# The Mantle Potential Temperature Anomaly Beneath Iceland is Insufficient for a Thermal Plume

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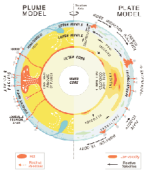

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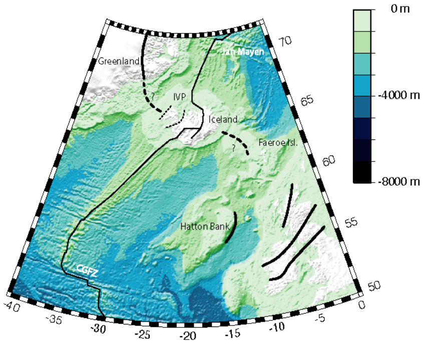
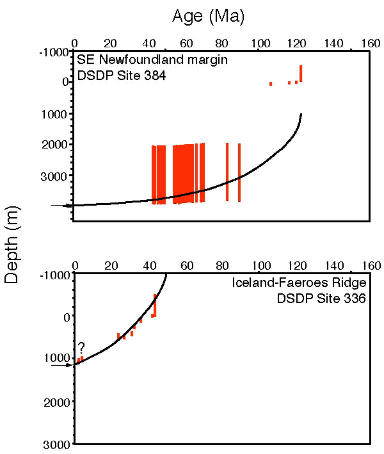
Conveners:
Ian Campbell, Gillian R. Foulger, James H. Natland & W. Jason Morgan.

## 1. INTRODUCTION

One of the few primary characteristics of mantle plumes is high temperature compared with the surrounding mantle. A temperature anomaly of at least 200-300 K is thought to be required for an upper-mantle plume rising from the base of the mantle transition zone. More than 15 methods, many of them independent, have been applied to estimate the temperature anomaly beneath Iceland.

Virtually all results either require or are compatible with a temperature anomaly of no more than ~ 50-100 K beneath Iceland. They are thus consistent in suggesting that the temperature anomaly beneath Iceland is modest, and insufficient for a thermal mantle plume that rises through its own thermal buoyancy.





*from Clift (in press)*

## 2. OCEAN-FLOOR SUBSIDENCE CURVES SUGGEST A MANTLE TEMPERATURE ANOMALY OF NO MORE THAN 100 K

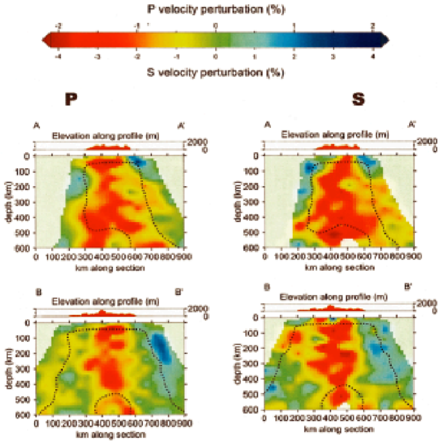
The mantle temperature where new ocean floor, volcanic margins and plateaus form can be determined by comparing subsidence curves derived using sedimentary indicators with similar curves from "normal" mid-ocean ridges. Subsidence profiles from the north Atlantic, including the Hatton Bank, the Voring plateau, east Greenland and the Iceland-Faeroes ridge reveal subsidence more rapid than at "normal" mid-ocean ridges, which are consistent with mantle temperature anomalies of ~100˚C down to ~100 km depth. Hot, thick plume-head models (e.g., $\Delta T = 350$˚C, D = 200 km) are precluded, however.

Higher temperatures are possible, but only if the hot asthenospheric layer isthinner. If part of the depth anomaly after magmatism were caused by buoyancy from mantle composition or dynamic mantle upwelling then the temperature anomalies inferred from the subsidence curves would be lower.

## 3. TELESEISMIC TOMOGRAPHY

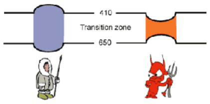
Iceland is underlain by a low seismic wave-speed anomaly that has been studied using on-land seismic networks. Iceland is ~ 450 km wide and this is thus the approximate depth limit of good resolution. The results reveal maximum anomaly strengths of ~ 2% in Vp and ~ 5% in Vs, although the anomaly is weaker than this throughout most of its volume.

If interpreted solely in terms of temperature, this anomaly corresponds to temperature variations beneath central Iceland of up to ~ 200 K relative to peripheral parts of the island. However, if some partial melt is present, the anomalies can also be explained by < 1% of partial melt and no temperature anomaly. This situation could arise if the material beneath Iceland is more fusible than elsewhere.



*from Foulger et al. (2000)*

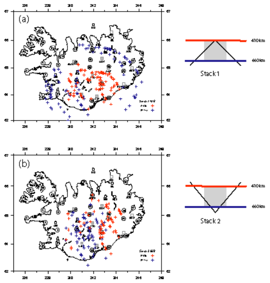
## 4. THE 660-KM DISCONTINUITY IS FLAT



Receiver function studies show that the transition zone is ~ 15 km thinner than average beneath south-central Iceland. If interpreted solely in terms of temperature, this variation would correspond to an anomaly of ~ 200 K. It has been argued that the thinning results from downwarping of the 410-km discontinuity and upwarping of the 650-km discontinuity, which would be consistent with a hot, through-going plume.

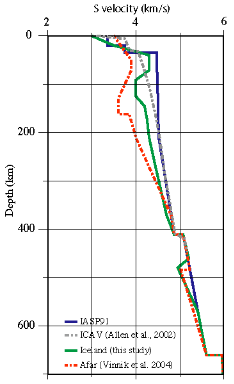
Probing of the two discontinuities separately, however, by studying receiver functions for rays that pass obliquely beneath Iceland, shows that the thinning results from downwarping of the 410-km discontinuity, whereas there is no resolvable deflection on the 650-km discontinuity (< 5 km).

This result suggests that if some or all of the thinning is due to elevated temperature, the anomaly dies out in the transition zone and does not extend as deep as 650 km. As much as half of the thinning could be explained by a realistic lower FeO content, which would reduce the estimated temperature anomaly to ~ 100 K.



*from Du et al., submitted*

## 5. S-WAVE RECEIVER-FUNCTION ANALYSIS SUGGESTS MODERATE TEMPERATURES IN THE SHALLOW UPPER MANTLE



*from Vinnik et al. (in press) GJI*

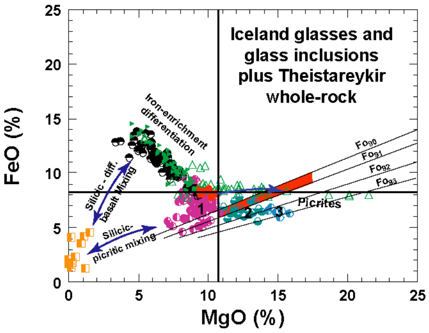
We studied *S*-to-*P* converted phases from upper mantle discontinuities beneath Iceland by stacking several tens of teleseisms. The magnitude and depth extent of the low-*Vs* anomaly in the upper mantle beneath Iceland are much larger than found in tomography studies. A clear discontinuity at 80±5 km depth separates the high-velocity mantle lid from the underlying low-*Vs* layer, and an additional discontinuity occurs at 135±5 km depth beneath peripheral parts of Iceland.

The discontinuities may represent a chemical boundary between dry harzburgite above and wet peridotite below (~ 80 km), and the onset of melting in wet peridotite (~ 135 km) (Hirth & Kohlstedt, 1996). This interpretation suggests a temperature anomaly of ~ 50 K, compared with ~ 120 K beneath Afar, obtained using the same methodology. Models of melting induced by $CO_2$ are also consistent with the seismic structure and with little or not temperature anomaly.

## 6. GLASS INCLUSIONS SUGGEST A TEMPERATURE ANOMALY OF ~ 70 K

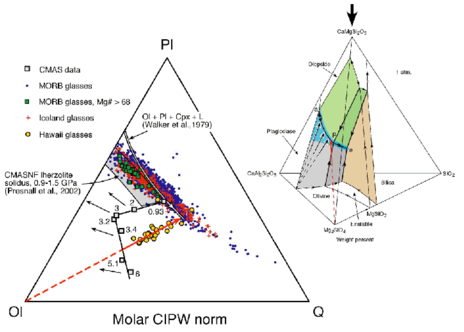
All mineral glass inclusions in Icelandic picrite cumulates have lower FeO than glass rims of picritic pillow lavas. Inclusions with 10-14% MgO could crystallize olivine ranging in composition Fo 90-91 at temperatures < 1300°C, applying the glass geothermometer of Beattie (1993). The highest likely liquidus temperature for Icelandic melt inclusions at 1 atmosphere is about 1300°C. The maximum potential temperature anomaly relative to primitive MORB (1230°C) is then ~70K.

Icelandic picritic basalts are claimed to follow a simple olivine-controlled line of descent, a situation which could allow a higher parent melt temperature. However, the presence of olivine with Fo <~ 85 and spinel with Mg# <~ 0.6, and plagioclase and clinopyroxene phenocrysts, indicates that they are hybrids with higher FeO at given MgO than any uncontaminated olivine-controlled primitive aggregate. No Icelandic tholeiite, not even a picrite, can thus be said to belong to a strictly olivine-controlled liquid line of descent.



Adding olivine incrementally to a hybrid composition (Herzberg and O'Hara, 2002) would yield an artificially high estimate of MgO (arrow), and temperature. This procedure cannot be applied to Icelandic picrite cumulates.

## 7. MANTLE POTENTIAL TEMPERATURES OF 1240-1260˚ C BEST EXPLAIN THE MAJOR-ELEMENT SYSTEMATICS OF ICELANDIC BASALTS

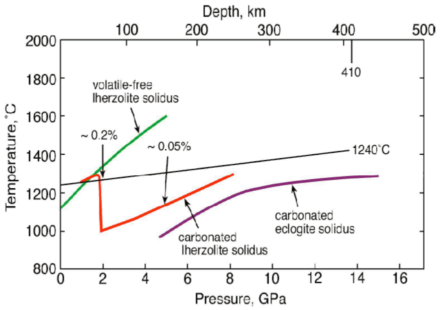


The figure shows mid-ocean ridge basalt glasses (Smithsonian database), Iceland basalt glasses (various sources plus unpublished analyses from NORDVOL), and Hawaiian picrite glasses (Clague et al., 1995) projected from diopside onto the plagioclase-olivine-quartz base of the basalt tetrahedron (inset; Presnall and Gudfinnsson, in prep.). The gray region is the plagioclase-spinel lherzolite solidus at 0.93-1.5 GPa in the CaO-MgO-$Al_2O_3$-$SiO_2$-$Na_2O$-FeO (CMASNF) system considered by Presnall et al. (2002) to be the source depth for generation of MORBs and Iceland basalts. This region appears to, but actually does not, overlap the field of MORBs and Iceland basalts. It lies directly beneath this field at lower normative Di contents.

Gray squares define the trace of solidus melts for spinel lherzolite (0.93-3 GPa) and garnet lherzolite (3-6 GPa) in the CMAS system, and the tips of the arrows show the approximate locations of solidus melts that contain ~ 1.5% $Na_2O$. Addition of FeO would have little additional effect. The chemical variation of all MORB and Iceland glasses (approximated by the blue area of the inset tetrahedron) can be understood in terms of fractional crystallization in shallow magma chambers.

MORBs and Icelandic glasses show no trace of olivine fractionation like that shown for Hawaii. More generally, the composition space for melts generated at pressures > 1.5 GPa is completely empty except for Hawaiian glasses. Thus, potential temperatures of 1240-1260˚C, appropriate for magma generation at 0.9-1.5 GPa best explain both MORBs and Iceland basalts. No evidence for high-pressure, high-temperature melt production exists.

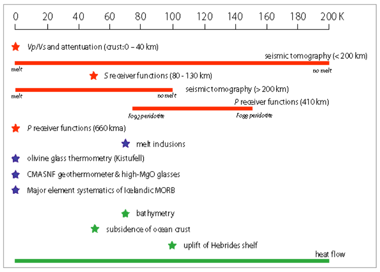
## 8. CMASNF GEOTHERMOMETRY IS CONSISTENT WITH LITTLE OR NO MANTLE TEMPERATURE ANOMALY BENEATH ICELAND



At left is a pressure-temperature diagram showing solidus curves (Presnall & Gudfinnsson, in press). Because of the abundance of $CO_2$ in Icelandic volcanics, the red curve is most appropriate for Iceland. However, if carbonated eclogite exists in the source region, the purple curve (Shirasaka & Takahashi, 2003, 8th Int. Kimberlite Conf.) would be appropriate. The steep drop of the solidus at 1.9 GPa (Falloon & Green, 1989) is caused by stabilization of dolomite at higher pressures. Basalt production occurs along the red curve at 0.9-1.5 GPa, 1240-1260˚C (Presnall et al., 2002). At higher pressures, melt compositions would be strongly enriched in carbonate and produced in very small amounts. For mantle $CO_2$ content of 200 ppm, max. melting along the 1240˚C adiabat above the stabilization pressure of carbonate would be ~ 0.2% and would occur just above the sharp decrease in the solidus temperature. The value of 0.05% indicates the amount of (carbonatitic) melt all along the solidus at pressures > 1.9 GPa. If eclogite is present in the source region, low-degree melts could occur at very great depths even for the very low 1240˚C adiabat.

## 9. SUMMARY

Diverse studies suggest or require a temperature anomaly in the mantle beneath Iceland of only 0 - 100 K, much less than is generally considered necessary for a thermally buoyant plume. Thus the high melt productivity must result from source fusibility and not high temperature.



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### *11. Acknowledgments*

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