INVEST White Paper September 2009: Using oceanic lithosphere as a record of evolving of mantle convection: testing the mantle plume hypothesis.

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Covering note and abstract:

The proponent:

Dr Bramley J Murton is a Principal Scientific Officer (NERC Grade 4) in the Geology and Geophysics Research Group at the National Oceanography Centre, Southampton. His principal research interest is the geology and geochemical evolution of oceanic crust, including geological controls of fluid-flow at hydrothermal vents, cold-seeps and mud-volcanoes and the volcanology of mid-ocean ridges. Murton has sailed on ODP legs, has been a PI on seven research cruises in the past ten years and he is currently a principal investigator on two NERC responsive-mode research programmes on the Mid-Atlantic Ridge. He has been strongly involved in technical innovations: in the 1990's as a PI on developing the SHRIMP seafloor imaging platform, and recently as the PI on developing the HyBIS TV-guided benthic lander and sampler platform. He is also a member of the Science Advisory Committee for UK-IODP and sits as ECORD representative on IODP's EPSP since 2003.

Abstract:

Time-dependent dynamics of global mantle convection generate V- Shaped Ridges (VSRs) at ridge-hotspot interaction coupltes around the world (e.g, Iceland, The Azores, Galapagos, Reunion, etc.). It is generally agreed that VSRs result from melting anomalies that propagate outward from mantle hotspots – or plumes - , but the cause of the melting anomalies, and what drives the mantle flow, are keenly debated. The Icelandic VSRs are the world's best window into these fluctuations in mantle dynamics. From their geometry, the VSRs appear to derive from purturbations in mantle melting that advect away from Iceland at a rate of 20cm per year. This astonishing velocity is 10 times faster than the adjacent mid-ocean ridge spreading rate, and the fluctuations in melting have affected the adjacent continental margins and deep ocean circulation in the past. Coincident with the timing of the origins of the VSR on Iceland are fluctuations in north Atlantic Ocean circulation. Thus there are direct links between fluctuations in mantle-driven processes and climate. Drilling a series of short holes into the oceanic basement along a spreading-parallel flow line provide a window into the changes in mantle composition, mantle melting and oceanic circulation, thereby testing the hypothesis for mantle plumes.

Background:
Regions of large-scale volcanism on the Earth's surface include two distinct kinds: those associated with plate-tectonic boundaries and those associated with intraplate volcanism or hotspots. In places, where intraplate hotspots and mid-ocean ridges are adjacent, their interactions provide a key to understanding differences in mantle convection. One of the most important of these effects are anomalous crustal structures on the flanks of the adjacent spreading ridge that record fluctuations in mantle dynamics through time. These ridge-flank features include V-shaped ridges that are postulated to result from variations in melt supply (on a 2 – 10 My time scale), that originate in the mantle beneath hotspots, and that propagate outwards through advective flow of the asthenosphere. Such features are common around the world (e.g. Iceland and the Azores in the Atlantic, Galapagos in the Pacific and Réunion and Bouvet in the Indian Ocean. At a fundamental level, such features provide unique opportunities to test competing hypotheses for the origin of hotspots and the existence mantle plumes. They also allow us to address equally compelling questions about the causes of fluctuations in hotspot activity and their effects on the Earth's environment including ocean circulation and climate.

Implementation:
The world's best window into temporal fluctuations in mantle dynamics, as recorded on the flanks of mid-ocean ridges, are the Icelandic V-shaped ridges (Figure 1). From their geometry, the V-shaped ridges appear to derive from perturbations in mantle melting that advect away from Iceland at a rate of 20cm per year. This astonishing velocity is 20 times faster than the adjacent mid-ocean ridge half-spreading rate. These fluctuations in melting have affected the adjacent continental margins and deep ocean circulation in the past. For example, detailed reconstructions of the chronology of the initiation of the V-shaped ridges support the notion that fluctuations in melt flux originating in the mantle beneath Icelandic have moderated overflow of North Atlantic Deep Water across the Greenland-Scotland Ridge during Neogene times. These perturbations have affected the returning upper water mass flux (i.e. the North Atlantic Drift) by varying the depth of the Greenland-Iceland-Scotland Ridge, and thus provide a direct link between mantle dynamics, ocean circulation and climate (Figures 2 and 3).

Drilling a series of spreading parallel holes across ocean crust that has been influenced by transient hotspot processes will yield important information about the nature of hotspot origins, mantle composition, melting and aging of the oceanic volcanic crust. Sediment recovered from these holes will yield information about the changing oceanography during and after transient ridge-hotspot interactions (e.g. changes to NADW circulation and flux). This relatively simple approach was used successfully to determine the changes in mantle sources at the Australian – Antacrtic Discordance.

The importance of sampling spreading-parallel flow lines in oceanic crust to unravel the processes of mantle convection and its effect on climate is unique to ocean drilling. It is only possible to explore the dynamics and evolution of mantle convection and melting by accessing the oceanic crust beneath the ridge flank sediment cover, and thereby utilizing the chemistry of the basaltic volcanic products as a window into these asthenospheric processes. *The significance of V-Shaped Ridges as indicators of the process of hotspot fluctuation has been recognised in recent IODP Workshops: Mantle, Melting, Magma and Life (Southampton, 2009); Large Igneous Provinces (Colrain, 2007); and Rift to Ridge (Southampton, 2007).*

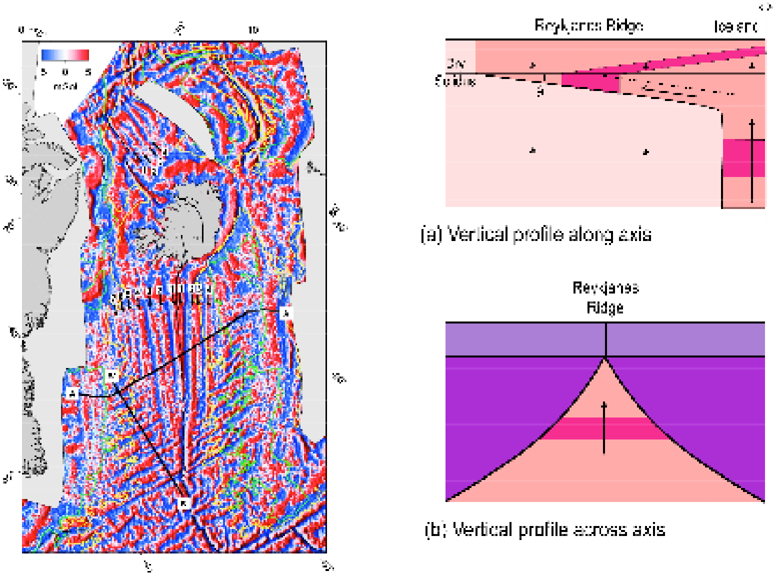

Figure 1a: V-Shaped Ridges as depicted south of Iceland from long-wavelength filtered free-air gravity; b: cartoon showing postulated causes of V-shaped Ridges with their origin as pulses within an ascending mantle plume.

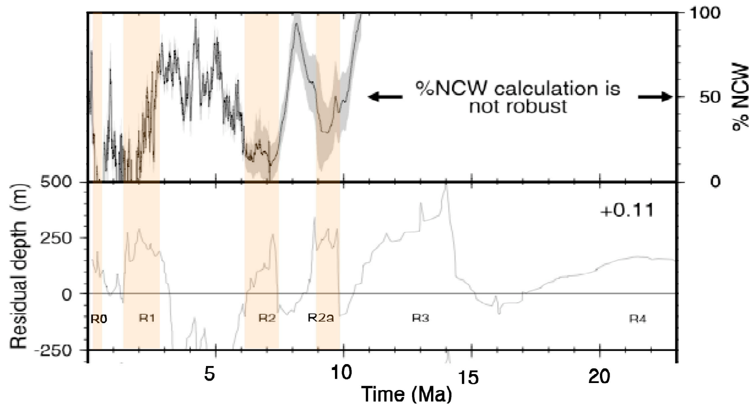

Figure 2: correlation between Northern Component Water – NCW (or North Atlantic Deep Water - NADW) and timing of origin of VSRs at Iceland.

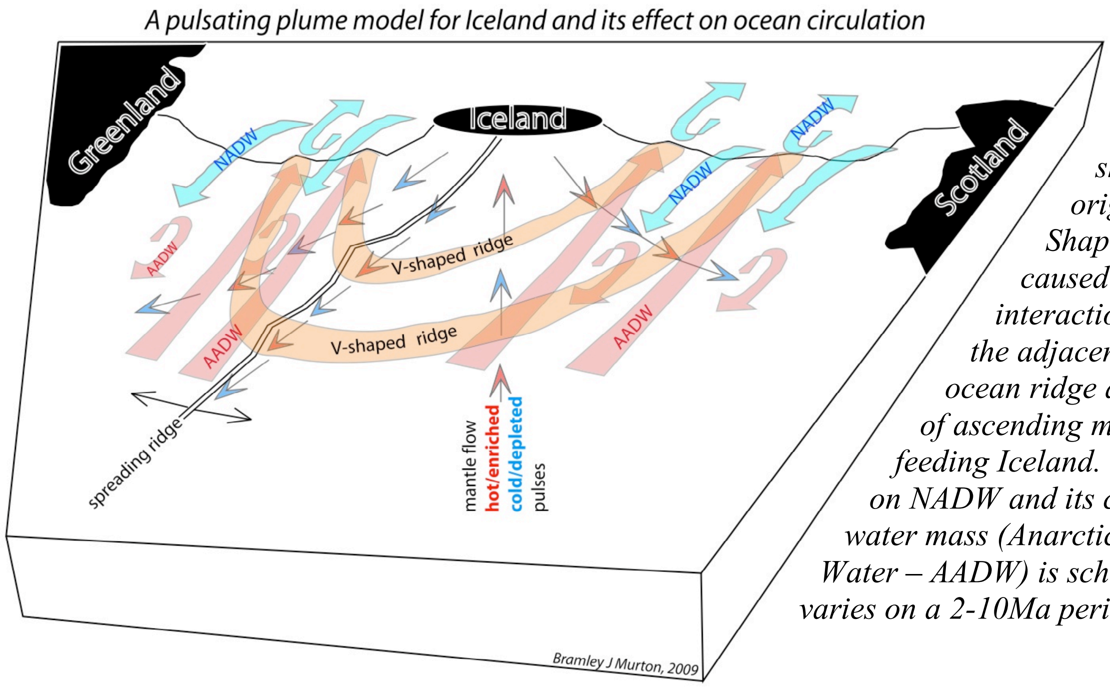

Figure3: A cartoon showing the origin of V-Shaped Ridges caused by interaction between the adjacent mid-ocean ridge and pulses of ascending mantle feeding Iceland. The effect on NADW and its counter water mass (Anarctic Deep Water – AADW) is schematic and varies on a 2-10Ma period.