trace element and Sr, Nd, Pb and Hf isotopic features of these samples (Chauvel et al., 2012) point towards relationships between shield and post-shield lavas more complex than previously thought. Here, we use geological settings combined with unspiked $^{40}K–^{40}Ar$ ages measured on groundmass and petrologic/geochemical features of this new sample set to demonstrate that the temporal evolution of the Marquesas volcanoes is rather different from that of Hawaiian volcanoes. We also discuss the constraints that they set on the corresponding plume/hotspot model.

2. Geological setting and previous work

2.1. The Marquesas archipelago

The ca. 350 km-long Marquesas archipelago, located in northern French Polynesia, includes eight main islands (Fig. 1) that cluster into a northern group (Eiao, Nuku Hiva, Ua Huka and Ua Pou) and a southern group (Hiva Oa, Tahuata, Motane, Fatu Hiva); few islets ("motu"), banks and seamounts also exist (Fig. 1). The age of the islands decreases towards the SE (Duncan and McDougall, 1974; Brousse et al., 1990) from 5.5 Ma in Eiao to 0.6–0.35 Ma on the DH12 seamount south of Fatu Hiva (Desonie et al., 1993). However, no active volcanoes are known at the southeastern edge of the chain. $^{40}K–^{40}Ar$ ages younger than 1 Ma have been obtained only on DH12 and on the Teepoepo (1.15–0.96 Ma) and Tahoatikikau (0.82–0.76 Ma) strombolian cones on Ua Huka (Legendre et al., 2006; Blais et al., 2008). These cones were emplaced after a 1.3 Myr quiescence period, and are considered as the only example of rejuvenated volcanism in the Marquesas (Legendre et al., 2006; Chauvel et al., 2012). Most authors believe that the Marquesas Fracture Zone (MFZ; Pautot and Dupont, 1974) overlies the present position of the hotspot activity (McNutt et al., 1989; Brousse et al., 1990; Guille et al., 2002). However, the MFZ is aseismic (Jordahl et al., 1995) and no young volcanic rock has been recovered from the adjacent Marquesas Fracture Zone Ridge (MFZR; Fig. 1). The seamount chain parallel to the MFZ ridge ca. 50 km to the north (Fig. 1) has not yet been dredged and it could possibly mark the present location of Marquesas hotspot activity.

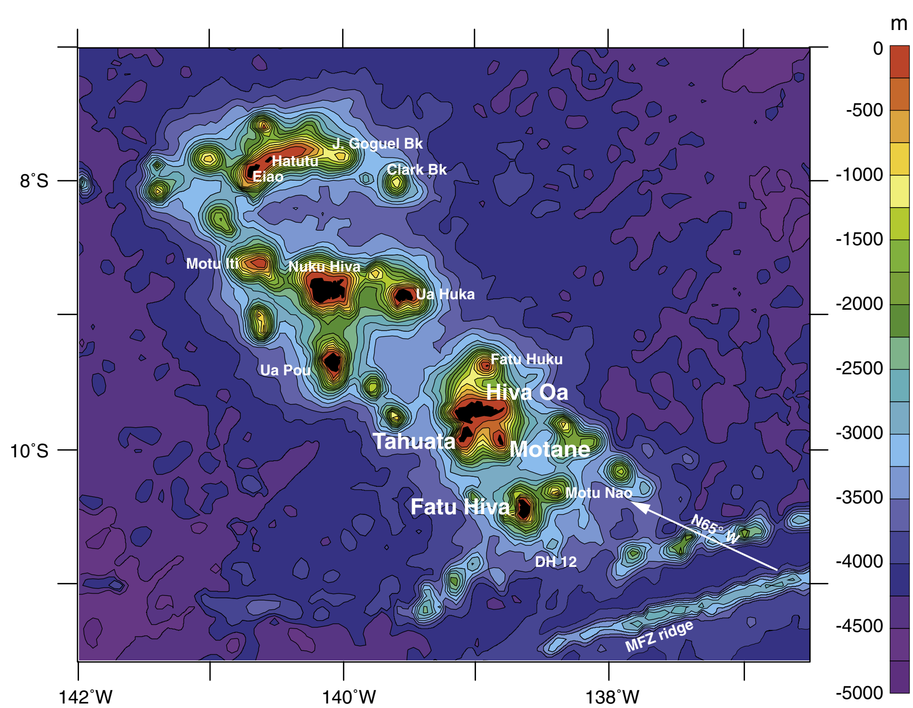

Fig. 1. Location map of Marquesas Islands. The bathymetry comes from the global altimetry data set of Smith and Sandwell (1997). The main trend of the Marquesas chain is N40W. Current Pacific plate motion is 10.5 cm/yr at N65W, corresponding to the line shown in white. The names of the southern islands are in large print. MFZ: Marquesas Fracture Zone.

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