



A joint geochemical–geophysical record of time-dependent mantle convection south of Iceland



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ABSTRACT

The North Atlantic V-Shaped Ridges (VSRs) provide a spatially extensive and clear record of unsteady mantle convective circulation over >40 My. VSRs are diachronous ridges of thick crust formed with a periodicity of ~5 My along the Mid Atlantic Ridge, south of Iceland. We present data from a set of dredged basalt samples that shows chemical variation associated with two complete VSR crustal thickness cycles where they intersect the Mid Atlantic Ridge. The new dataset also records chemical variation associated with a VSR crustal thickness cycle along a plate spreading flow-line. Inverse correlations between crustal thickness and both incompatible trace element concentrations and incompatible element ratios such as Nb/Y and La/Sm are observed. Geochemical and crustal thickness observations can be matched using a time-dependent mid-ocean ridge melting model with a basal boundary condition of sinusoidally varying potential temperature. Our observations and models suggest that VSRs are generated when hot patches are carried up the plume stem beneath SE Iceland and spread radially outward within the asthenosphere. These patches are then drawn upward into the melting region when passing beneath the Mid Atlantic Ridge. The geometry of the VSRs and the size of the dynamically supported swell suggest that the Iceland Plume is the strongest plume in the Earth at present, with a volume flux of $49 \pm 14 \text{ km}^3 \text{ yr}^{-1}$.

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1. Introduction

Convection within the upper mantle is expected to be time-dependent because the Rayleigh number is super-critical by 3 to 5 orders of magnitude (Schubert et al., 2001). Time-dependence can take two basic forms, one in which convection cells move laterally with respect to one another (plume wander) and another in which patches of differing temperature are advected round a convection cell (plume pulsing) (White and McKenzie, 1995). The North Atlantic V-Shaped Ridges (VSRs) provide a long period, spatially extensive and clear record of the plume pulsing type of unsteady mantle convection over time periods of order 1 to 10 million yr (Vogt, 1971; Jones et al., 2002b). VSRs are diachronous ridges of thick crust formed at the Mid Atlantic Ridge

to the north and south of Iceland (Fig. 1). Since their discovery, it has been generally agreed that the diachronous geometry results from melting anomalies that propagate away from Iceland within the asthenosphere (Vogt, 1971; Jones et al., 2002b; Poore et al., 2011). The process that generates VSRs also appears to modulate Atlantic oceanic circulation, since the VSR record correlates with stable isotope proxies for meridional overturning circulation (Wright and Miller, 1996; Poore et al., 2006).

The North Atlantic VSRs comprise one of the most important mantle convection records on Earth because no other plume–ridge system records as many melt pulses over such a large distance from a hotspot. However, knowledge of geochemical variability associated with the VSRs is lacking in comparison with available geophysical records of crustal thickness and oceanographic records of deep-water flow. There is still debate over whether VSR melt fluctuations are caused by thermal or compositional variability in the mantle, or whether they reflect neither and result instead from crustal accretion processes (Jones et al., 2002b; Hey et al., 2010). Here we report dredged basalt samples obtained during RV *Celtic Explorer* cruise CE0806. For the first time, we have

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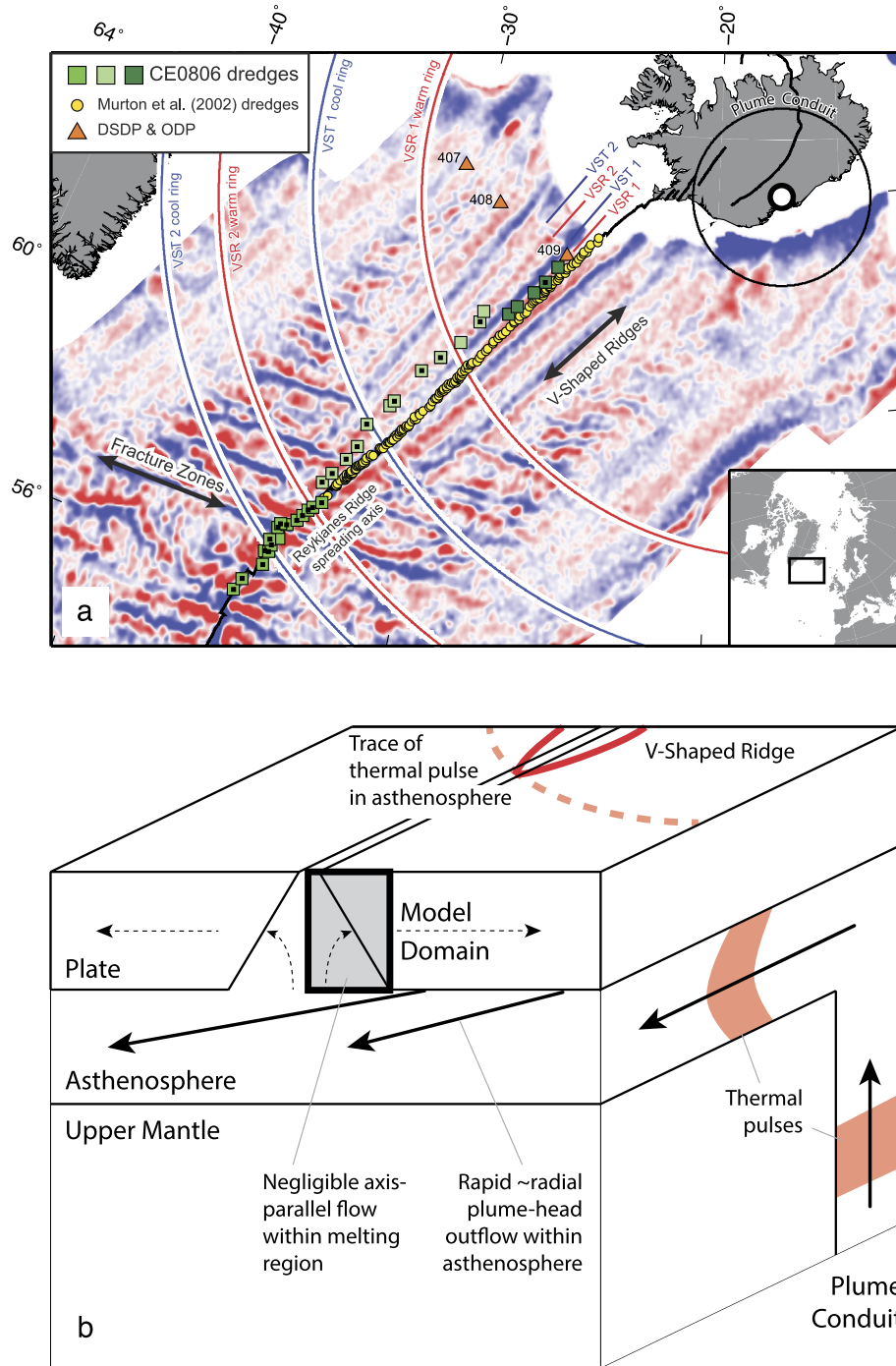


Fig. 1. North Atlantic study area and sample locations. (a) Gravity proxy for oceanic crustal structure: high-pass filtered free-air gravity field, after Jones et al. (2002b). Dredge locations with black centres yielded samples of local basalt. Plume centre from Shorttle et al. (2010). Coloured arcs show traces of hot and cool rings within the asthenosphere, and correspond to vertical coloured stripes in Figs. 3, 4 and 6. (b) Relationship between 2D model slice and 3D ridge–plume interaction geometry, showing likely path of mantle arriving and melting beneath study area.

a record of basalt geochemistry covering two complete VSR crustal thickness cycles where they intersect the Mid Atlantic Ridge, as well as a VSR crustal thickness cycle along a plate spreading flow-line.

Coincident geochemical and geophysical datasets are key to determining the cause of VSR melting anomalies. We analyse seismic and gravity data to estimate crustal thicknesses along V-shaped ridge crests, V-shaped troughs and the Mid-Atlantic Ridge axis (Section 3). We identify the geochemical signature of the VSRs by correlating geochemical proxies for degree of melting with crustal

thickness (Section 5). We then develop a numerical melting model that tracks passage of hotter and cooler mantle patches through the melting region beneath a mid-ocean ridge axis (Section 6). This model can reproduce the main characteristics of both geochemical and crustal thickness VSR datasets. The new model provides estimates of the temperature variation between hotter and cooler mantle patches, rather than the average temperature change within the melting region estimated by previous studies (White et al., 1995; Poore et al., 2011). Finally, we discuss implications of our results for mantle plume flux (Section 7).

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