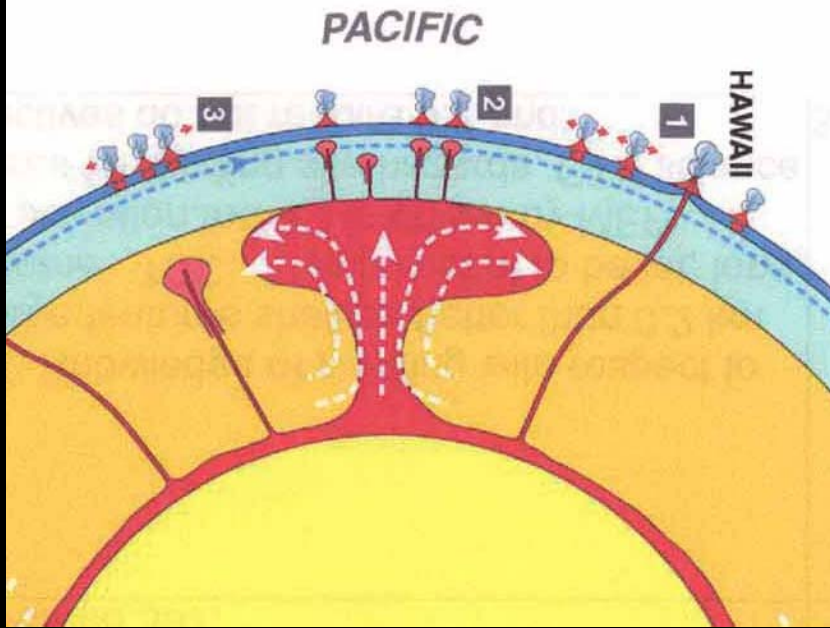
The image features three planets against a black background with scattered white stars. On the top left is a view of Earth showing blue oceans and white clouds. On the top right is a view of Venus, appearing as a greenish-brown planet with a prominent reddish-brown feature. On the bottom left is a view of Mars, showing its reddish-brown surface and several white polar ice caps. The text is overlaid on the Earth and Venus images.

**Volcanic Rises and Upwelling:
Hotspots on
Venus, Earth and Mars**

Ellen Stofan, Sue Smrekar and Paula Martin

ESLAB, 12-5-09



Hotspots

- Site of anomalous melting at the surface of a planet, that is either abundant or accompanied by a broad topographic swell (after Burke and Wilson, 1976; Crough, 1983)
- Originally hypothesized to form over relatively narrow, hot plumes that formed at core-mantle boundary (Morgan, 1971)
- Typically form island chains on Earth (Hawaii, Galapagos), very large volcanoes on Venus and Mars



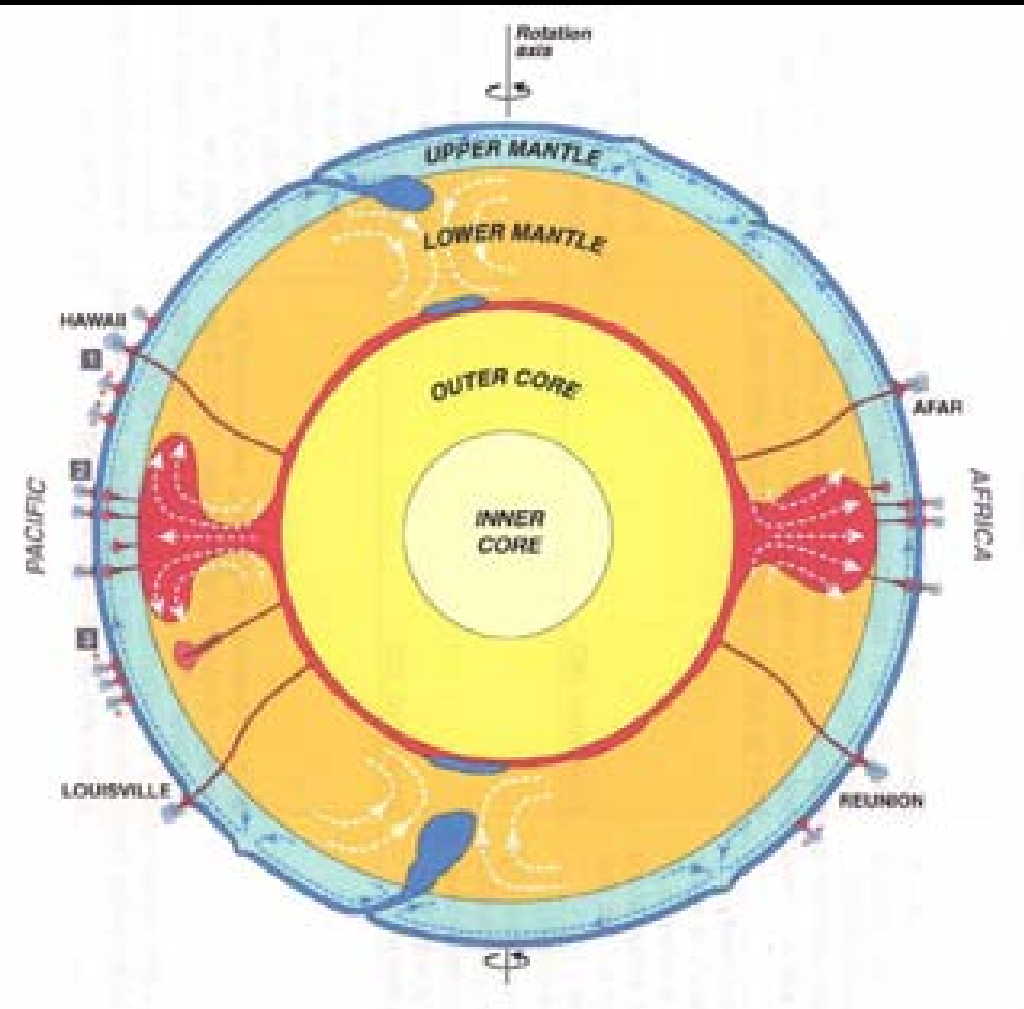


Paradigm Challenges



- Foulger et al. (2000, 2001) interpret tomographic data to indicate that Iceland lacks a deep plume
- Geochemical and seismic evidence at Yellowstone has been interpreted to not support a deep mantle plume origin (Christiansen et al., 2002).
- Other processes related to plate tectonics may be responsible for terrestrial ‘hotspots’, including propagating cracks (Hieronimus and Bercovici, 1999; Christiansen et al., 2002), melting of recycled crust (Foulger, 2002), and edge-driven convection for flood basalts at continental margins (King and Anderson, 1998).

But.....



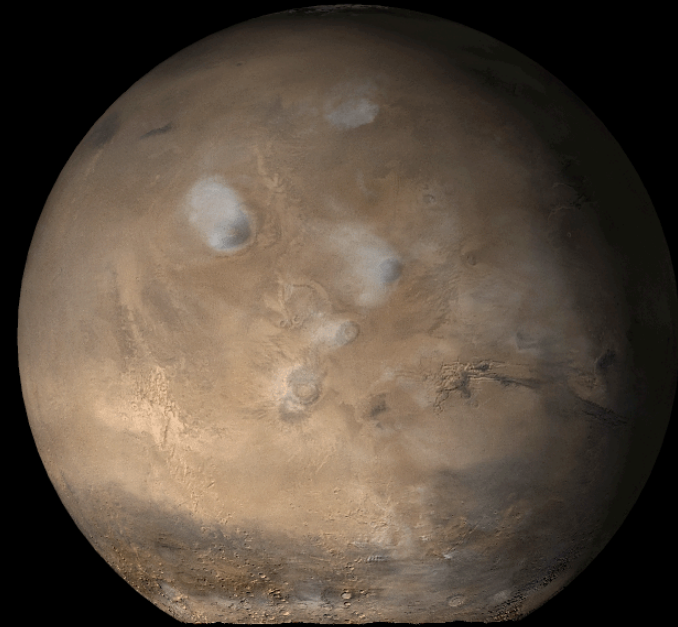
- Courtillot et al. (2003) suggested a model with three depths of plume origin:
 - Deep or core-mantle boundary plumes (~10)
 - Intermediate or secondary plumes that originate at the base of the upper mantle
 - Shallow or tertiary plumes that originate in the lithosphere.

- Hotspot features interpreted to have formed over mantle plumes have been identified on both Venus and Mars
- Comparisons between possible plume-related features on the terrestrial planets may help to constrain hotspot origin

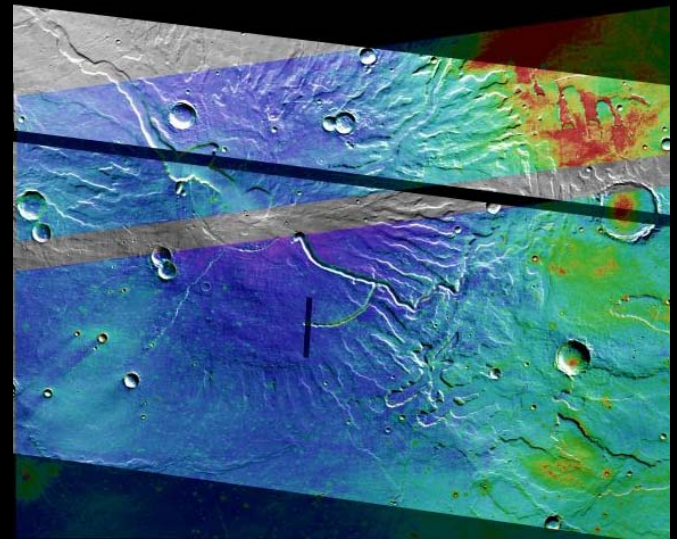
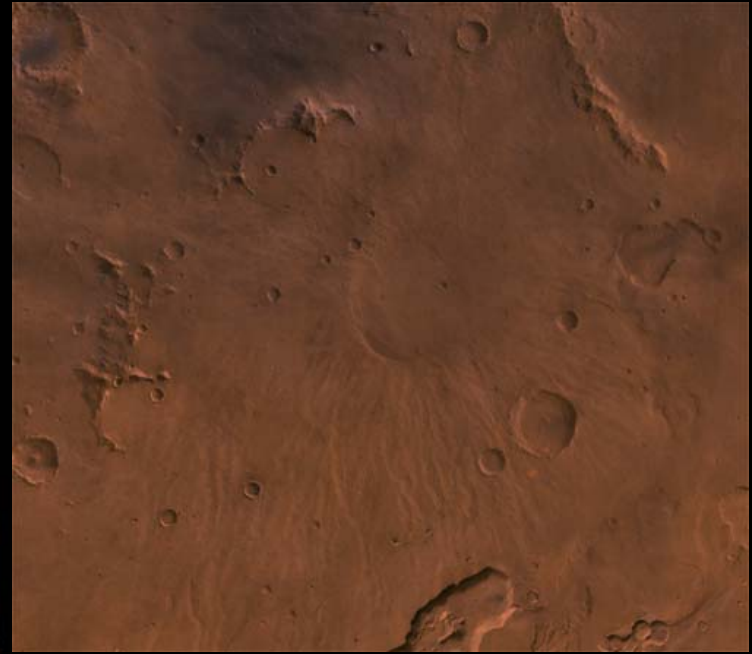


Tharsis

- Requires long duration plume to create massive rise
- Mars is relatively small and most activity occurred in the first few by
- Possible evidence for recent volcanism, within the last 1 m.y. or possibly even more recent (Hartmanm and Neukum, 2001; Neukum et al., 2004).
- Explanations include sequestering of heat producing elements in deep layers that form in an initial magma ocean (Zaranak and Manga, 2007); temperature-dependent rheology with specific characteristics (Li and Kiefer, 2007); or a major impact (Reese et al., 2004).

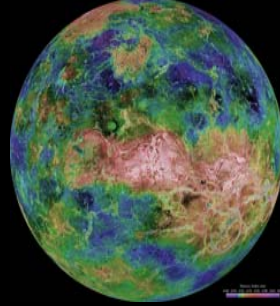


- Relatively small number of other possible hotspots-
Elysium rise, Hadriaca, Tyrrhena





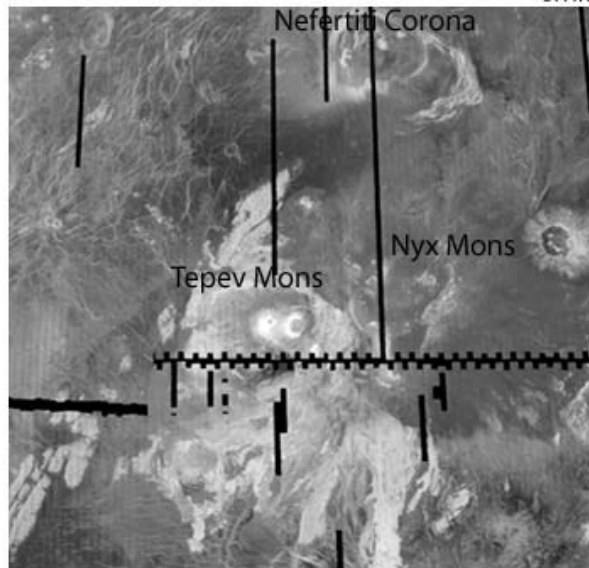
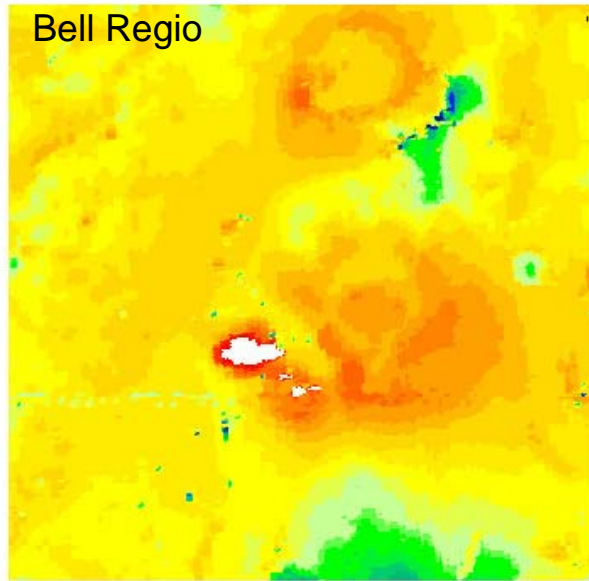
Venus



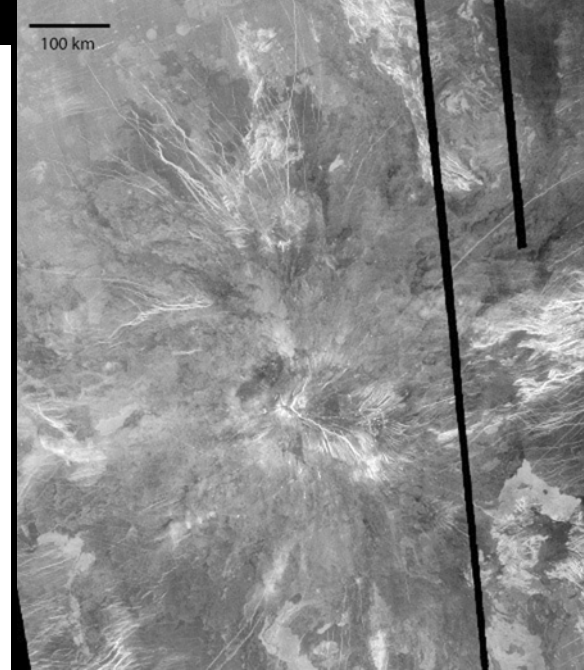
- Single plate planet, producing Earth-like amount of heat
- ~750 my crater retention age (McKinnon et al., 1997); can't reliably use impact crater population for age dating
- Debate over rate of resurfacing, origin of tessera, Ishtar
- Stagnant-lid regime (lithosphere is so dry and strong that it cannot readily be deformed)? (e.g. Moresi and Solomatov, 1998; Reese et al., 1999; Solomatov and Moresi, 2000)



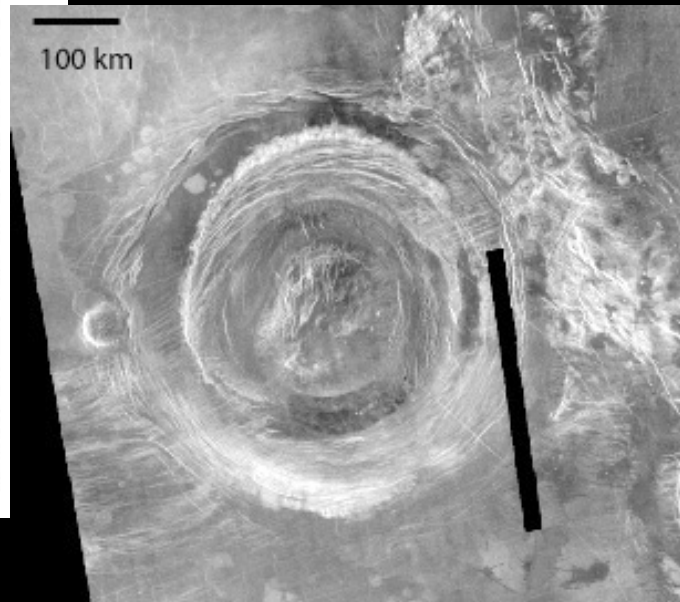
Large flow fields



Topographic rises

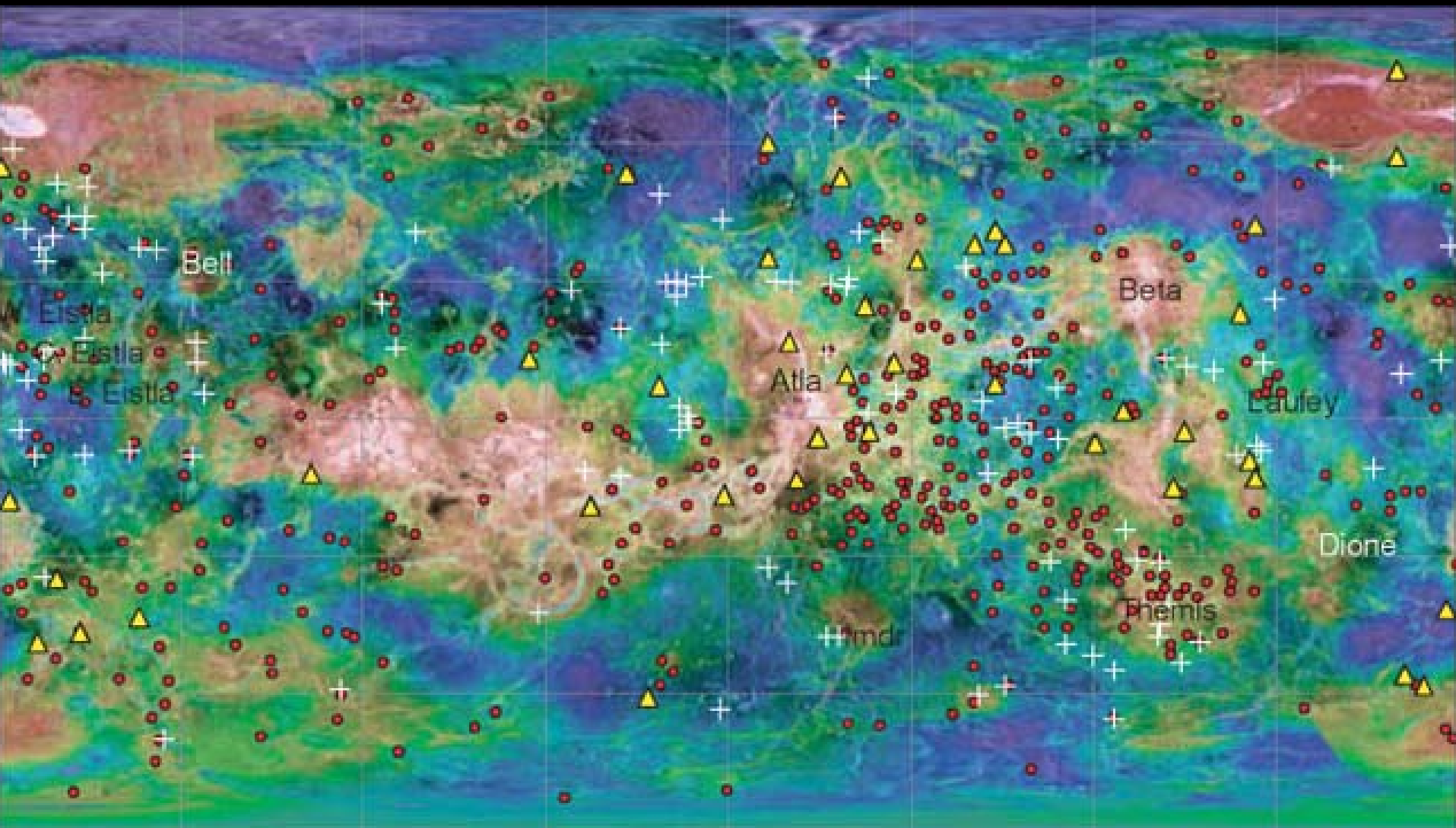


Large volcanoes



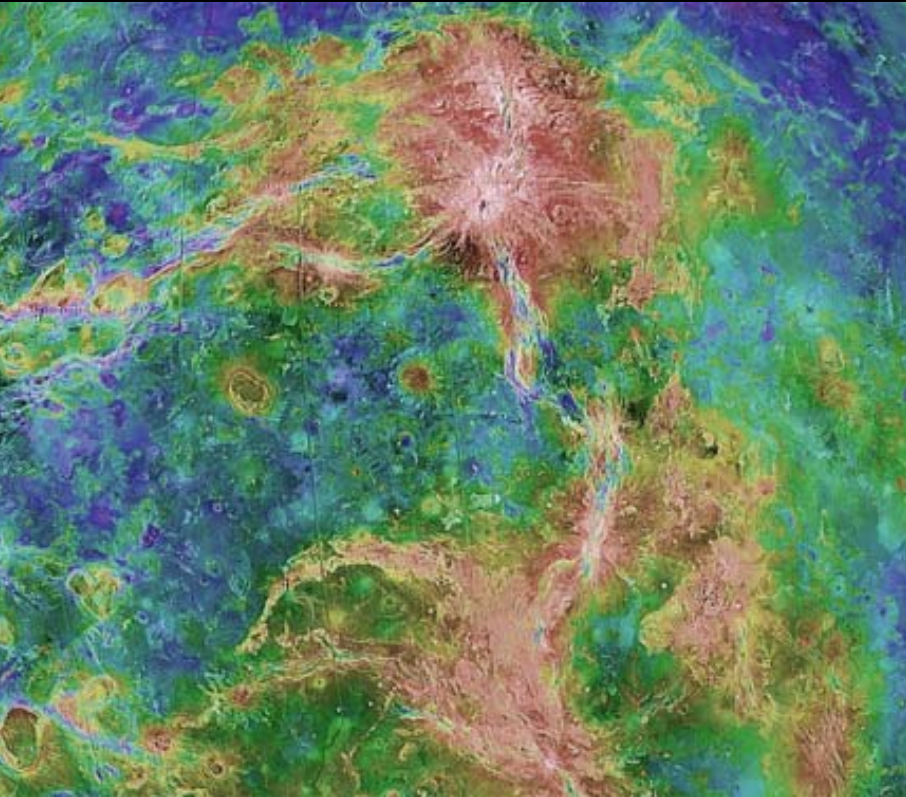
Coronae

Venus



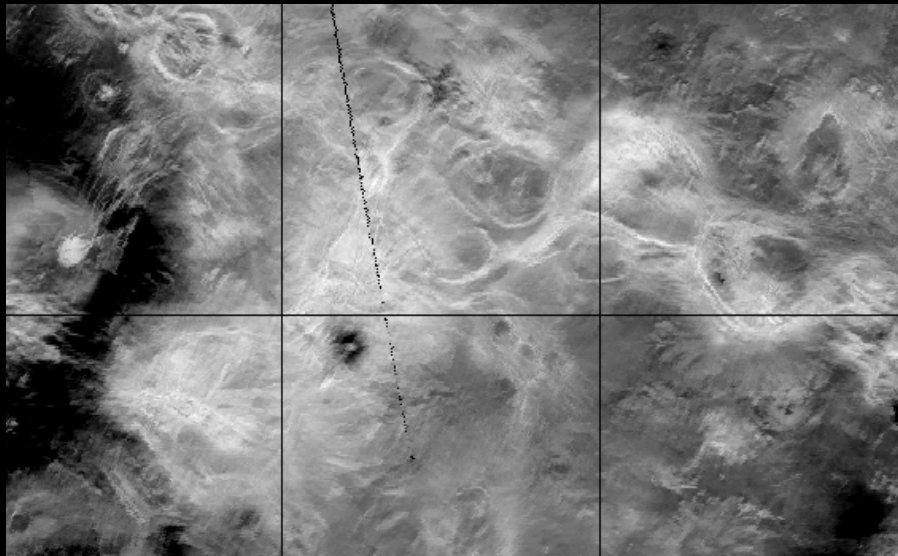
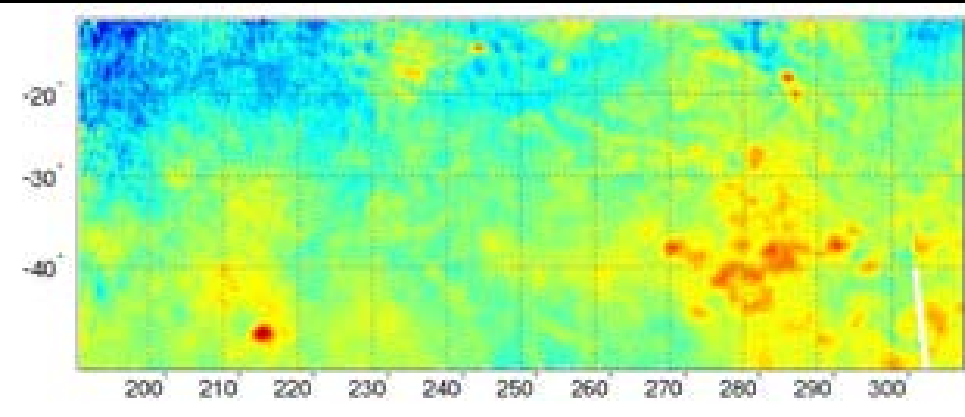
Type 1 Coronae-dots; Type 2 Coronae- crosses; Flow fields- triangles

Venusian Hotspot Rises



- Ten primary plumes on Venus (topographic rises) (Stofan and Smrekar, 2005)
- Number of deep-seated plumes for Earth debated- at least 9 from the core-mantle boundary, 8 from around the 670 discontinuity (Montelli et al., 2003)
- 513 coronae on Venus, interpreted as secondary hotspots (133 large volcanoes, 41 LIPs?)

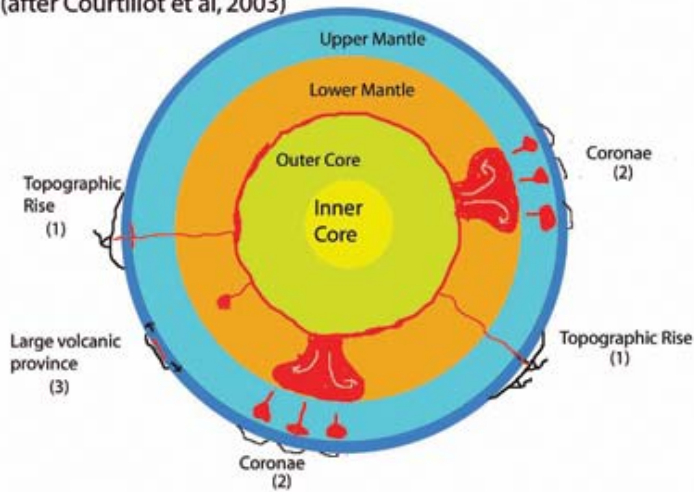
Active?



- Gravity data - some hotspots such as Bell Regio may still be active (Smrekar 1994)
- Venus Express VIRTIS data shows strong correlation between high emissivity spots and hotspots/coronae (Mueller et al., 2008, Helbert et al., 2008) (Imdr- Themis-Dione)
- Themis Regio shows strong correlations with corona and volcano flows (Smrekar et al., 2008; Stofan et al., 2009)
- Likely explanation may be unweathered (young) volcanism

- Jellinek et al. suggest absence of subducting slabs would preclude large plumes and favor formation of small plumes, but model requires deeper plumes to have formed earlier

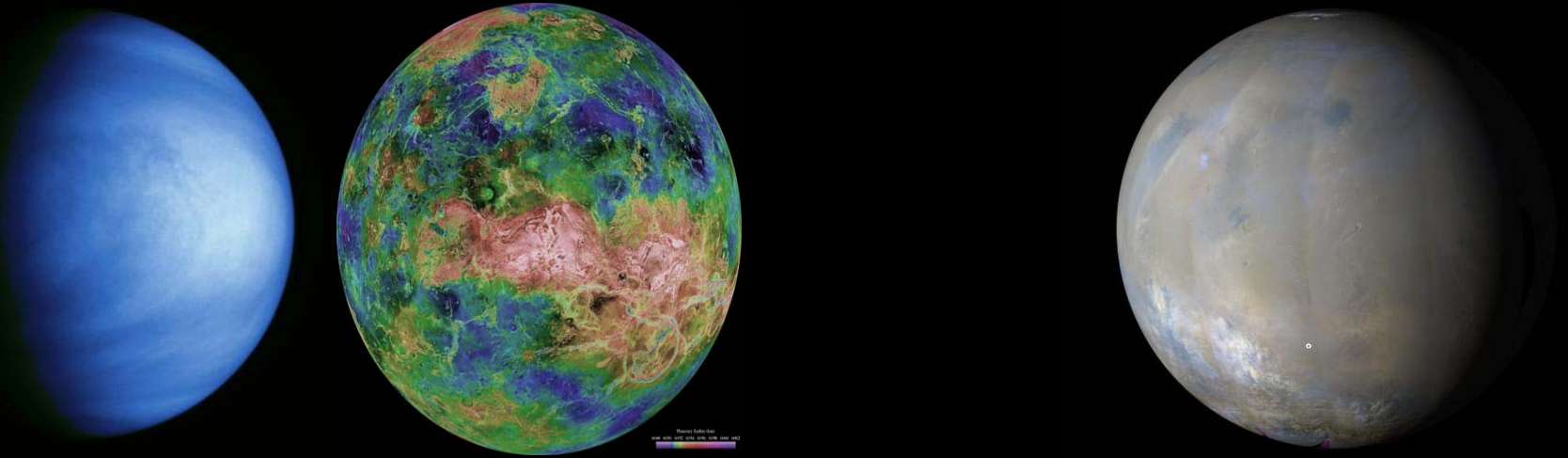
Venus Model
(after Courtillot et al, 2003)



- Coronae (secondary plumes) may result from absence of plate tectonics and proposed stagnant lid regime
- In absence of plate tectonics, secondary plumes may become a more significant heat loss mechanism



- Despite models that suggest all hotspot features on Earth not related to mantle plumes, similar features on one-plate planets Mars and Venus suggest process is important
- On Mars, fewer, older hotspots is consistent with Mars' smaller size
- Venus has Earth-like number of probable deep-seated plume-related features, but much larger number of secondary features
- On Earth, low viscosity zone and thick lithosphere could mask many secondary plumes (Smrekar and Stofan, 1997), or they may be disrupted by slabs in a mode similar to that suggested by Jellinek et al. (2002)



What we need:

Mars

- Seismic data for interior structure, age of young volcanics

Venus

- High resolution topography/surface change, composition (tessera), Constrain outgassing/escape (ocean), interior Structure (seismic data)