Petrological evidence for secular cooling in mantle plumes

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Holden, J.C. & P.R. Vogt,
EOS Trans. AGU, 56,
573-580, 1977.

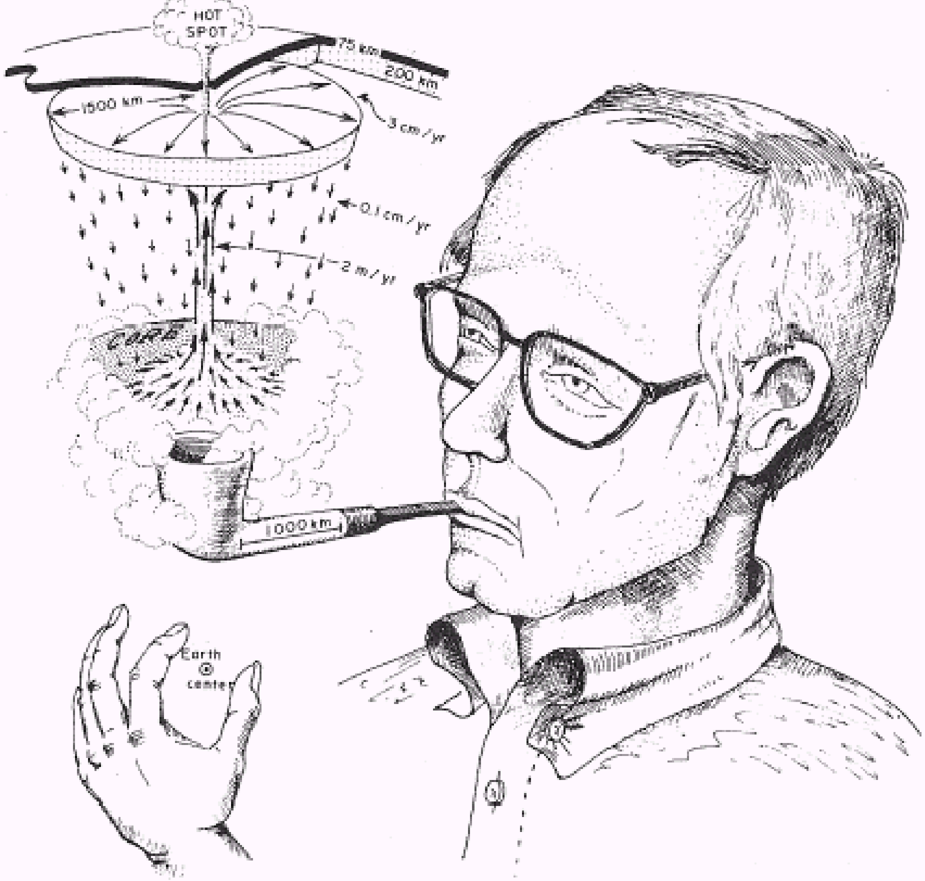
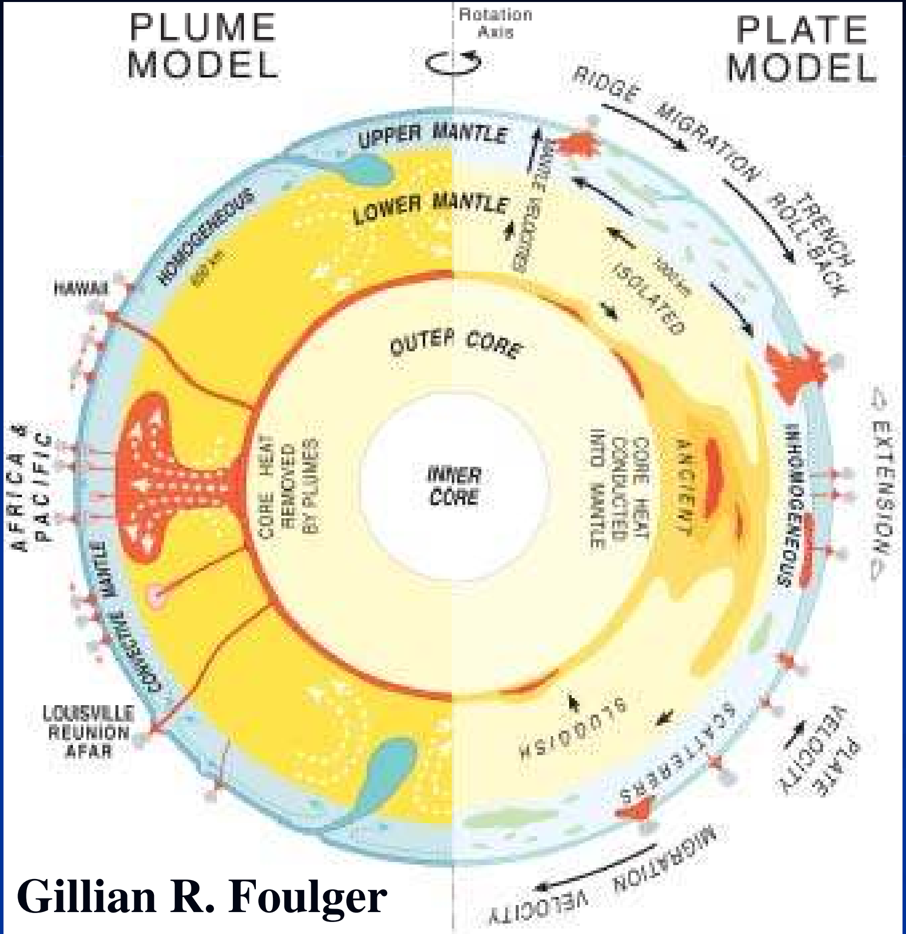


Fig. 1. Conception of the mantle plume theory, adapted liberally from W. J. Morgan (unpuffed data, 1977).

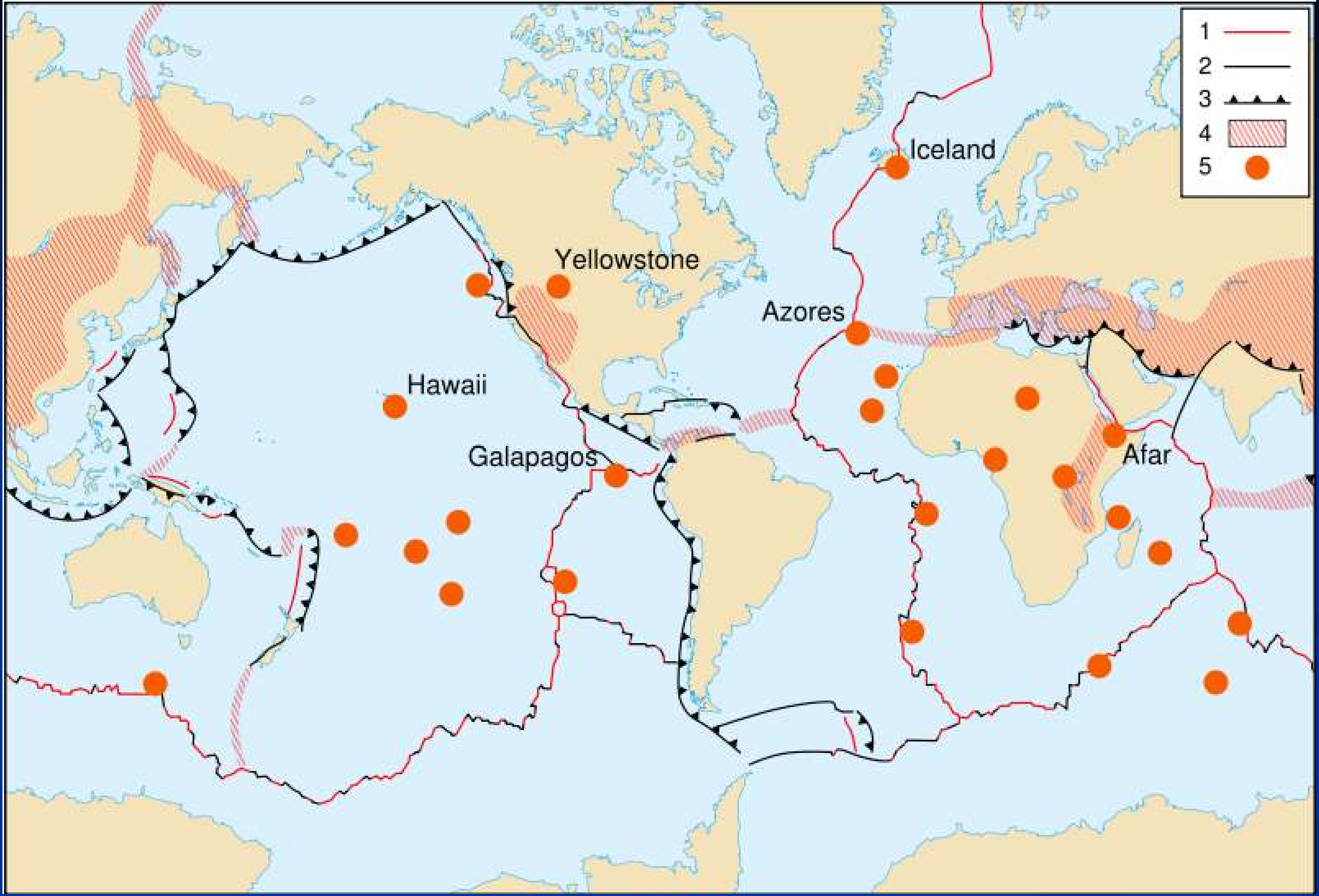
- **In 1971, geophysicist W. Jason Morgan proposed the theory of mantle plumes.**
- **In this theory, convection in the mantle slowly transports heat from the core to the Earth's surface.**
- **It is now understood that two convective processes drive heat exchange within the earth: plate tectonics and mantle plumes.**



Gillian R. Foulger

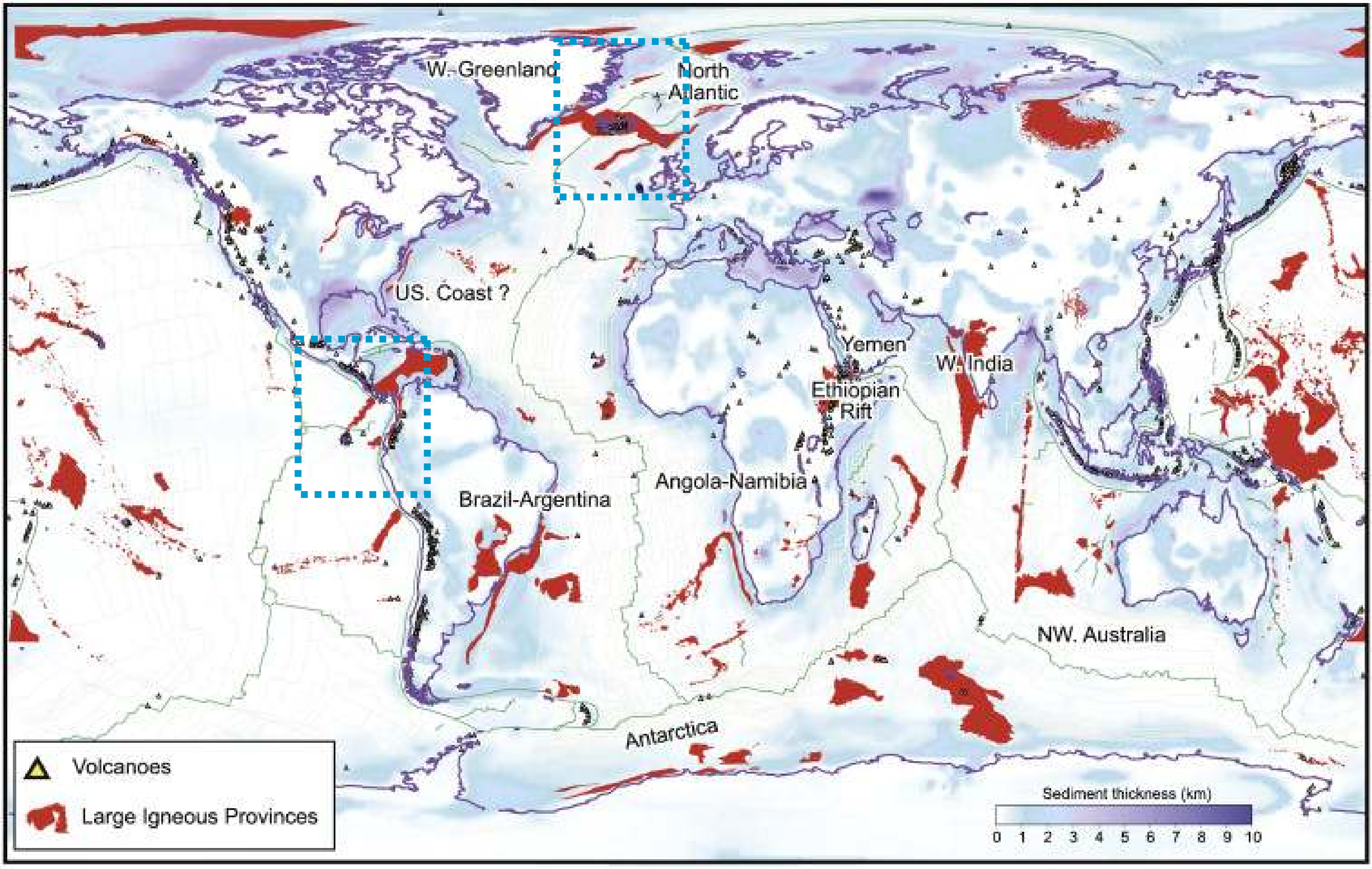
- **Plate tectonics** is driven primarily by the **sinking of cold plates** of lithosphere back **into the mantle** asthenosphere
- **Mantle plumes** carry heat upward in rising columns of hot material, and is driven by **heat exchange** across the **core-mantle boundary.**

(www. wikipedia.com)



1 : Divergent plate boundaries ; 2 : Transform plate boundaries ; 3 : Convergent plate boundaries ; 4 : Plate boundary zones ; 5 : Selected prominent hotspots.

(www. wikipedia.com)



(Yamasaki, T., and L. 2009.)

Problems ?

- Much lower eruption rates for ocean island basalts (OIBs) in comparison with those of lavas from large igneous provinces (LIPs)

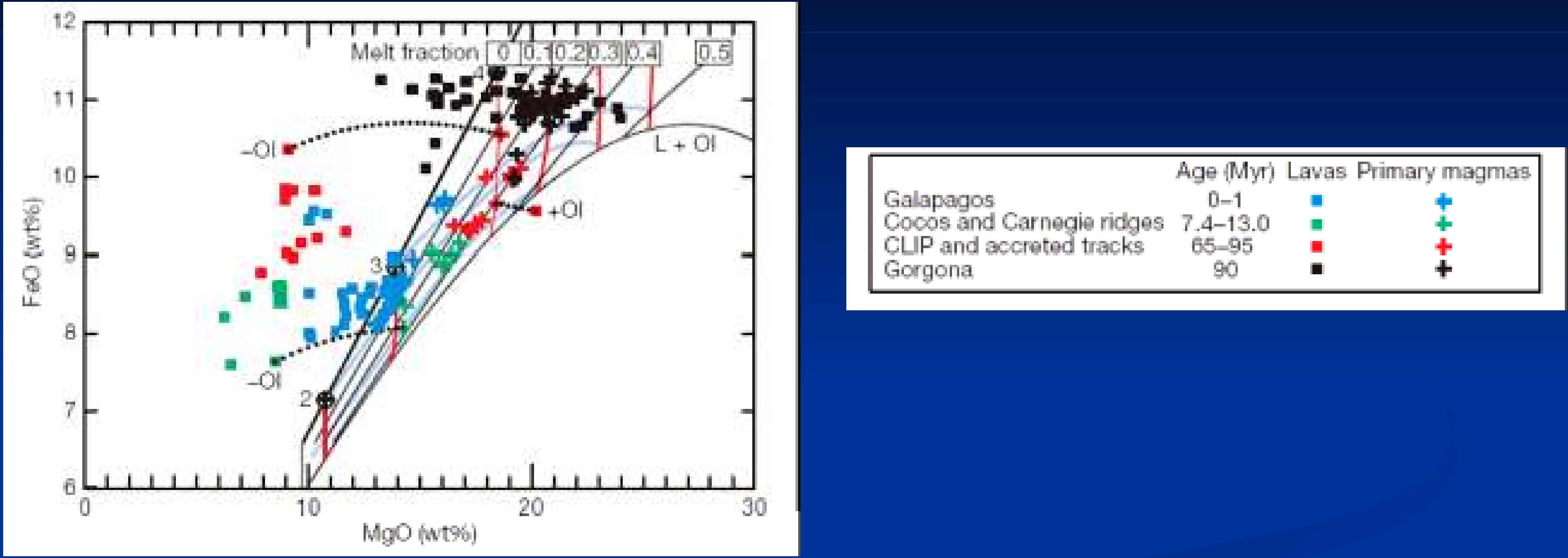
- No quantitative petrological comparison has been made between mantle source temperature and the extent of melting for OIB and LIP sources

Methods

- **Primary magma compositions, mantle potential temperatures and source melt fractions were calculated from primitive whole-rock compositions using PRIMELT2 spreadsheet software.**
- **The algorithm calculates the primary magma composition for a primitive lava by determining the variable amounts of olivine that were added or subtracted.**
- **All calculated primary magma compositions were assumed to have been derived by fractional melting.**

  - **Magmas that have been degassed from CO_2-rich sources were identified and similarly excluded.**
  - **Lavas that had experienced plagioclase and/or clinopyroxene fractionation were excluded from this analysis.**
  - **Fe_2O_3 content was calculated using $Fe_2O_3/TiO_2=0.5$, a reduced mode, on the basis of MORB-like FeO enrichment for most LIPs.**

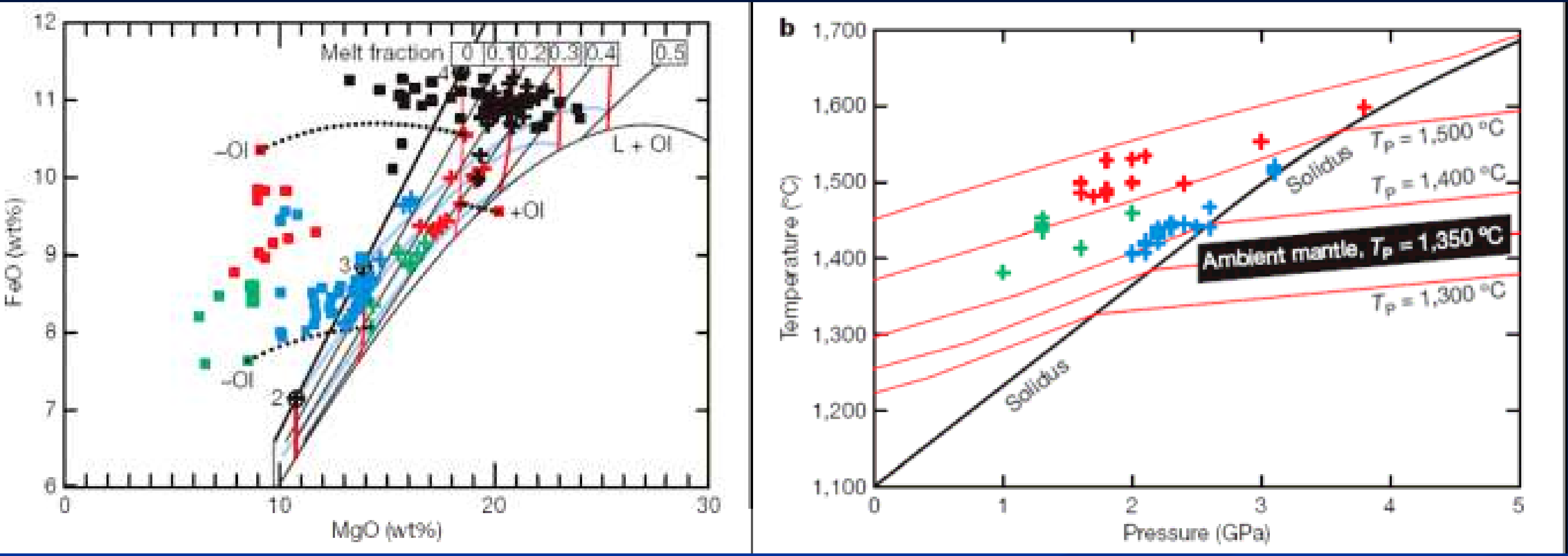
Primary magma compositions



	Age (Myr)	Lavas	Primary magmas
Galapagos	0–1	🟦	✚
Cocos and Carnegie ridges	7.4–13.0	🟩	✚
CLIP and accreted tracks	65–95	🟥	✚
Gorgona	90	■	✚

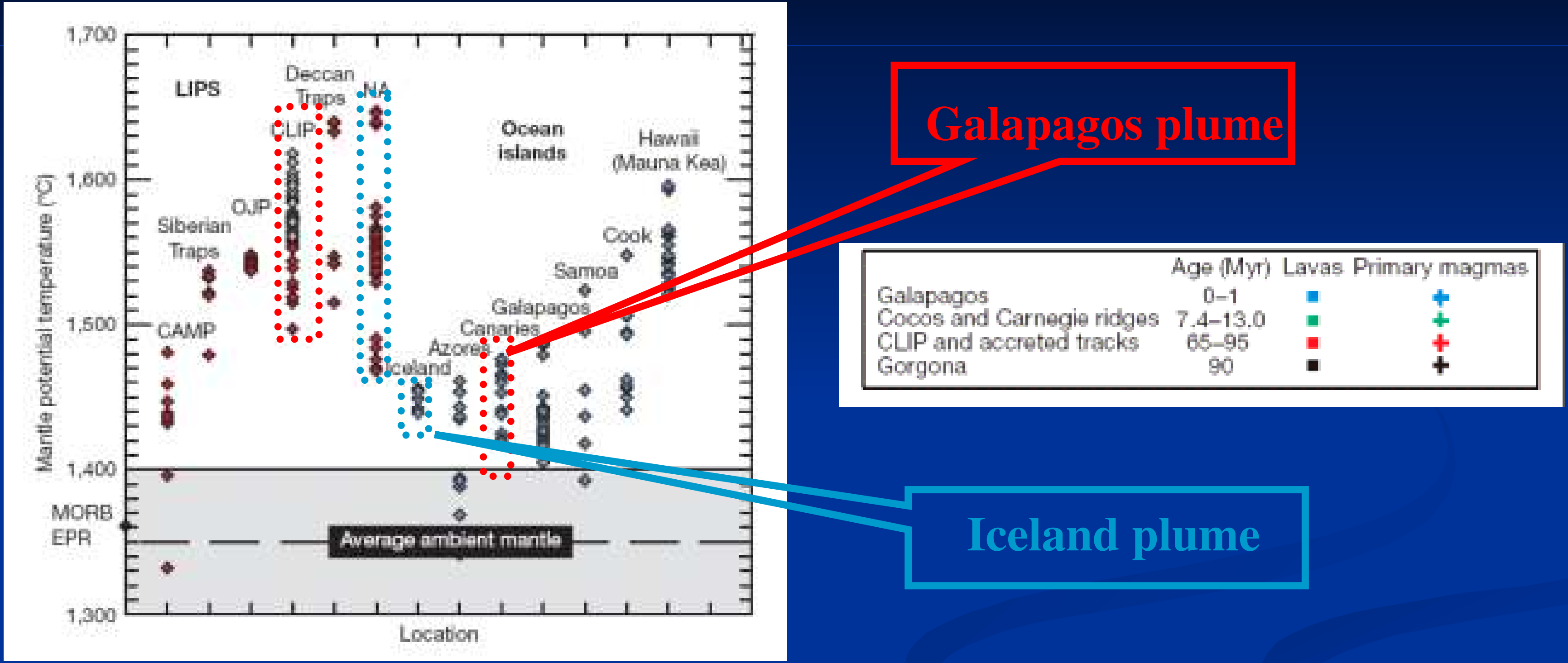
- The **lowest FeO** contents are mostly found in lavas of **0–13 Myr** old.
- FeO contents are **highest for Gorgona komatiites** and intermediate for all other lavas.
- Lavas with **higher FeO contents** can be differentiated from peridotite-source **primary magmas with higher FeO and MgO** contents.
- **Addition or subtraction of olivine** from a primary magma will produce lavas having **higher or lower MgO contents**, respectively, with **minor change in FeO** content.

Mantle potential temperatures



- The **MgO** content of a volatile-deficient primary magmais **positively** correlated with the **temperature of the mantle.**
- **MgO** content provides a petrological record of mantle potential temperature, $T_{P.}$
- Using the relationship $T_P=1463+12.74\text{MgO}-2924/\ \text{MgO}$; we can now readily calculate how hot the mantle had to be to yield the primary magma compositions given in Fig. 1a.

Mantle potential temperatures



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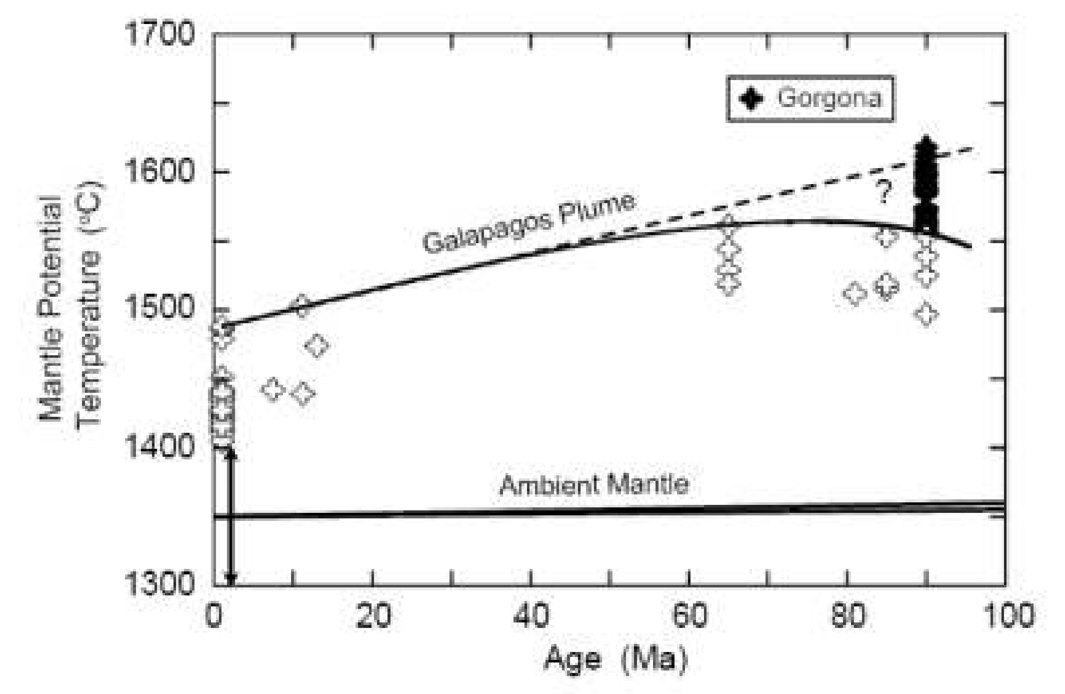
	65~95 Myr (LIPS)	Present-day (OIS)
Galapagos Plume	1500~1560(1620)	1400~1500
Iceland Plume	1460~1650	1460 (from 55 Myr)

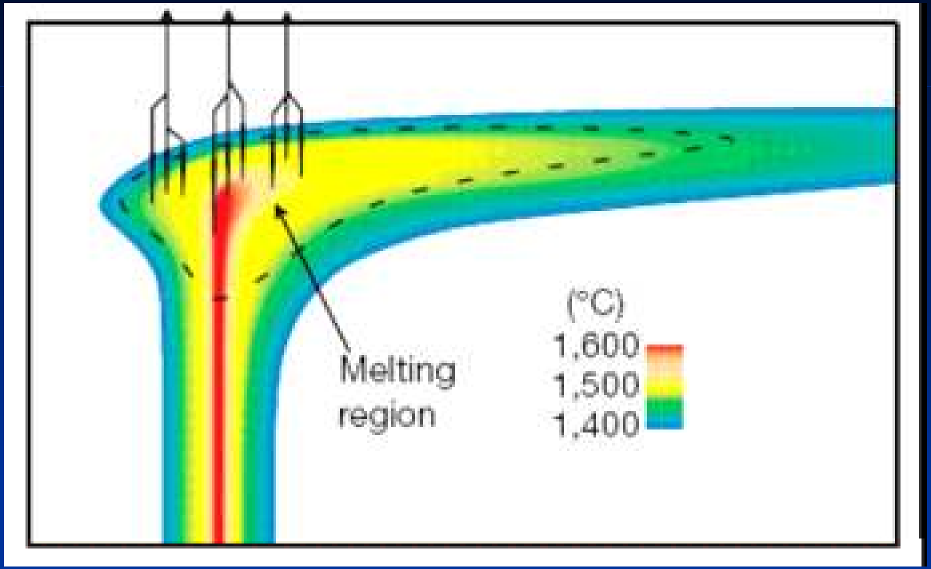
Galapagos plume



- The Galápagos plume is cooling at ~ 1 □ /Ma as shown in Fig. S3, but two different secular cooling curves are possible, depending on whether TP for Gorgona komatiites are included.
- Note the gap in data for rocks with ages between 10 and 65 Ma, but these can be filled in by future work on rocks from the accreted Galápagos tracks on Costa Rica and Panama.

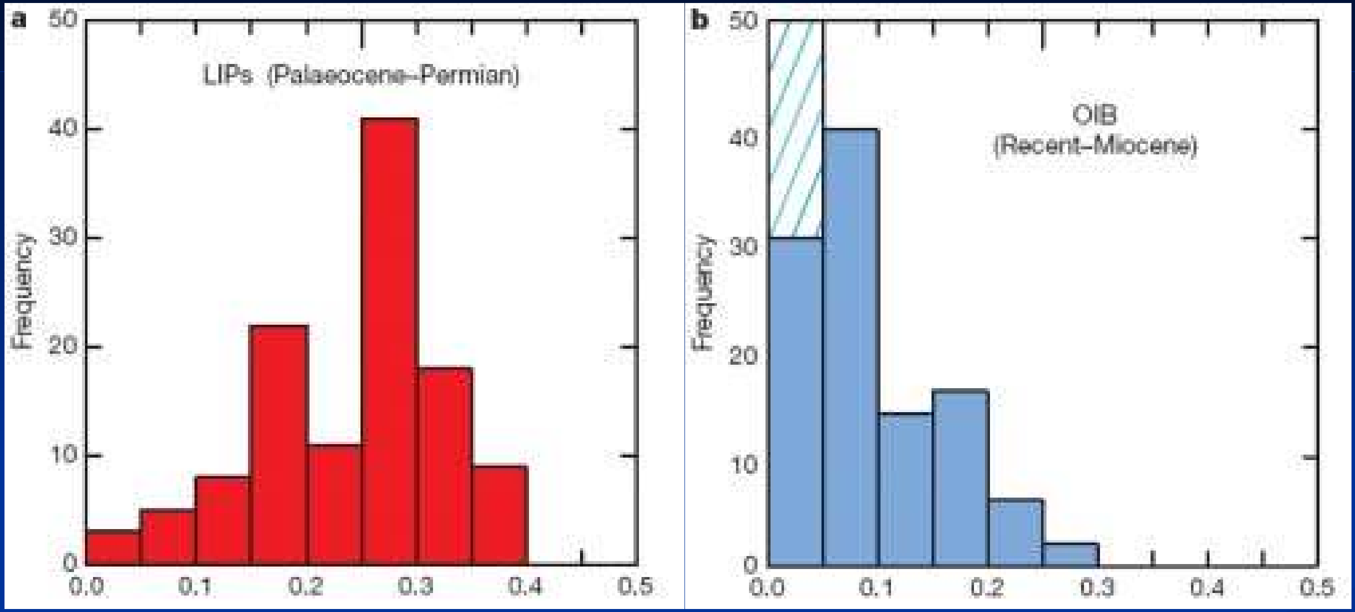
Iceland plume

- A very high cooling rate is inferred for the Icelandic plume.
- Our work indicates that T_P decreased from the range 1,460–1,650 □ to 1,460 □ in about 5 Myr.
- The T_P value for the Icelandic plume appears unchanged at about 1,460 □ from 55 Myr ago to the present, and is now in a comparatively steady state.



- Noteworthy is the wide range of primary magma compositions and inferred T_P for each LIP and ocean island occurrence.
- These ranges have been interpreted as originating from a hotspot, a spatially localized source of heat and magmatism restricted in time.
- Primary magmas are tapped from both the hot axis and the cool periphery of the plume as illustrated above.

Melt fraction

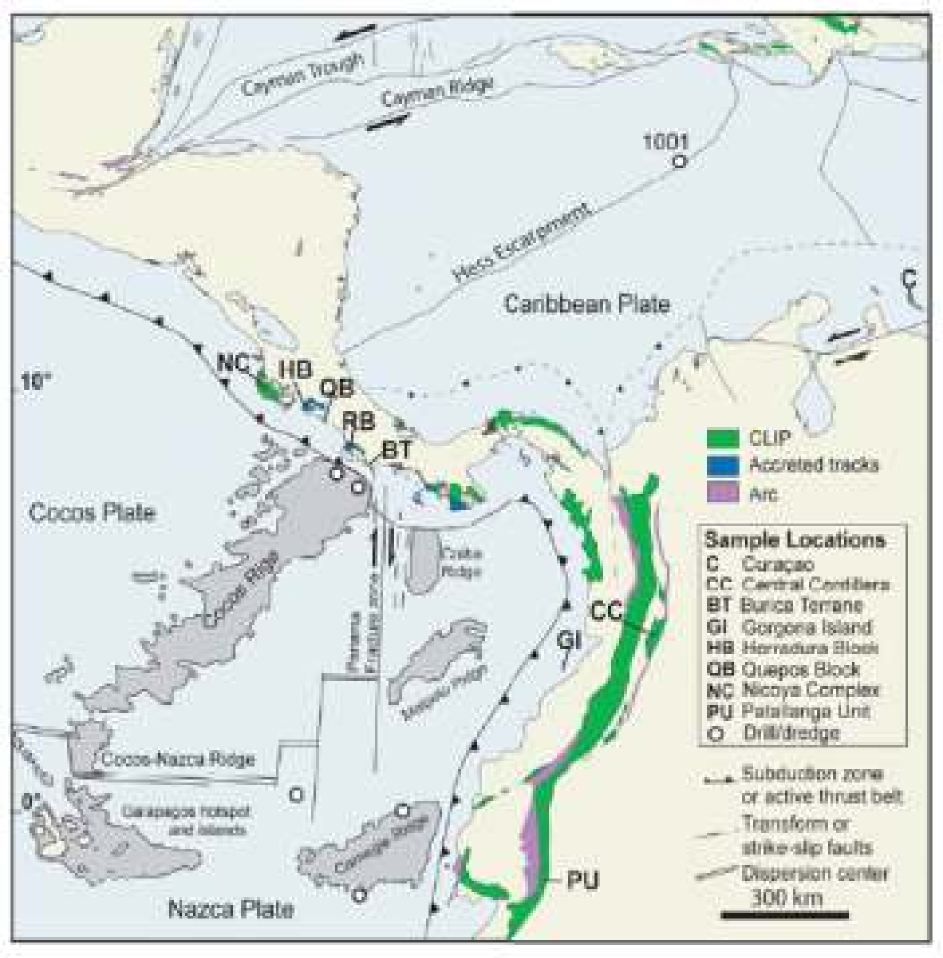


- Melt fractions are higher for LIPs than for ocean islands , consistent with suggestions of higher eruption rates.
- The high melt fractions, high T_P and vast areas of magmatism associated with the largest LIPs are all consistent with formation in mantle plume.
- Results for these OIB occurrences are interpreted as the transport of low-melt-fraction magmas from the cool plume peripheries and high-melt-fraction magmas from the hotter plume axes .
- Low-melt-fraction OIB can also form without a plume by volatile-induced melting of ambient mantle and transport through lithospheric fractures.

Summary

- The MgO and FeO contents of Galapagos related lavas and their primary magmas have decreased since the Cretaceous period
- These changes reflect a cooling of the Galapagos mantle plume from a potential temperature of 1,560–1,620 □ in the Cretaceous to 1,500 □ at present
- Iceland also exhibits secular cooling, in agreement with previous studies
- Mantle plumes for LIPs with Palaeocene–Permian ages were hotter and melted more extensively than plumes of more modern ocean islands
- Reflect episodic flow from lower-mantle domains that are lithologically and geochemically heterogeneous

Thank you !


Cayman Trough
Cayman Ridge
1001
Hess Escarpment
Caribbean Plate
C
NC
HB
QB
RB
BT
16°
Cocos Plate
Cocos Ridge
Panama Fracture Zone
Coiba Ridge
Malpelo Ridge
CC
GI
Cocos-Nazca Ridge
0°
Galapagos Hotspot and Islands
Carnegie Ridge
Nazca Plate
PU
🟩 CLIP
🟦 Accreted tracks
🟪 Arc
Sample Locations
C Curaçao
CC Central Cordillera
BT Burica Terrane
GI Gorgona Island
HB Herradura Block
QB Quepos Block
NC Nicoya Complex
PU Pallatanga Unit
○ Drill/dredge
Subduction zone or active thrust belt
Transform or strike-slip faults
Dispersion center
300 km

Era	Period	Epoch	Start (million years ag0)
Cenozoic	Paleogene	Paleocene	65.5(3)
Mesozoic	Cretaceous		99.6(9)
	Jurassic		199.6(6)
	Triassic		251.0(4)
Paleozoic	Permian		299.0(8)