Distinguishing local from deep sources using high-resolution age-mapping of oceanic-hotspot volcanism?

J.M. O'Connor[1], P. Stoffers[1], J.R. Wijbrans[2]
[1]*Institute for Geosciences, Christian-Albrechts University, D-24118 Kiel, Germany*
email: joconnor@gpi.uni-kiel.de
[2]*Department of Isotope Geochemistry, Vrije Universiteit, 1081 HV Amsterdam, The Netherlands*

Introduction

The temporal, spatial and geochemical distribution of hotspot volcanism has long been a key to investigating the processes controlling hotspot-lithosphere interaction and the hypothesis of deep mantle plumes. High-precision dating is therefore of first-order importance when seeking to understand the long-term processes controlling the history and distribution of hotspot volcanism. Our aim here is to draw attention to the issue of plume theory developing much faster than the accumulation of real data due to the prohibitive cost of ship time and post-cruise analyses. Recent studies indicate that data remain far too scarce to provide robust ocean-wide understanding of histories and distributions of hotspot provinces. We support this proposition with the example of recent $^{40}Ar/^{39}Ar$ data for rocks from the Foundation Seamount Chain (O'Connor et al. 1998, 2001, 2002) (Figs. 1 & 2). Our results show how a detailed understanding of the long-term history of time progressive volcanism along seamount chains and their surrounding structures can begin the process of distinguishing long term (i.e., deep?) plume-hotspot behavior from local lithospheric control.

Short-lived (local) versus long-lived (deep?) control of Foundation hotspot volcanism

The main trend in the Foundation age data is one of linear migration of midplate – often geochemically enriched – volcanism at a rate of 91 ± 2 mm/yr along the Foundation Chain for at least the past 22 Myr. Such time progressive volcanism supports the conventional model of the Pacific plate drifting over a narrow, stationary plume of hot mantle material upwelling from depth. Furthermore, similarity between rates of migration of volcanism along the Hawaiian and Foundation chains supports a stationary Foundation versus Hawaiian mantle plume, at least for the past 22 Myr.

However, our dredge-sampling covered volcanic elongated ridges (VER) flanking the Foundation Chain at different stages of development (Fig. 2). The transition from a narrow line of seamounts to a broad region of volcanic elongate ridges (VERs) about 5 Myr ago was assumed initially to be the result of interaction between the Foundation plume and the encroaching Pacific-Antarctic spreading-center. Some of our data support this notion by showing that volcanism along morphologically distinct VERs can develop occasionally as rapidly formed continuous lines of coeval volcanism extending from a region of intraplate volcanism to the Pacific-Antarctic spreading center. However, a significantly more dominant trend is for coeval, yet structurally disconnected, segments of Foundation Chain VERs to develop in a series of *en echelon*, NE-SW elongate 'zones' of coeval hotspot volcanism. These elongate zones developed at intervals of approximately 1 Myr while maintaining a basically steady-state orientation and size as the Pacific-Antarctic spreading center migrated continually closer to the Foundation plume hotspot. Although such VER development was controlled in part by local factors (e.g. location of nearest spreading center segment, lithospheric stress), long-lived attributes of the Foundation plume hotspot (e.g. size, orientation, periodicity) appear to have played a significant role.

The key to testing this notion is the fact that the Foundation Chain represents a rare, possibly unique, case of a hotspot trail crossing a fossil microplate. Prior to encountering the Selkirk Microplate the Foundation Chain formed as broad zones of scattered, synchronous Foundation volcanism – similar to those identified west of the present Pacific-Antarctic spreading center (Fig. 2). However, once the significantly older microplate lithosphere began capping the plume hotspot about 14 Myr ago, the chain narrowed abruptly into a line of discrete seamounts, only broadening again about 5 Myr ago when sufficiently young lithosphere once again drifted over the plume hotspot. Foundation hotspot volcanism can therefore be prevented across elongate hotspot zones if the capping tectonic plate is too thick for plume melts to penetrate to the surface. (O'Connor et al., 1998, 2001, 2002). The lack of a seamount chain connecting the Foundation and the Ngatemato chains (McNutt et al., 1997) can be similarly explained, so supporting the notion that the Pacific plate has drifted a distance of at least 3400 km over a Foundation plume-hotspot during the last ~34 Myr. We infer from this information that Foundation Chain development was controlled primarily by tectonic plate migration over broad zones of hot plume material of fundamentally constant size and orientation created with an apparent periodicity of about once per Myr (O'Connor et al., 2002).

Creation of broad zones of synchronous Foundation magmatism at regular ~1 Myr intervals leads us – in combination with recent numerical plume modeling (e.g., Larsen and Yuen, 1997; Larsen et al., 1999) – to propose that the Foundation Chain is the product of a stationary plume pulsing hot masses against the base of the Pacific plate from depth with an apparent periodicity of once per Myr (O'Connor et al., 2002). Assuming the validity of the hypothesis of deep mantle plumes (Morgan, 1971), our model for Foundation Chain development has implications for future investigations of Pacific midplate volcanism. We propose that plume-hotspots such as Foundation, spreading on impact with the lithosphere, influence very wide areas such that apparently unconnected hotspot volcanism can be produced simultaneously across wide swaths, often crosscutting seamount chains. Thus, variations in the age, structure and stress patterns of tectonic plates drifting over (pulsing?) mantle plumes might control if, where and how hotspot volcanism develops on the Pacific plate. This modified plume-hotspot theory might also explain widespread scattered midplate volcanism (e.g., VERs) revealed by satellite altimetry mapping as well as randomly distributed reheating events warming and raising Pacific lithosphere (Smith and Sandwell, 1997) – given that many other mantle plumes are similarly pulsing large masses of hot plume material (not necessarily with the same periodicity or mass) into broad regions impacting the base of the Pacific lithosphere.

Conclusion

While we find evidence for a link between local plate tectonic processes (lithospheric architecture, stress, rifting) and the distribution of hotspot volcanism we also see evidence for long-term underlying episodic/periodic 'plume-hotspot' control. Thus, in the case of the Foundation hotspot we believe that we can distinguish between second-order lithospheric and first-order 'plume-hotspot' processes controlling the history and distribution of volcanism. This insight would not have been possible without an unusually extensive dredge-sampling and post-cruise analytical program. For example, the conventional wisdom that the broad region of volcanic elongate ridges near the Pacific-Antarctic spreading axis are primarily the product of plume-ridge interaction would still prevail – especially considering the focus of so many resources on active spreading-ridge research.

Inferring plume behavior from localized studies of oceanic volcanism inevitably produces a 'snap-shot' of what could well be a long-term dynamic mantle process. We believe therefore that the possibility of distinguishing local from long-lived (deep?) processes controlling the history and distribution of hotspot provinces provides the opportunity of 1) better testing current plume-hotspot theory and 2) merging new multidisciplinary thinking with the acquisition of real data from selected volcanic provinces. In short, developing and testing old – and especially new ideas and models – requires significantly more detailed sampling and age/geochemical analyses.

References

Larsen TB, Yuen DA (1997) Ultrafast upwelling bursting through the upper mantle. Earth Planet. Sci. Lett. 146:393–399.

Larsen TB, Yuen DA, Storey M (1999) Ultrafast mantle plumes and implication for flood basalt volcanism in the Northern Atlantic Region. Tectonophysics 311:31–43.

Mammerickx J (1992) The Foundation seamounts: tectonic setting of a newly discovered seamount chain in the South Pacific. Earth Planet. Sci. Lett. 113:293–306.

McNutt MK, Caress DW, Reynolds J, Jordahl KA, Duncan RA (1997) Failure of plume theory to explain the southern Austral Islands. Nature 389:479–482.

Morgan WJ (1971) Convection plumes in the lower mantle. Nature 230:42–43.

O'Connor JM, Stoffers P, Wijbrans, JR (1998) Migration rate of volcanism along the Foundation Chain, SE Pacific. Earth Planet Sci. Lett. 164:41- 59.

O'Connor JM, Stoffers P, Wijbrans JR (2001) En Echelon volcanic elongate ridges connecting intraplate Foundation Chain volcanism to the Pacific-Antarctic spreading center. Earth Planet Sci. Lett. 192:633-648.

O'Connor JM, Stoffers P, Wijbrans JR (2002) Pulsing of a focused mantle plume Geophys. Res. Lett. 29:10.1029/2002GL014681.

Smith WHF, Sandwell DT (1997) Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings. Science 277:1956-1962.

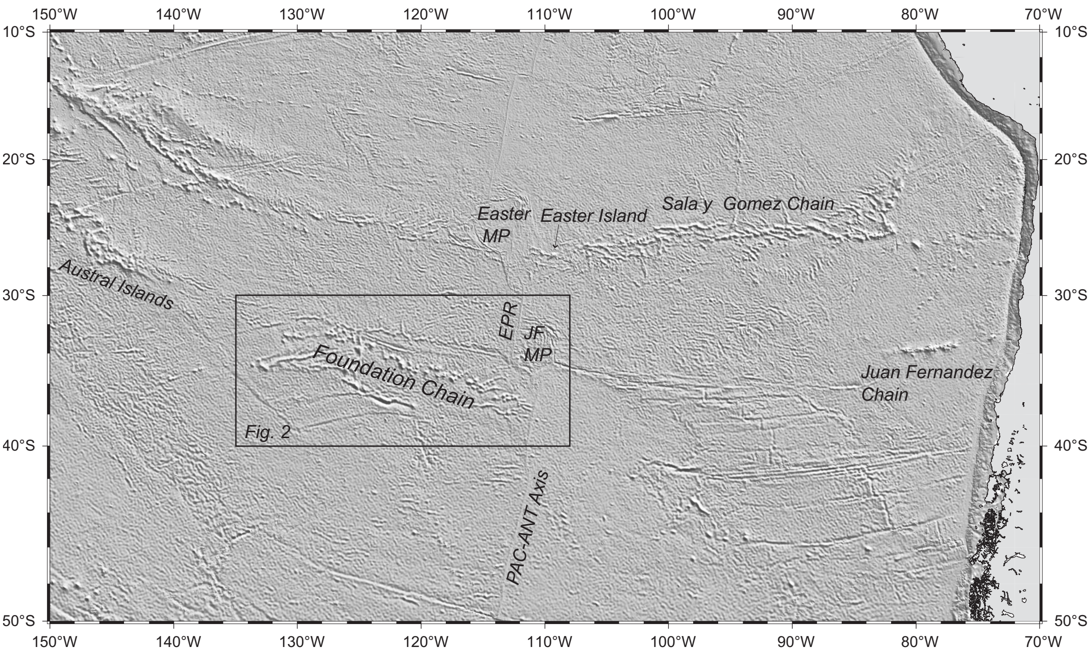

Figure 1. Predicted topography (Smith and Sandwell, 1997) of SE Pacific seafloor showing the location of the Foundation Chain. MP = microplate; JF = Juan Fernandez; EPR = East Pacific Rise. Figure modified after O'Connor et al., 1998

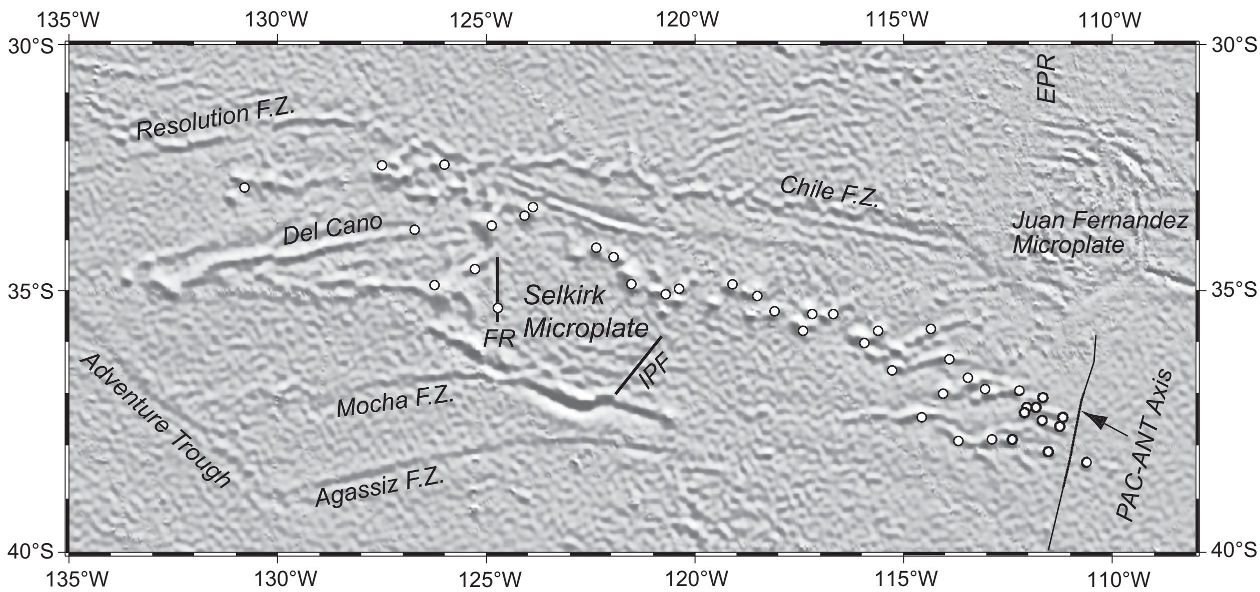

Figure 2. Predicted topography of the Foundation Chain (Smith and Sandwell, 1997). *F. S. Sonne* and *N/O Atalante* dredge sites are indicated by black rimmed white dots. $^{40}Ar/^{39}Ar$ ages, details of sample information and analytical date are in (O'Connor et al., 1998, 2001, 2002). IPF = inner pseudo fault and FR = failed rift of Selkirk microplate (Mammerickx, 1992). Figure modified after O'Connor et al., 1998