

**MAGMATISM ON VENUS: UPSIDE-DOWN MELTING IN GRAVITATIONAL INSTABILITIES AND A POSSIBLE ANALOG IN THE SIBERIAN LARGE IGNEOUS PROVINCE.** L. T. Elkins-Tanton<sup>1</sup> and S. E. Smrekar<sup>2</sup>, <sup>1</sup>MIT, Cambridge MA, LTELKINS@mit.edu, <sup>2</sup>Jet Propulsion Laboratory, Pasadena CA, suzanne.e.smrekar@nasa.gov.

**Introduction:** On Earth magmatism occurs on continents in the absence of subduction, often producing volatile-rich magmas such as those in the Leucite Hills, the Sierra Nevada, and Peru's Altiplano [1]. The primary hypothesis to explain this volcanism is foundering of the lower lithosphere into the mantle. The surface of Venus displays volcanic features indicating eruption of lavas with a wide range of viscosities, and its apparent one-plate structure is best compared to these continental settings on Earth.

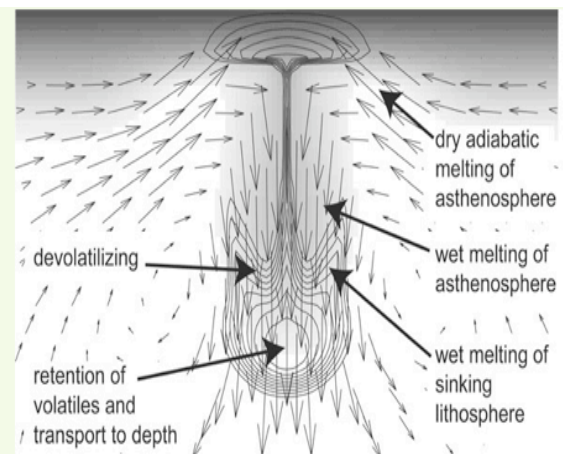
Parmentier and Hess [2] suggest that Venus has undergone cyclic catastrophic crustal recycling through gravitational instability. Both Dupeyrat and Sotin [3] and Hoogenboom and Houseman [4] suggest that eclogitization of the lower lithosphere can be a driving force for gravitational instabilities sinking from the lithosphere, the same process that has been invoked on Earth [1, 5, 6]. Instabilities may also be coupled with rising plumes [2-4, 7], which may provide both the source of the eclogitization and heat to promote ductile flow.

**Upside-down melting:** A gravitational instability forms when a perturbation in an internal planetary boundary grows through lateral flow. The material begins to sink into the underlying mantle material as a drip, exactly analogous to but reversed in the sense of growth from an ascending plume head. The unstable material will sink more rapidly than lateral flow in the lower lithosphere can feed it, resulting in an annulus of thinned lithosphere centered on the instability. Thus no dome forms in the lower lithosphere during ductile delamination. Traditionally magmatism associated with instabilities has been attributed to return flow of the asthenosphere into such a dome, but maintaining a dome in the lithosphere requires unusual rheological conditions not expected in such a setting [8].

This loss of the lower lithosphere is hypothesized to occur in response to a density contrast that may be caused by intruding mantle melts that freeze as eclogites. This mechanism requires no specific structural weakness beyond a dense region in the lithosphere that is gravitationally unstable with respect to the underlying mantle and that possesses a rheology conducive to flow. Density contrasts of as little as 1% are fully sufficient to drive gravitational instabilities.

Any volatile content in the sinking material may act in petrologically significant ways. The sinking lower lithosphere on Earth may contain 0.1 to 0.2 mass% of water even if only nominally anhydrous

minerals are present. The sinking lithospheric material heats conductively as it is surrounded by hot asthenosphere. Depending upon its rate of descent and volatile content, the sinking material may (1) devolatilize (as a descending slab in a subduction zone does), (2) carry volatiles to depth, sinking in some cases faster than slabs and thus carrying volatiles to depth more efficiently, or (3) heat sufficiently quickly to cross its solidus and itself produce magma. Because this melting in instabilities would occur as they sink, we have termed this novel melting mechanism "upside-down melting" [8] (Figure 1).



**Figure 1:** Schematic of a gravitationally-driven drip with the melting and volatile transport potentials marked. Here "wet" melting can mean melting caused by any slight incompatible element increase, for example, by an excess of potassium or carbon.

**Models for Venus:** We presented numerical experiments showing that lithospheric gravitational instabilities can produce lavas with compositions consistent with the range of volcanic forms seen on Venus in Elkins-Tanton et al. [9]. The existence of incompatible elements and their oxides (specifically, water, carbon, sulfur, and alkali elements) in even trace-level concentrations in the Venusian mantle allow the formation of a variety of magmatic source regions. The pressure and temperature paths that the dense lithospheric materials travel as they sink into the Venusian mantle indicate that the lithospheric material may devolatilize as it sinks, enriching the surrounding upper mantle, or it may itself melt [8,9].

The physical and chemical processes associated with gravitationally-driven sinking plumes can produce

magmas with a variety of compositions and viscosities, potentially consistent with the range of Venusian volcanic forms. These models predict melting in a range of source compositions in the absence of plate tectonics, creating both basaltic magmas and magmas with higher levels of incompatible elements, including alkalis and low amounts of volatiles (consistent with the suggestions of McKenzie et al. [10]).

These processes also suggests that Venus may recycle incompatible elements internally. Indeed, if Venus began with an internal volatile content, then no amount of partial melting can make it entirely volatile-free even in the absence of recycling into the interior. These models therefore suggest geodynamic processes that can produce a range of magmatic activity and retain some interior volatiles on a one-plate planet. Up-side-down melting on a one-plate planet may also provide some continuous, if minimal, contributions to the planetary atmosphere.

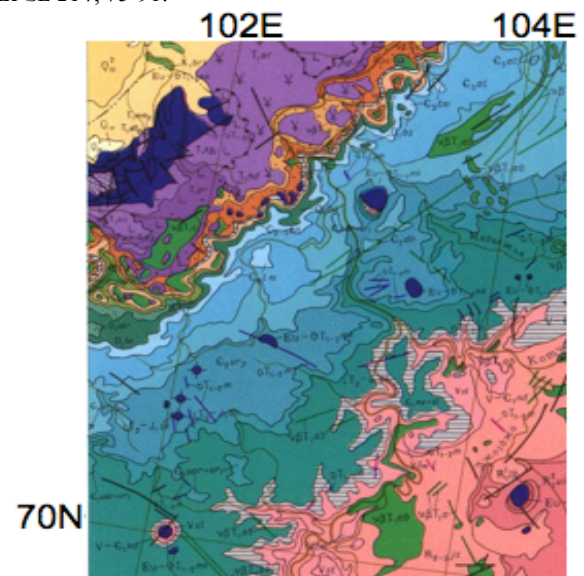
**Earth analog?** The compositions of Venusian lavas and the processes that create them on an apparently one-plate planet remain open questions. On the Earth, the best-understood volcanic processes operate at mid-ocean ridges and at volcanic arcs, both of which are the result of Earth's apparently unique plate tectonics. On Venus, a similar or even larger range of magmatic viscosities appears to be produced in the absence of plate tectonics. On Earth, the closest analog is volcanism on stable cratons, such as is seen in Siberia in the form of flood basalts, kimberlites, and carbonatite complexes [e.g. 11,12].

In the summer of 2008 Elkins-Tanton and a team of scientists visited the Guli alkaline intrusion in Arctic Siberia. This 1500 to 1800 km<sup>2</sup> igneous complex [13] consists of concentric rings of the following lithologies, starting from the center: Calcic carbonatites, magnesian carbonatites, highly metasomatized lavas (largely converted to phlogopite), alkaline lavas, and dunites and pyroxenites. The complex is certainly eroded but still indicates that deep rocks were brought up and that some violent eruptions may have occurred; the compositions are conspicuously volatile-rich.

Similar centers occur on a fairly regular spacing and may have been drips triggered by the hot plume (Fig. 2). Their lithology and deep structure may be revealed by their gravity signature: by far the highest amplitude gravity anomaly in the region is located over the Guli, with lesser gravity anomalies over the other alkaline provinces [Bradford Hager, personal communication]. This gravity anomaly has no significant topographic counterpart, suggesting that deep structure, perhaps a thin lithosphere with near-surface mantle materials, causes this anomaly.

Preliminary ages obtained from Guli rocks [14] indicate it is slightly younger than the bulk of the Siberian flood basalts, which are widely thought to have been caused by a plume. Thus intrusion of melt from the plume may have created a dense, unstable lithosphere, triggering drip formation at the lithosphere-aesthenosphere interface, and producing magmatism. Continuing studies of the compositions and structures of these Siberian alkaline provinces should inform whether or not they are consistent with gravitational instabilities, and thus may strengthen their parallel to structures and processes on Venus.

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**Figure 2.** Alkaline complexes in dark blue, showing extent and spacing, in Arctic Siberia. All associated in time with the Siberian flood basalts and thus presumably with their plume formation. Flood basalts themselves in purple. Detail from *Geological Map of the Siberian Platform* (1999).