Time-scales and mechanisms of geochemical fluctuations in the Piton de la Fournaise volcano, Réunion Island

F. Albarède *Ecole Normale Supérieure de Lyon*
P. Bachelery *Université de la Réunion*
J.G. Fitton *University of Edinburgh*
J.L. Joron *Laboratoire P. Sue, Saclay*
E. Kaminski *Ecole Normale Supérieure de Lyon*
B. Luais
M. Semet *IPG Paris*
B. Upton *University of Edinburgh*

Introduction

Le Piton de la Fournaise (Réunion Island, Indian Ocean) is a major shield volcano which has been active for more than 500 ka. In order to understand the basic features controlling the dynamic of mass transfer between the mantle and the volcanic system, a systematic geochemical investigation of the eruptive history of the volcano has been undertaken within the frame of the INSU/EEC program on the Réunion island. Three time-windows were investigated: (a) individual historical eruptions over the 1915–1991 interval with particular emphasis on hardly accessible cones from the Grandes Pentes (b) 32 lava flows cored at nearly regular intervals in the 1000 m high cliff of Riviere des Remparts (RR) with K–Ar ages extending over 250–500 ka, and (c) 24 lava flows cored in the upper 500 meters of the Morne Langevin cliff and aged 50–100 ka.

Techniques

The samples were analysed by istope dilution-ICPMS (Montpellier), INAA (Saclay), and XRF (Edinburgh) for major and trace elements. Combined with electron probe analyses on each sample, modal phenocryst abundances can be estimated. In order to assess possible source heterogeneities, strontium isotope compositions were determined on the Isomass 54E of Clermont-Ferrand.

Petrology

As found by previous studies, historic lavas are alternating phenocryst-poor basalts and olivine-rich basalts (picrites) with transitional characters. Several occurrences of disagregating inclusions and mineral clusters complement the microscopic observation of multiple generations of dislocations in olivine, thus supporting the largely xenocrystic origin of this mineral in picrites. The mineralogy of the ancient basalts is only partly similar to the modern rock types. Occurrence of clinopyroxene-rich lavas (oceanites), only known as pebbles until now, was located at mid-height in the RR cliff. Highly differentiated lavas (hawaiites and mugearites) are found at an elevation of ~ 1200 m. The lowermost part of the RR section consists of plagioclase-rich lavas.

Geochemistry

Nearly constant ratios of very incompatible elements (VI = Th, Ta, Nb, La) confirm earlier findings of a rather homogeneous source. Variations of the $^{87}Sr/^{86}Sr$ ratios are small (0.70392–0.70415) and show little correlation with incompatible element ratios. In contrast, the RR section shows a conspicuous correlation between the ratios of compatible and moderately compatible (MC = Sc, Zr, Hf, Tb, Yb) to VI elements and the CaO/Al_2O_3 ratios indicative of strong clinopyroxene/ liquid fractionation. We believe that the enrichment of Eu relative to Eu* when the CaO/Al_2O_3 ratio decreases also reflects the removal of substantial amounts of cpx. The extent of MC/VI ratio variations (>50% for Sc/Ta, >20% for Zr/Th) may be explained by massive (>40%) removal of cpx plus minor amount of olivine. Alternatively, these ranges could reflect few percent variations in the degree of melting. Large variations of the CaO/Al_2O_3 ratio tend, however, to support the hypothesis of massive cpx fractionation.

The historical series opposes periods of increasing fractionation (1938–1986) and replenishment by less differentiated basalts (1931–1936 and 1986–1991). Replenishment seems to be associated with higher eruption rates (0.45 m^3/s) and major collapse events. Rapid chemical fluctuations indicate short magma residence times (< few years) incompatible with large size intermediate reservoirs.

Discussion mechanisms of magma differentiation

It is suggested that lavas continuously ascend through the lithosphere forming veinlets with continuous deposition of a cpx veneer on the walls. Thin magma conduits have stronger hydrodynamic resistance and loose more heat to the walls. They are therefore prone to more extensive mineral fractionation. Assuming that large magma conduits form at the expense of thinner ones, extensive fractionation must take place at deep lithospheric levels rather than in superficial reservoirs. These conditions explain why chemical data seem to require large amounts of clinopyroxene and no plagioclase on the liquidus of Réunion basalts. The cpx veneer isolates the magma from interacting with the lithospheric depleted mantle thus preserving the plume isotopic signature. Underestimated cpx fractionation may explain why experiments on ol-saturated basalts have failed to reproduce phase equilibria indicated by trace elements. A mass of pyroxenite roughly equivalent to that of the entire edifice should be seismically observable in the lithospheric mantle underlying the volcano.