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EM1 goes walkabout: Atlantic vs. Pacific and the true geochemical essence of Enriched Mantle one

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Question:

What does an ‘enriched mantle one’ ocean island basalt look like geochemically? It is believed this type of ocean island basalt is formed through melting of ‘chemically similar’ mantle, but is this reasonable given the amount of heterogeneity in the mantle due to subduction and other processes?

Abstract

Ocean island volcanism is considered to be fed by mantle plumes from the deep Earth’s interior. A possible reason for this upwelling of material from the lowermost mantle is thermal heat transfer from the Earth’s core to the overlying so-called thermal boundary layer. Geochemical investigation, predominantly isotope ratios, of rocks from different ocean islands that are associated with such hot-spots show distinct chemical signatures, which indicate different chemical reservoirs in their respective mantle sources. One of these chemical reservoirs is enriched mantle one (EM1, characterised by moderate $^{87}Sr/^{86}Sr$ and low, i.e., crust-like $^{143}Nd/^{144}Nd$); another one is pristine, unmodified mantle, termed FOZO. This paper compares the geochemistry (elemental and isotopic) of two oceanic islands: Tristan da Cunha, which is located in the mid-Atlantic Ocean, and Pitcairn, residing in the South Pacific Ocean. Despite the geographic offset (> 10 000 km apart), basaltic rocks from these two locations exhibit similar isotope features that are geochemically classified as EM1-FOZO. Currently, there is an ongoing debate how such seemingly unique isotope characteristics can be sampled by oceanic islands that cannot plausibly be related in a geodynamics sense. Key for the understanding of radiogenic isotope ratios is the relative distribution of parent vs. daughter nuclides. However, the true geochemical nature of the elemental distributions in the deeper mantle source of the oceanic islands is masked by processes during melt-generation. Our evaluation of major and trace elements and isotope ratios reveals that, when corrected for magmatic differentiation, both islands show distinct primitive melts with isotope compositions that relate to a common parent-daughter fractionation processes in the mantle rather than a common mantle source. This implies that a generic classification of mantle end-members is not reflecting the true nature of the chemical diversity in the Earth’s mantle and calls for a nomenclature of an EM-1 process rather than an EM-1 reservoir.

Background & Method

The characteristic tholeiitic basalt is the igneous rock formed at mid-ocean ridges, and occurs usually via decompression melting from the underlying depleted and heterogeneous upper mantle – this type of oceanic basalt is labelled Mid Ocean Ridge Basalt (MORB). Intra-plate basalts are a different type of oceanic basalt and are believed to originate from mantle plumes, rather than melting of the upper mantle. Mantle plumes are concentrated heat sources and form from thermal anomalies at the core-mantle boundary, migrating towards the surface and piercing the oceanic crust, sometimes receiving the term *hotspot* or *Ocean Island Basalt* (OIB). Tristan da Cunha and Pitcairn located in the Atlantic and Pacific respectively, are both oceanic islands associated with hotspot volcanism. They will be compared geochemically and all plots have been created from data obtained from http://georoc.mpch-mainz.gwdg.de/georoc/.

Enriched Mantle one (EM1) OIB

Due to the mantle being on average 2 850 km thick, it is the largest part of the Earth’s interior and is where mantle plumes are believed to originate. The genesis of mantle plumes is still debated however upon their ascent to the Earth’s surface, the magmas will reflect different chemical characteristics based on source heterogeneities and processes. EM1 is believed to be created from delamination of continental lithosphere and then mixing with the underlying upper mantle (Lustrino, 2003) and can be defined in lead (Pb), neodymium (Nd) and strontium (Sr) isotope space. Isotopes are used in this study because of their resistance to fraction processes (unlike major oxides e.g. SiO_2 and MgO) like fractional crystallisation, which means they will reflect the source of melting.

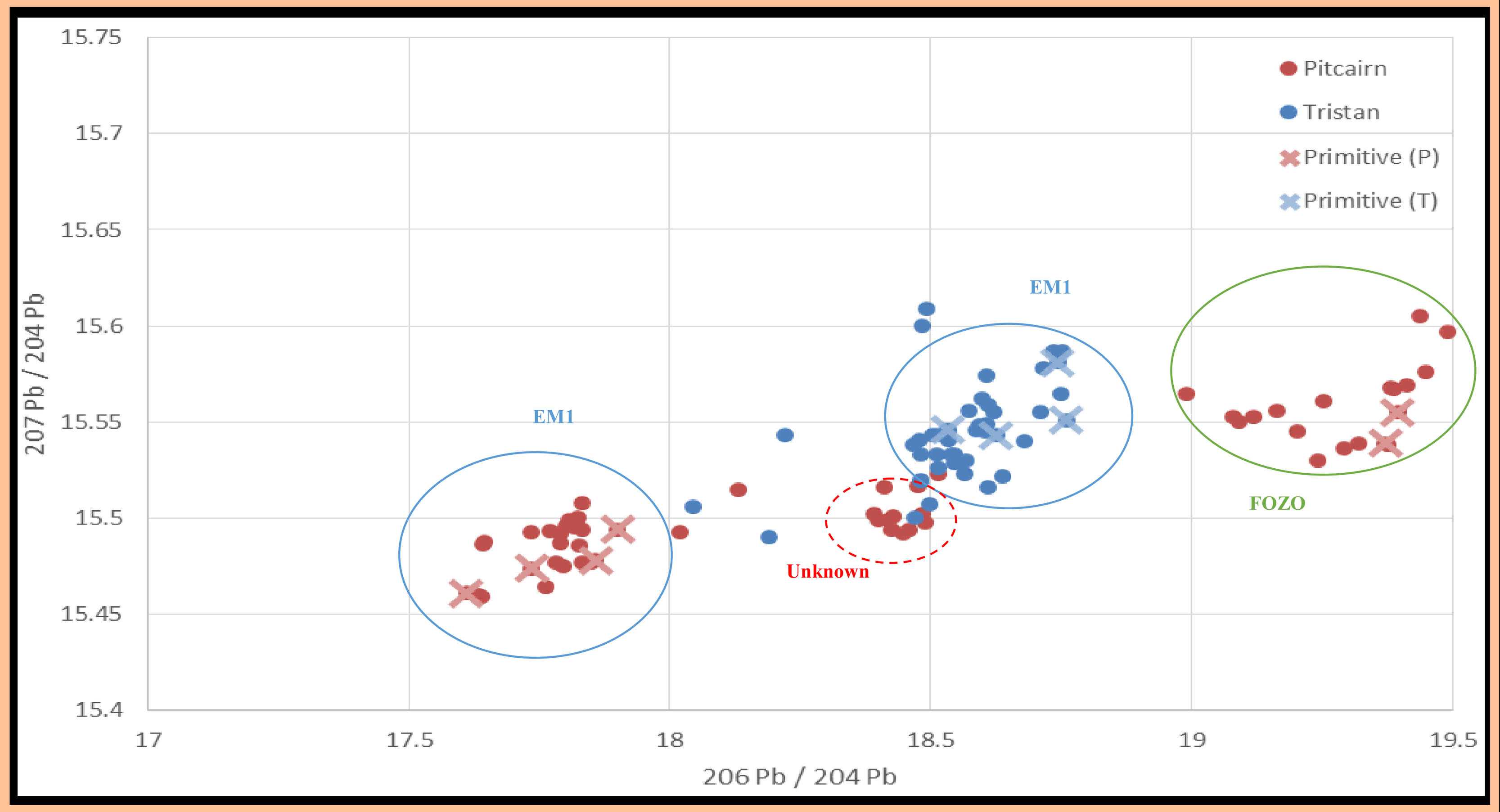

Fig. 1 — Plot showing data clusters (and primitive magmas) with the red ‘unknown’ cluster.

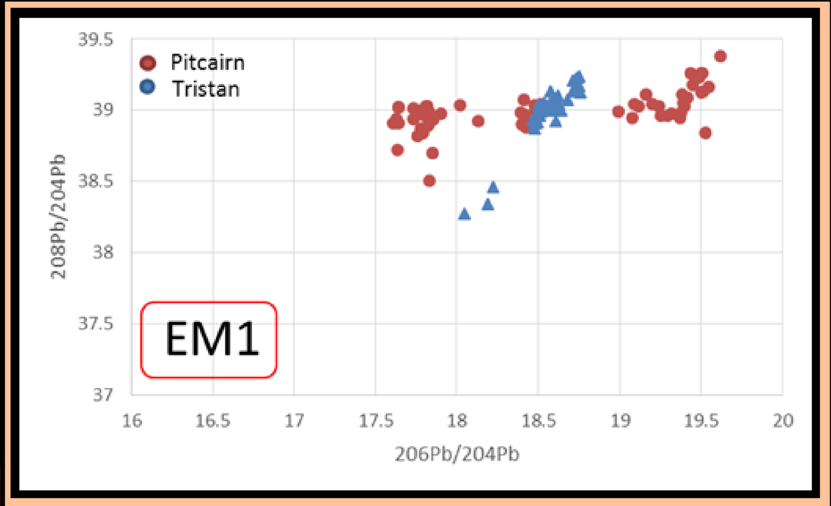

Fig. 2 — Pb-isotope plot showing 3 domains & EM1 constraints from Lustrino (2003) (red rectangle).

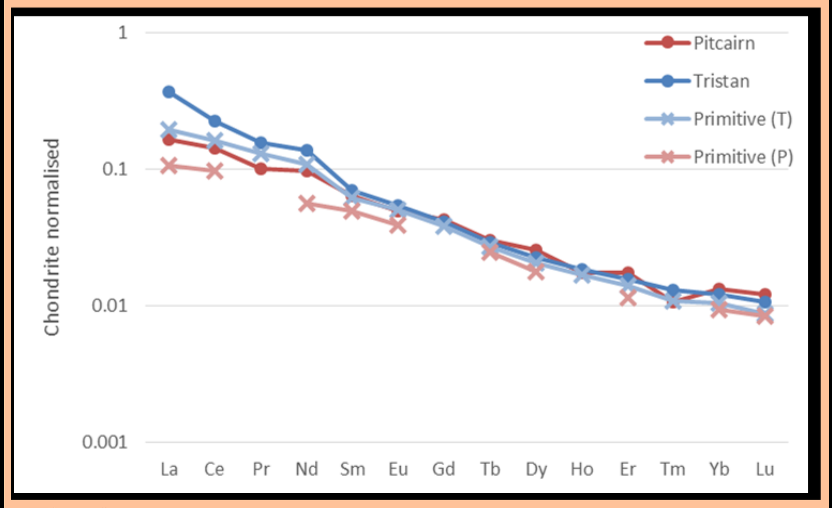

Fig. 3 — Rare Earth Elements (REE) plot showing strong depletion in the heavy REEs.

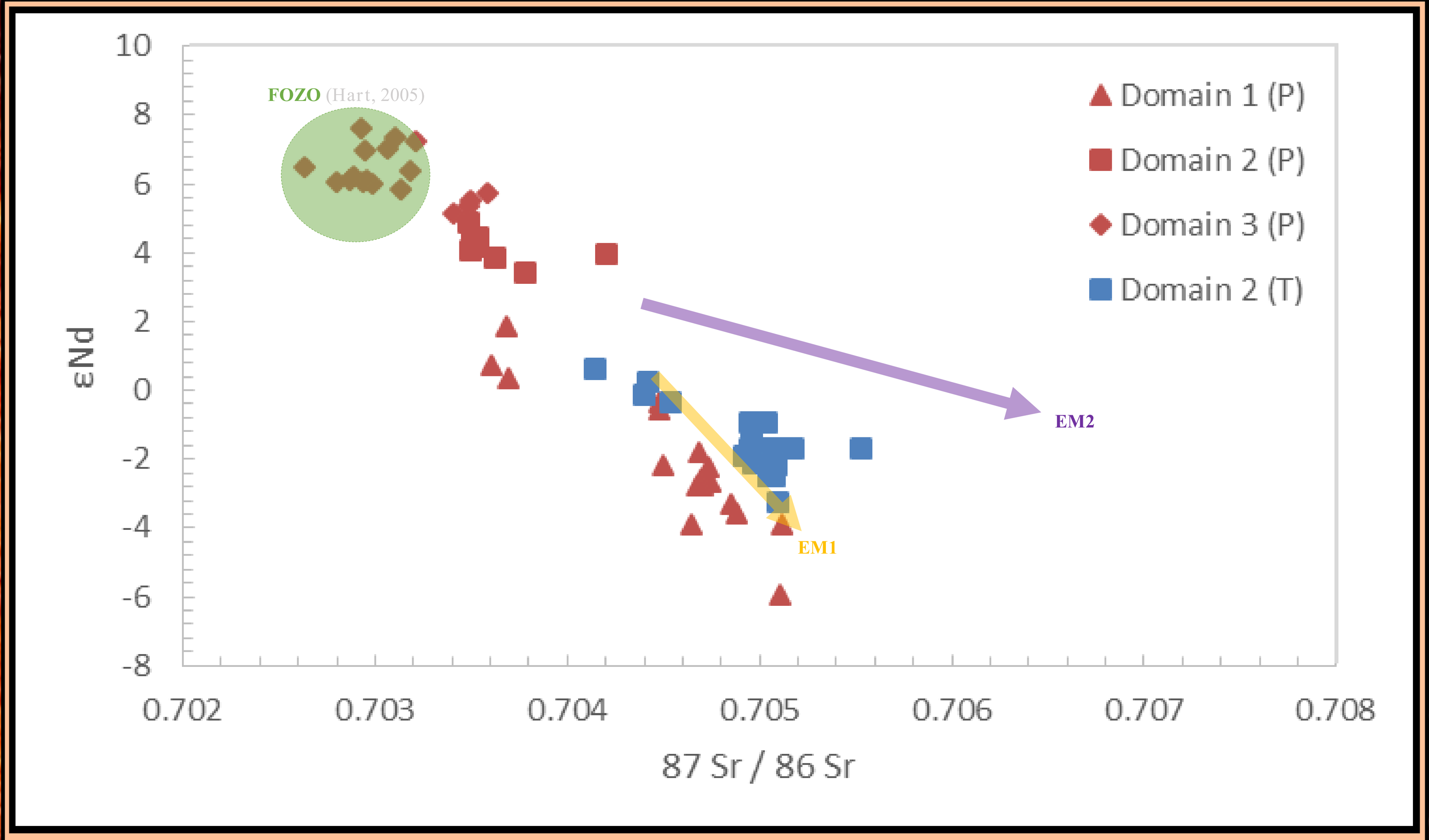

Fig. 4 — The yellow and purple lines show the trends of EM1 and for comparison EM2 (not explained—but different from EM1). The green circle encompasses value from FOZO (after Hart, 2005).

References

Hart, S. R., 2005. FOZO, HIMU, and the rest of the mantle zoo. *Geochemistry Geophysics Geosystems,* p. 20.
Lustrino, M. & Dallai, L., 2003. On the origin of EM-1 end-member. *Stuttgart,* pp. 85-100.
Landry, Matther G.. *Arenal Volcano Eruption*. N.d. N/A, La Fortuna, Costa Rica. https://www.flickr.com/photos/mattlandry/297589488/sizes/z/in/set-72157594376579278/. Web. 5 Sept. 2014. (background photo)

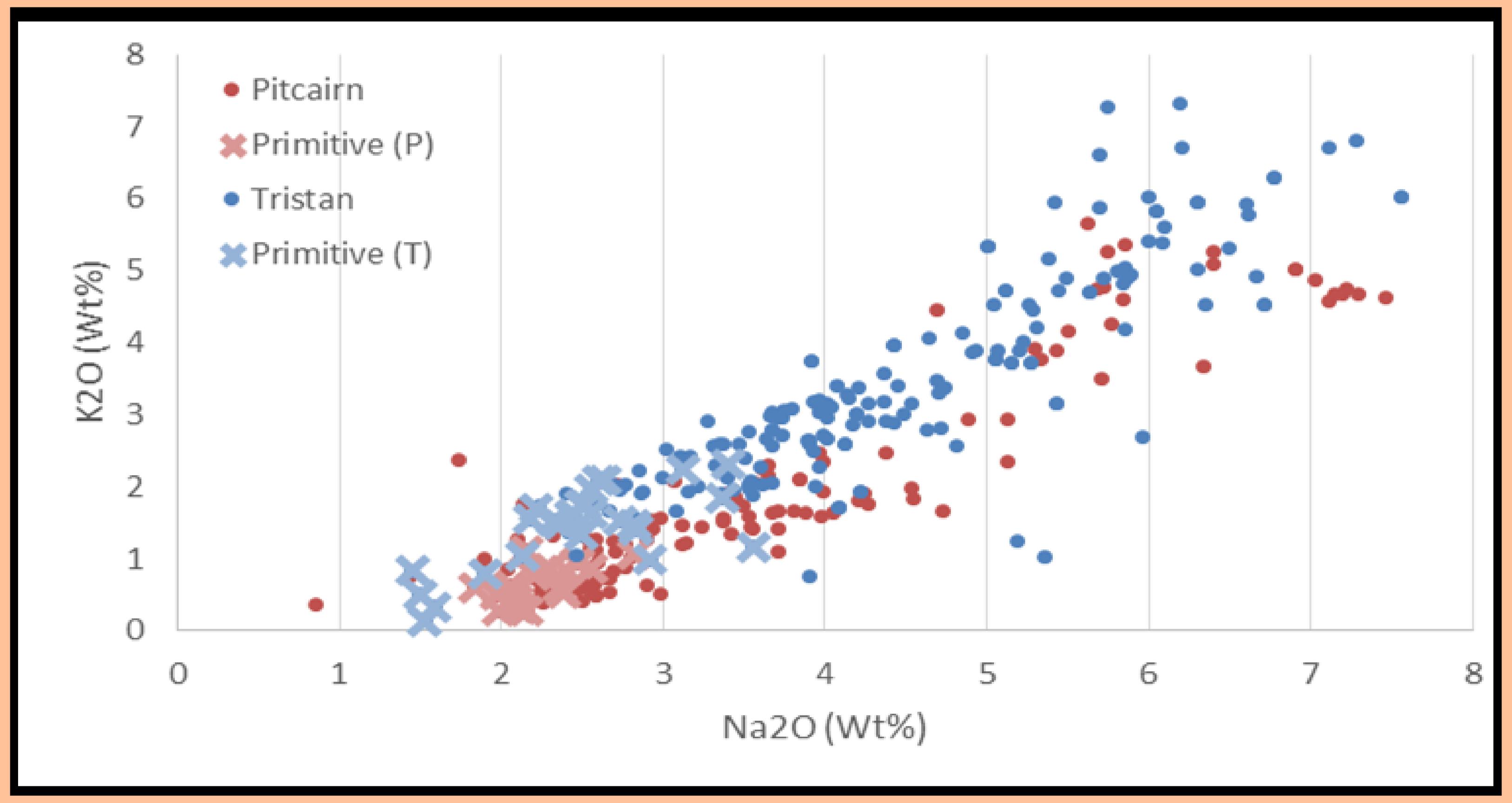

Fig. 5 — Primitive magmas plot at low Na_2O meaning a high degree of melting.

Results

Primitive magmas have been isolated from the data (then plotted on top) with values between 7.5-12 Wt% MgO—these data are considered the least evolved and are denoted with a cross. The data splits up into 3 distinct domains when looking in Pb-isotope space (see Fig. 2) these domains are all above what Lustrino (2003) defined for EM1 in Pb-isotope space (red rectangle in Fig. 2). The increased Pb values and domains suggest a large amount of mantle source heterogeneity. Fig. 1 shows a blue circle (EM1) a green circle (FOZO) and a dotted red ‘unknown’ circle. All circles (apart from the red) exhibit primitive magmas (most primary melts) within the cluster. However the red circle doesn’t show primitive magmas meaning there hasn’t been melting from mantle of this isotopic composition. Many of the data points are plotting in the “FOZO” region which is distinct from EM1 as described by Hart (2005). Fig. 3 shows the *Rare Earth Element* (REE) pattern which shows a distinct depletion in the elements Dy to Lu also known as the *Heavy REEs* (HREE). This depletion can be attributed to the aluminous phase garnet, being in the source. Garnet will take in a lot of the HREEs which will cause the resulting magma to be depleted in the HREEs. Fig. 4 shows the evolution paths for EM1 and EM2, no data points are following an EM2 path meaning the data is mostly EM1 and FOZO. The magmas are high degree melts based on the low concentration Na_2O. Sodium is incompatible which means it will jump into the first magma created and will be at a high concentration. As more magma is created (high degree) this concentration will decrease (see Fig. 5).

Conclusions

1. ‘Unknown’ domain in Pb-isotope space doesn’t have a primitive magma, meaning there is an EM1 process at work. This means EM1 is not just sourced from melting of common mantle but also a common mantle process.
2. Most of the data represents EM1 however there are FOZO data points present (from Pitcairn) showing the diversity of magma compositions.
3. Pb-isotope values are more enriched (compared to Lustrino, 2003) pointing to a lot of source heterogeneity.
4. These magmas are the result of a high degree of melting in the mantle.