

# Systematics of $^{238}\text{U}$ - $^{230}\text{Th}$ - $^{226}\text{Ra}$ in primitive lavas from the 1730–36 eruption on Lanzarote, Canary Islands, and implications for oceanic basalt formations

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The differences in petrogenesis of alkaline and subalkaline basalts have classically been explained by smaller partial mantle melting at greater depths for the former. The peculiar 1730–36 eruption of Lanzarote, Canary Islands, produced variable magma composition with time from basanites through alkaline basalts to olivine tholeiites. All the lavas are of primitive composition and frequently contain ultramafic xenoliths, which suggest an absence of a magma chamber at depth. This eruption is a particularly interesting application of U-Th-Ra disequilibria since its duration is well defined, magma composition varied considerably over the 6 years, and the lavas were of an often extremely primitive nature. Thus the behaviour of the U-series nuclides in near-primary melts over a fixed period was observable.

## Lanzarote

Abundances of Ba, Th and U generally decreased towards the end of the 1730–36 eruption, and show more than four-fold variations (e.g. Th = 5.75 - 1.55 ppm). Ba/Th and Ba/U vary by more than 75%, whereas Th/U vary by less than 10%. Excesses of  $^{230}\text{Th}$  over  $^{238}\text{U}$  range from 18% to 33% and generally increase with alkalinity. ( $^{230}\text{Th}/^{232}\text{Th}$ ) decreased significantly from 1.02 to 0.94 with time and is positively correlated with the alkalinity of the lavas. Isotope ratios of Sr and ( $^{226}\text{Ra}/^{232}\text{Th}$ ) also correlate with  $\text{SiO}_2$ . ( $^{226}\text{Ra}/^{232}\text{Th}$ ) increased with time from 1.10 to 1.72 at the end of the eruption.

The first lavas erupted in 1730 have higher incompatible trace element abundances,

( $^{230}\text{Th}/^{232}\text{Th}$ ) and ( $^{230}\text{Th}/^{238}\text{U}$ ) and lower  $^{87}\text{Sr}/^{86}\text{Sr}$  relative to the subsequently erupted lavas, suggesting minimal interaction with the lithosphere beneath the Lanzarote. Excess  $^{226}\text{Ra}$  is not readily explained by partial melting alone but could reflect fluid addition to the mantle source. In order to conserve the systematic variations of Ra-Th disequilibria with other geochemical variables, transfer time through the lithosphere is likely to have been short relative to the half-life of  $^{226}\text{Ra}$ . A magma velocity through the lithosphere on the order of  $10^{-5}$  m/s (0.5 km/year) is compatible with the data.

The correlations between ( $^{230}\text{Th}/^{232}\text{Th}$ ),  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $\text{SiO}_2$  suggest that the lava compositions represent nearly unmodified primary melts from a lithologically and compositionally heterogeneous mantle source. A source composed of garnet pyroxenites appears instrumental in the production of the early alkaline basalts, whereas melting of a source containing less garnet (garnet lherzolite) produced the tholeiites. Both the Th-U disequilibria and the Th-isotope ratios are clearly related to the mantle source lithology and composition. Furthermore, correlations are observed between ( $^{230}\text{Th}/^{238}\text{U}$ ) and ( $^{232}\text{Th}/^{238}\text{U}$ ) in mafic lavas from different volcanic provinces worldwide.

## Garnet pyroxenites and Th-U fractionation

Results from the literature on oceanic basalts reveal strong positive correlations between ( $^{230}\text{Th}/^{238}\text{U}$ ) and ( $^{232}\text{Th}/^{238}\text{U}$ ) for individual volcanic provinces (Fig. 1). This is the case for Lanzarote, Hawaii, non-crustal contaminated Icelandic basalts and MORB away

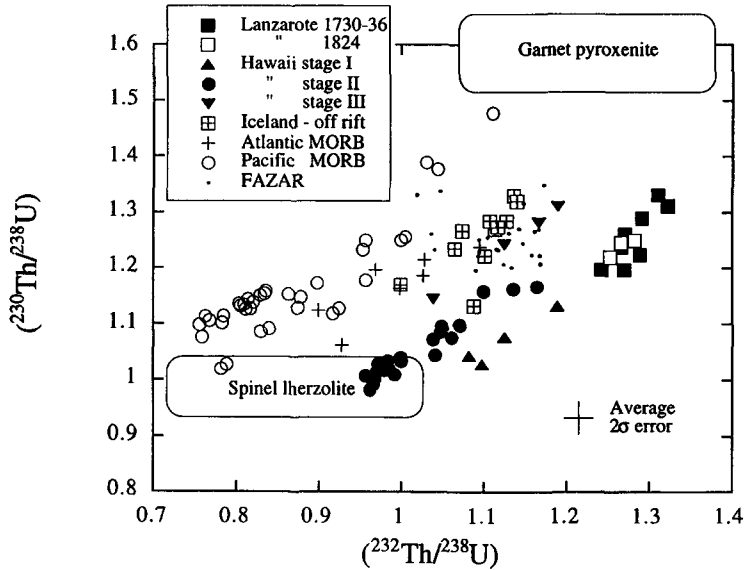


FIG. 1.

from hot-spots, with MORB having lower Th/U than OIB for a given  $^{230}\text{Th}$  excess. Individual ridge segments from the Pacific Ocean show much stronger correlations than the pooled results in Fig. 1. Correlations between  $(^{230}\text{Th}/^{238}\text{U})$  and  $(^{232}\text{Th}/^{238}\text{U})$ , therefore, exist both locally and globally.

The linear correlations in Fig. 1 could, in principle, result from different melting degrees of a homogeneous source. In that case, a very recent or zero-age fractionation of U and Th would produce magmas whose  $(^{230}\text{Th}/^{238}\text{U})$  and  $(^{232}\text{Th}/^{238}\text{U})$  would form a straight line with a slope of 1 passing through the origin. However, more than a half of the linear correlations in Fig. 1 have slopes exceeding unity, which in addition to the fact that many of the samples have  $^{226}\text{Ra}$ -excesses, precludes them from being isochrons. Furthermore, most of the volcanic regions show variable Sr- and Th isotope compositions. Hence, these correlations cannot represent different melting degrees of a homogeneous mantle, but could be mixing lines between different mantle sources or their melts.

Results from Hawaii clearly define three arrays in Fig. 1 corresponding to the different evolutionary stages of the volcanoes. The pre-shield stage (I) samples come from Loihi and South Arc. Samples from the shield stage (II) volcanoes are from Kilauea, Mauna Loa and Hualalai. Only one sample from the post-shield stage (III) at Mauna Kea has been

analysed for U-Th isotopes, and three samples from Haleakala which may be at the transition between stage III and the final post-erosional stage (IV). Decreasing Th/U and increasing  $(^{230}\text{Th}/^{232}\text{Th})$  correlates with a generally decreasing  $^3\text{He}/^4\text{He}$  from stage I to stage III-IV.

Samples of non-crustal contaminated basalts from Iceland and those from the MAR close to the Azores (FAZAR) have intermediate Th/U between those of MORB and OIB. The FAZAR samples show no clear correlation between  $(^{230}\text{Th}/^{238}\text{U})$  and  $(^{232}\text{Th}/^{238}\text{U})$ , but plot between MORB and results from Sao Miguel in the Azores. Interaction between MORB and hot-spot sources is likely at both these localities.

Increasing  $(^{232}\text{Th}/^{238}\text{U})$ , or Th/U, for a given  $^{230}\text{Th}$  excess, correlates with decreasing  $(^{230}\text{Th}/^{232}\text{Th})$  and increasing  $^{87}\text{Sr}/^{86}\text{Sr}$  or mantle heterogeneity. Therefore,  $(^{230}\text{Th}/^{238}\text{U})$  and  $(^{230}\text{Th}/^{232}\text{Th})$  variations in oceanic basalts may primarily reflect variable mantle source composition, both on a local and a global scale. Most of the  $^{230}\text{Th}$ - $^{238}\text{U}$  disequilibrium could result from alkalic melts of garnet pyroxenite and the observed  $(^{230}\text{Th}/^{238}\text{U})$  in the lavas would depend largely on the degree of dilution by subalkalic melts of the generally lherzolitic mantle source. Important melting of a depleted source composed of spinel lherzolite would produce melts with  $^{238}\text{U}$ - $^{230}\text{Th}$  closer to equilibrium.