

The geochemistry of Mangaia (Cook Islands) and evaluation of the recycling model for the origin of the HIMU OIB signature

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Introduction

The volcanic hills of Mangaia, the second largest and most southerly of the Cook Islands, have been subjected to extensive tropical weathering over a period of some 20 Ma and are deeply eroded: only in the deeper stream valleys are small outcrops of relatively fresh volcanic material exposed. The few available analyses of volcanic rocks from Mangaia, however, reveal the most radiogenic Pb isotope ratios known in the ocean basins (with $^{206}\text{Pb}/^{204}\text{Pb}$ ratios of up to 22), forming the most extreme example of the so-called 'HIMU' mantle component (Zindler and Hart, 1989) known at the present time. Although the isotopic characteristics of HIMU mantle sources are well known, there are relatively few comprehensive trace element studies, especially those in which isotope determinations have been performed on the same samples. This gap in the literature for one of the most important of oceanic islands prompted the current study in which full trace element and isotope analyses are presented for a new collection of samples from Mangaia.

Temporal variation in the Mangaia plume

The radiogenic Pb signature observed in the islands of Mangaia, Tubuai and Rurutu ($^{206}\text{Pb}/^{204}\text{Pb} > 20$), is absent or poorly developed in the other Austral and Cook islands. Nakamura & Tatsumoto (1988) considered the possibility that this feature developed relatively recently, but as no direct correlations were observed between Pb isotopic composition and K-Ar ages for individual lavas they concluded that HIMU must be an ancient source signature. K-Ar ages for individual volcanic rocks, however, date eruption processes (at best) and do not necessarily bear any relation to plume dynamics. It is more useful to consider geochemical changes in relation to the best estimate for the initiation of volcanism at each island, which is essentially the oldest reliable K-Ar date obtained from the lavas of any particular island.

The use of this parameter provides very good correlations with Pb isotope ratios, indicating, in

contrast to the findings of Nakamura and Tatsumoto (1988), that there is a clear shift in Pb isotopic composition with time within both the Austral-Mangaia and Cook Island groups, such that older islands display relatively more radiogenic values. Further it is clear that the Cook islands form part of the same geochemical continuum as the Austral-Mangaia segment, implying a genetic link. Initially, this observation appears to accord with the hypothesis that the extreme radiogenic Pb signature observed in islands such as Mangaia has developed over a relatively short time span of around 20 Ma. However, to produce the observed shifts in Pb isotopic composition within 20 Ma would require a $^{238}\text{U}/^{204}\text{Pb}$ ratio of over 1000 which is clearly unrealistic (in most volcanic rocks this ratio rarely exceeds 40). The most reasonable explanation for the observed Pb isotopic evolution would seem to be a gradual waning of the influence of the HIMU source with time such that the initial volcanic products seen at Mangaia island contain a large HIMU component, whereas the present day volcanics at MacDonalld seamount do not. Similar temporal trends are seen in the isotopic evolution of lavas from the Balleny Province and St. Helena.

The origin of the HIMU signature

The isotope geochemistry of most OIB appears to be broadly explicable in terms of mixing between four or five end-members, tentatively assigned from extrapolation of existing data arrays in isotopic multi-space (e.g. White, 1985). Of these, the origin of the HIMU signature remains perhaps the most controversial and has been variously ascribed to preferential partitioning of Pb into the core during early Earth accretion, recycling of ancient oceanic crust, delamination of the subcontinental lithosphere, metasomatism by CO_2 -rich fluids, and the possibility that Pb is more incompatible than U during partial melting.

The concept of Pb partitioning into the core during accretion has now been largely discredited

primarily because the age of the HIMU source appears younger than that of early Earth accretion (Hart, 1988) and abundances of the siderophile and chalcophile elements in oceanic basalts are not readily compatible with such a model - in particular no correlations are observed between Pb isotope ratios and Pb/Ce, Mo/Pr and W/Ba ratios (Newsom *et al.*, 1986). Furthermore, data for oceanic basalts have also now confirmed that U is in fact more incompatible than Pb during partial melting. Distinguishing between recycling models, delamination and metasomatism is, however, a more difficult undertaking.

Recently considerable evidence has been mounting for the involvement of recycled continental crust in the mantle source of EM-type oceanic islands, including oxygen isotope variations (Woodhead *et al.*, 1993) and correlations between Ce/Pb and isotope parameters (Devey *et al.*, 1990). Many aspects of the geochemistry of the HIMU sources also make recycling of oceanic crust a very attractive model.

HIMU islands are marked by their extreme homogeneity, when compared to other OIB types, such that isotopic variability decreases considerably towards high $^{206}\text{Pb}/^{204}\text{Pb}$ ratios. It could be argued that such a correlation implies that HIMU sources experience less mixing with depleted reservoirs than other OIB types but, if this represents real source heterogeneity, it is not a result which would be expected from either metasomatism or the involvement of sub-continental lithosphere which most available data suggests is highly heterogeneous (see compilation of xenolith data in Hart (1988) for example). It would be in keeping with the recycling of oceanic crust, however, since this is perhaps the most homogeneous geochemical reservoir we know.

HIMU sources are well known to have higher FeO contents at a given differentiation index than other OIB. Lanyon (1994), in a detailed consideration of the major element characteristics of OIB, suggested that HIMU OIB are also distinguished by the lowest silica and highest CaO contents and further concluded that these features are unlikely to represent a melting effect and probably reflect source compositional differences. If this is the case the high FeO and CaO contents of HIMU sources present another strong argument for the involvement of recycled MORB-type crust in their genesis. Furthermore, HIMU sources also have very distinct trace element abundances patterns when compared to other OIB types showing higher concentrations of the HFSE and greater depletion in the highly incompatible elements. Depletion in the highly incompatible elements is another characteristic shared with MORB and

Weaver (1991) has suggested that the higher levels of HFSE compared to other OIB sources indicate that HIMU, like MORB, can be viewed as a complementary reservoir to the Nb and Ta depleted continental crust. The Sr and Nd isotope characteristics of HIMU sources are more akin to those of MORB than any other OIB type and Chauvel *et al.* (1992) have demonstrated that long-term storage and isotopic evolution of recycled MORB crust can reproduce the Sr, Nd, and Pb isotope characteristics of the HIMU source.

Finally, recent osmium isotope data provide strong evidence for the role of subducted oceanic crust in HIMU OIB from Tubuai, Mangaia, and St. Helena (Hauri & Hart, 1993; Resberg *et al.*, 1994). These islands all show $^{187}\text{Os}/^{186}\text{Os}$ ratios (from around 1.2 to 1.7) which are distinctly higher than those of mantle peridotites and other oceanic basalts. In contrast, $^{187}\text{Os}/^{186}\text{Os}$ ratios of metasomatised xenoliths from S. Africa and Siberia (e.g. Walker *et al.*, 1989) are all less than 1.08 suggesting that metasomatic processes are incapable of generating the HIMU Os signature. Ancient subducted oceanic crust is however an important high Re/Os, high $^{187}\text{Os}/^{186}\text{Os}$ reservoir in the mantle and the mixing of between 16 and 75% (depending upon age) of such crust into the HIMU source can readily account for the observed Os isotopic ratios. These attributes all strongly favour the recycling model over metasomatism or delamination hypotheses.

It is clear that HIMU sources have evolved under conditions of high U/Pb ratio for considerable periods of time and it has been suggested that either U enrichment of oceanic crust during hydrothermal alteration or Pb loss during alteration or subduction could produce such conditions. As indicated by Chauvel *et al.* (1992) the fact that HIMU have Ce/Pb ratios higher than MORB and yet Nb/U and Nb/Th ratios similar to MORB strongly suggests that Pb depletion is the more likely cause. Whether this occurs largely during hydrothermal leaching at oceanic ridges or during the dehydration reactions accompanying subduction remains unknown.

References

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