Temporal geochemical evolution in oceanic intra-plate volcanics: a case study from the Marquesas (French Polynesia) and comparison with other hotspots

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Abstract. Sr-, Nd-isotopic and trace element data are reported for a suite of Marquesan volcanic rocks. These data complement earlier work on the island of Ua Pou and reveal that the marked shifts in source composition between shield-building and post-shield eruptives noted there are common to most islands in the archipelago. In addition, there appears to be a relationship between the magnitude of these shifts and the repose period between shield-building and post-shield activity such that, the longer the period of volcanic inactivity, the larger the isotopic and trace element differences between the two phases of volcanism. This, coupled with the compositional uniformity of the shield-building phase, and its close geochemical similarity to depleted mantle reservoirs, implies a strong lithospheric control on magmatic evolution: models invoking entrainment of asthenospheric material during plume ascent are not readily compatible with the observed time-compositional paths. Comparisons with other oceanic islands reveal two ‘end member’ styles of temporal evolution, herein termed ‘Marquesan’ and ‘Hawaiian’, and attributed to the interaction between the oceanic lithosphere and respectively weak and strong plumes, terms used to denote penetrative capacity and not necessarily size or buoyancy flux. Many other plumes may display characteristics intermediate between these extremes. The state of stress and temperature within the oceanic lithosphere in the region of an ascending diapir is also likely to exert a strong control on the geochemical evolution of OIB suites.

Introduction

The geochemical characteristics of most ocean island basalt (OIB) suites can be interpreted in terms of multicomponent mixing processes involving up to five distinct end-members (e.g. White 1985; Zindler and Hart 1986). However, many recent studies of OIB show considerable structure in the data for individual islands and, in particular, often reveal an apparent temporal shift in source composition, as revealed by isotope and trace element analyses, between shield-building and post-shield phases of volcanism: for example, a geochemical study of the island of Ua Pou in the Marquesas (Duncan et al. 1986). In the case of the Marquesas, considerable debate has focused on the question of whether such changes reflect the influence of distinct plume sources (e.g. Dupuy et al. 1987) or the interaction of a single plume with the oceanic lithosphere or asthenosphere (e.g. Duncan et al. 1986). In the present study, new isotope and trace element data have been obtained on Marquesan samples for which a detailed K-Ar chronology is already available. These have then been combined with existing data, collated from the literature, to provide a synthesis of the geochemical evolution of the Marquesan chain, thus allowing comparison with other oceanic intra-plate settings.

Geology and previous work

The Marquesas comprise a group of 12 volcanic islands and associated seamounts which rise as discrete volcanic edifices from oceanic crust of Palaeocene age in the south central Pacific (Fig. 1). The group stretches northwesterly from Fatu Hiva (10°35′ S 138°35′ W) to Hao (8°00′ S 141°27′ W) in an approximately linear arrangement, sub-parallel to the other volcanic archipelagos of the region. Most of the islands are small but often attain heights in excess of 1000 m, with rugged relief.

Early accounts of the geology of the Marquesas are provided by Lacroux (1928), Chubb (1930) and Obellianne (1955), while, more recently, major and trace element data have been published by Bishop and Woolley (1973), Brousse and Guille (1978), Brousse et al. (1978) and Liotard et al. (1986). Trace element, isotopic, and geochronological studies have been provided by Duncan and McDougall (1974), Vidal et al. (1984), Duncan et al. (1986), and Dupuy et al. (1987). These papers reveal a considerable trace element and isotopic heterogeneity within the Marquesan lavas which is comparable to, if not greater than, that observed in most other OIB suites.
K-Ar geochronology of subaerial lavas (Duncan and McDouggall 1974) shows a general age progression to the southeast implying a plate migration rate of ~9.9 cm/yr, although some marked irregularities in this general trend seem to occur e.g. volcanic activity at Ua Pou spans most of the range noted in the other islands (Fig. 1c). In common with many other oceanic islands, the initial shield-building phase of volcanism is often separated from post-shield activity by a hiatus, during which erosion of the volcanic edifice can occur and, in addition, a detailed isotopic study of Ua Pou has shown that, on this island, the shield-building and post-shield volcanics also appear to have very distinct sources (Duncan et al. 1986). Coupled with these variations is a pronounced increase in alkalinity with time throughout the archipelago, which is largely attributed to a steady decrease in the degree of partial melting (Vidal et al. 1984; Liotard et al. 1984).

**Analytical techniques**

Samples analyzed in this study are a subset of those collected for K-Ar geochronology by Duncan (1975); sample locations and major element analyses can be found in this reference. Trace element concentrations were determined at the Department of Earth Sciences, Oxford by X-ray fluorescence techniques on pressed powder pellets, using a Philips PW1400 spectrometer with data processing by PDP11 minicomputer. Calibration lines were constructed using up to 25 recommended USGS standards. Details of counting times, operating conditions and detection limits can be found in Woodhead (1987). Precision is generally better than 5%. Uranium concentrations were determined by isotope dilution and precision, based upon duplicate sample dissolutions, is estimated to be better than 1%.

Sr and Nd were separated at the Australian National University by conventional ion exchange techniques on 100 mg samples, after a brief 6N HCl wash to remove any potential surficial contaminants; chemical and loading blanks are negligible. Uranium samples were separated on anion exchange columns in 7N HNO₃, the U eluted in H₂O. Sr and Nd samples were run on single Ta and Re-Ta double filaments respectively; uranums were run on single Ta filaments with H₃PO₄ (as for Sr). All isotope ratio determinations were performed on a Finnigan MAT 261 mass spectrometer used in static multi-collector mode.

$^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$ and $^{144}\text{Nd}/^{144}\text{Nd}=0.7129$ respectively. Over the course of this study analysis of NBS 987 Sr standard and the La Jolla Nd standard provided mean values of $^{87}\text{Sr}/^{86}\text{Sr}=0.710208\pm0.000004$ and $^{143}\text{Nd}/^{144}\text{Nd}=0.511869\pm0.000002$ respectively. 2σ precision in Table 1 refers to within-run statistics.