

Origin and evolution of Mount Etna magmatism: isotope constraints

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Introduction

The origin and evolution of magmatism in Mt. Etna region, the largest active volcano in Europe, are still unclear. While the occurrence of subducted lithosphere is supported by geophysical and petrological data further north and east beneath continental Italy, there is no clear evidence that subducted lithosphere occurs beneath Etna itself and most of Etna's volcanic characteristics are more suggestive of intraplate or hotspot than subduction-related volcanism. The volcanic products display a temporal trend from early emission of tholeiitic lavas to later emission of alkali basalts, reminiscent of the well-known tholeiitic-alkali transition in Hawaii. However, Etna differs from large intra-oceanic volcanoes in that it occurs above approximately 30 km of continental crust plus sediments. Based on several isotopic tracers (He, Ar, O, Sr, Nd) examined in rock samples from throughout Etna's history, we evaluate the nature of magma and volatile sources and constrain the role of geochemical heterogeneities by examining the temporal evolution of erupted volcanic products.

Results

Helium. He analyses performed by crushing cogenetic pyroxene and olivine phenocrysts show a tendency to lower $^3\text{He}/^4\text{He}$ ratios in pyroxenes. This is best explained by crystallization of pyroxenes at a depth shallower than that of olivines and/or by exchange of helium trapped in pyroxenes with atmospheric or radiogenic He before eruption. The near-constancy of the isotopic compositions of oxygen ($\delta^{18}\text{O} = 5.4 \pm 0.3\text{‰}$) and of helium trapped in olivine phenocrysts (6.7 ± 0.4 Ra), despite significant

changes in the volcano structure, petrological variations of Etnean lavas, Sr isotope evolution (Figure 1) and recent alkali enrichments argues against models which invoke the contribution of geodynamically diverse mantle sources [1] but is in agreement with the evolution from a single source [2].

$\text{C}/^3\text{He}$ ratios in emanations and lavas between 0.9×10^9 and 5.8×10^9 are within the range of MORB and hot spot values and in the lower end of typical values recorded at subduction zones. $\delta^{13}\text{C}$ values of Etnean volcanic gases [3] are similar to the range recorded in mantle-derived C samples, and above the $\delta^{13}\text{C}$ range of carbonate rocks and we tentatively favour a deep, volatile-rich source rather than a contribution from the sedimentary sequences underlying the volcanic edifice, as sometimes proposed in order to account for the exceptionally high CO_2 plume flux recorded at Mount Etna [3].

Argon. $^{40}\text{Ar}/^{36}\text{Ar}$ ratios vary between the air value of 295.5 and 444, and the Etnean $^3\text{He}/^{36}\text{Ar}$ ratios are closer to those of air (2.32×10^{-7}) than those of Loihi seamount (3.0×10^{-2}) or MORB (3.6) [4]. Atmospheric addition appears to have preferentially affected the shallower crystallizing pyroxene samples, which all have lower $^3\text{He}/^{36}\text{Ar}$ ratios than cogenetic olivines. Given the low Ar isotopic ratios measured in olivine crystals, some of which were formed at 11 ~ 24 km depth, it follows that atmospheric contamination must have also occurred to at least these depths. The computed initial magmatic ^{36}Ar content admits a lower limit of $\sim 10^{-11}$ mol/g and requires an extensive contribution of atmospheric argon in the source region, together with a selective enrichment (metasomatic ?) process.

Strontium. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios show a remarkable increase through time, which is not accompanied

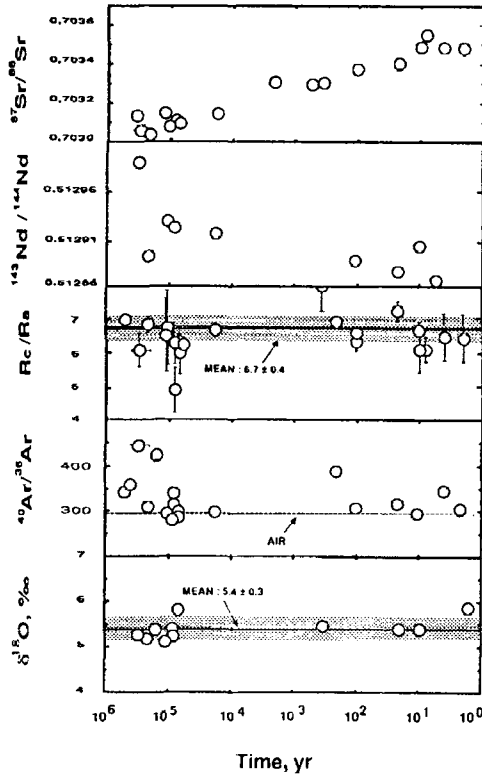


FIG. 1. Temporal variations of Sr, Nd, He (olivine), Ar (olivine) and O isotopic compositions from 0.5 Myr to present.

by a correlated shift of Nd, O, or He isotopic ratios (Figure 1). He mobility in mantle minerals appears too low to allow homogenization of He isotopes over the probable kilometre length scales of magma sources, given the lifetime of magmatism in this region. Thus, the constancy of the $^3\text{He}/^4\text{He}$ ratio implies that the mantle source was homogeneous on the scale of melting, or that some fluid-mediated homogenisation took place, which would also be expected to have homogenised the Sr isotope ratios, and the contrasting behaviour of Sr and He isotopes appears to rule out mantle source heterogeneity as a cause of Sr isotopic variations. Sr isotope variations could also be the result of shallow assimilation but the lack of co-variations between REE fractionation (e.g., Ce/

Yb) and $^{87}\text{Sr}/^{86}\text{Sr}$ shift does not support the occurrence of a AFC-type process. Another possibility is selective contamination of strontium by sediments underlying Mount Etna as has been proposed for alkali elements on the basis of a Rb/Th ratio variations [5]. We observe a good correlation between Sr isotope and Rb/Th ratios which is regarded as resulting from selective contamination of the magma en route to the surface by sedimentary flysh material.

Discussion

This study shows that selected isotopic tracers have recorded two types of processes, those related to source(s) effects (O, He in olivine) and those related to interactions of the magma en route to the surface (He in pyroxene, Sr). The nature of the magma source can be precised from the He isotopic composition. A recent study of He isotopes in continental xenoliths from Tertiary-Quaternary volcanic regions of Western Europe by Dunai and Baur [6] has shown a striking uniformity of $^3\text{He}/^4\text{He}$ ratios within 6–7Ra when radiogenic and cosmogenic contributions are filtered. The observation that the Etnean mean $^3\text{He}/^4\text{He}$ ratio falls within the same range suggests that the nature of the sampled geochemical reservoir by Mount Etna magma is the subcontinental mantle, having a well defined He isotopic composition in Western Europe.

This study was partly funded by the Commission of the European Community, Environment Programme, contract EV5V-CT92-0177.

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