Hot Spot Volcanism on Venus, Earth and Mars

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Terrestrial volcanic rises have been interpreted to form over relatively narrow, hot plumes of material originating from the core/mantle boundary. Possible plume-related features like the Hawaiian Islands exhibit characteristics consistent with the general predictions of the interaction of a mantle plume with a planet's surface, including a topographic swell, abundant volcanism, and a positive gravity anomaly. More recently, the hotspot or mantle plume origin for a number of features on Earth has come into question. Processes related to plate tectonics have been suggested to be responsible for many terrestrial 'hotspots', locations of variable composition, especially volatiles, including propagating cracks, melting of recycled crust, and edge-driven convection for flood basalts at continental margins. This new view of the number of active hotspots decreased the number of unequivocal hotspots from ~30 down to ~3. Courtillot et al. (2003) put forward an alternate model that could account for some of the issues with the hotspot model, suggesting three depths of plume origin: deep or core-mantle boundary plumes, intermediate or secondary plumes that originate at the base of the upper mantle, and shallow or tertiary plumes that originate in the lithosphere. The number of deep-seated plumes for Earth is debated. Montelli et al. (2003) find at least nine plumes originating from the core-mantle boundary, and eight from around the 670 discontinuity, consistent with the Courtilot et al. (2003) model.

We recognize hotspots on Mars and Venus by analogy with terrestrial hotspots. For Mars, volcanism and mantle upwelling are dominated by the massive Tharsis rise; other potential hotspot features are Elysium and the large edifices Tyrrhena and Hadriaca Paterae. For Tharsis, the question has been how to keep surface volcanism active for over a b.y. Since Mars is relatively small, more geologic activity occurred in the 1st b.y. However, there is evidence for recent volcanism within the last 1 m.y. or possibly even more recent. Possible heat sources include sequestering of heat producing elements in deep layers that form in an initial magna ocean or temperature-dependent rheology with specific characteristics, but there is no evidence for an active plume.

Venus has nine recognized hotspots. Their gravity signatures are consistent with mantle plumes at depth. Surface emissivity data from VIRTIS shows that all 3 hotspots covered by this data set have high emissivity flows, which we interpret as relatively unweathered flows. Current volcanism has important implications for the resurfacing and climate history of Venus. Venus also has >500 coronae. Coronae are circular features 100 to 1500 km across, with an annulus of fractures and associated interior and flanking volcanism. Coronae have been proposed to be a result of small-scale mantle upwelling (perhaps originating in the upper mantle), mantle downwelling, or a combination of the two. One question for Venus is how the two scales of upwelling occur. Do coronae arise in the upper mantle and hotspots from the core mantle-boundary? Or do they require different convective regimes?

Hotspots provide a window into past or current convective regimes, heat loss from the core or elsewhere in the mantle, and internal versus bottom heating. By studying hotspots on these three terrestrial planets, we can examine how plumes interact with plate tectonics and stagnant lid convective systems, as well as how hotspot volcanism contributes to atmospheric volatiles and climate variations.