Why does Venus lack a magnetic field?

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Introduction

- Venus is similar to Earth in size and composition, and has an at least partially molten iron core

- yet Venus lacks an appreciable magnetic field…why?

- possible explanation is the lack of plate tectonics on Venus

Core Heat Flux and Convection

- planetary magnetic fields are produced by motion in a planet's iron core; the motion is due to either thermal convection or compositional convection (driven by core solidification)

- maximum heat flux than can be extracted from the core without thermal convection is:

$$F_c = k\alpha g T / C_p$$

- for Venus, Fc is in the range of 11-30 mW/m^2

- thermal convection will cease if the heat being extracted from the core is less than Fc

- rate at which the core loses heat depends on the temperature difference between the mantle and the core

Heat Flux Estimates on Venus

- on Earth, the mantle is cooling (the rate of heat loss exceeds the rate at which radioactive heat is being generated by a factor of 1.7-2.7)

- the near surface heat flux can be calculated from elastic thicknesses

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Please see:

Nimmo, Francis. *Geology* 30, no. 11 (2002): 987-990

- subcrustal heat flux F is less than 10 mW/m^2

- changing some parameters give F<20 mW/m^2

- H is at least 1.5 times F

Parametrized thermal-evolution model

- Heat flux out of the core calculations: the lower thermal boundary layer has a mean thickness that keeps it at Ra_c.

- Core heat flux increases with ΔT_{CM} and with γ in viscosity formulation: $\exp(-\gamma T)$ and decreases with layer thickness

- Starts with $F_{surface}$ = heat generation rate

Consequences of Mantle Heating

- Prior to 0.6 Ga plate tectonics is active

- Heat flux drops to 15 mW/m^2 at 0.6 Ga

$\rightarrow$ T$_{Mantle}$ increases $\rightarrow$ F$_{core}$ decreases to zero over 1 b.y.

$\rightarrow$ F$_{core}$ < F$_c$ no convection in the core $\rightarrow$ no geodynamo in the present

Resurfacing stopped and heat flux dropped; stagnant lid convection starts; What is 15 mW/m^2 heat flux based on? □□
   Plate tectonics cools mantle efficiently and the core heat flux is ~ 13 mW/m^2. □□□□

The result

- Energy is conserved

- Varying parameters (viscosity, mantle layering, amount of radiogenic elements in the crust, initial temperature of the core) doesn't change the result much

- Similar results for T_{Mantle} after plate tectonics stop and for present-day $F_{surface}$ obtained by others

$\rightarrow$ the result is robust

compare to the model of Solomatov and it's similar; core is assumed in equilibrium with mantle in this model

Core solidification examined

- Core solidification may drive geodynamo even if $F_{core} < F_c$
- Amount of sulfur is unknown on Venus
- Observations: core is partially liquid
- Models with no ΔF at 0.6 Ga: high sulfur amounts $\rightarrow$ geodynamo
- Models with ΔF: independent of sulfur $\rightarrow$ geodynamo before 0.6 Ga, no geodynamo or reduction in strength after

Similar models to this were examined and they find that models without heat flux drop at 0.6 Ga examined limited parameters space and didn't always produce geodynamo Point out the reason for this sequence: conservation of energy: reduction in heat flux out of the core leads to halt in freezing. □□

Discussion

- Link between halt in plate tectonics and geodynamo

- Many uncertainties in parameters (e.g. sulfur) → unknown if geodynamo ever operated but likely

- Could be tested in principle if surface contains magnetite

Comparison with Other Bodies

- Probable that plate tectonics helps to drive geodynamo on Earth
- However, Mercury and Ganymede have geodynamos today, but

> Mercury has not had plate tectonics for 4 b.y.

> And on Ganymede tidal heating may have heated the mantle

On Earth conducting slabs increases temp. diff. between core and mantle and thus inc. core heat flux

Conclusion

- <u>Hypothesis</u>: lack of plate tectonics may explain lack of magnetic field

- Plate tectonics depends on rigidity of lithosphere and presence of water

- If true, might be used to constrain thermal histories of planetary bodies with geodynamos