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Possible lithospheric recycling on Venus: Results from laboratory experiments and coronae examples

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Abstract

Researchers have identified numerous sites of both possible subduction and lithospheric delamination on Venus based on the presence of flexural troughs, deformation features, and gravity anomalies [1-4]. Others argue against subduction based on the presence of characteristics of mantle upwelling, such as radial fractures attributed to doming [5]. Recent laboratory experiments [6], as well as numerical models [7], have shown that failure of heated lithosphere at the edge of a plume head can lead to the initiation of subduction. Here we present an example of this process occurring in a fluid dynamics experiment and show that the gravity data supports this interpretation at features such as Lada Terra.

1. Introduction

The possible role of plate tectonics in creating habitable zones and the conditions required to start plate tectonics are currently hotly debated due to the discovery of many Earth-sized exoplanets. The initiation of subduction is both the gateway to plate tectonics and a key link between interior convection and lithospheric rheology. Modeling the details of plate failure and the initiation of subduction is very challenging due to the complexity of plate rheology and differences in viscosity between the lithosphere and mantle. For this reason, laboratory fluid dynamic experiments play an essential role in illuminating deformation and the relationship with convection. At Lada Terra, data from the VIRTIS spectrometer [8] on Venus Express also shows high thermal emissivity [9,10], which has been interpreted to indicate geologically recent volcanism [11].

2. Methods and Results

2.1 Laboratory Experiments.

We carried out experiments on convection in aqueous colloidal dispersions heated from below, and dried and cooled from above. The rheology of these fluids depends strongly on solid particle fraction φp, being Newtonian at low φp, and presenting yield stress, elasticity, and brittle properties as φp increases [6]. So if drying is sufficiently rapid, a skin forms on the surface and may participate (or not) to the convective motions, depending on the experimental parameters [8]. More-over, we recently observed that (1) the existence of upwelling plumes help trigger subduction, the asymmetric subduction zone being localized on the rim of the plume impingement zone under the lithosphere (Fig.1); (2) depending on the lithospheric rheology, the nascent subduction can then either stop as the result of subducted plate necking, or continue to sink smoothly.

2.2 Data Analysis

Lada Terra is ~1000 km diameter topographic rise centered near 65°S, 10°E. The 800 km diameter Quetzelpetlatl Corona (QC) defines the western margin (Figure 2). The western edge of QC is defined by a trench and outer rise. The Lada Terra regions has several areas of high thermal emissivity 9]. [10] Interpreted these anomalies as indicative of variations in flow composition. [9] suggested two possible interpretations: compositional variations or unweathered basalt. [11] interpreted the high emissivity flows at other 3 large volcanic rises as indicative of recent, unweathered flow based on the prior interpretation of these regions as overlying active plumes, the position of the flows at the top of the stratigraphic column, and the fact that basaltic flows with compositions consistent with high emissivity anomalies are expected to rapidly weather to minerals with lower emissivity.

The resolution of the Magellan gravity field at LT/QC is only about degree and order 70, corresponding to a spatial scale of ~500 km. The low resolution of the data makes examining the admittance signature of little value. However, the long wavelength data do provide insight into the apparent depth of compensation for the topographic rise. At over 45 m, the geoid high at LT/QC is one of the largest geoid anomalies on Venus. The long wavelength topography peaks at just over 2 km. The geoid-to-topography ratio for LT/QC is ~25 m. This value is comparable to those of other large volcanic rises, such as Beta, Atla, and Imdr Regiones. Assuming a model of thermal (Pratt) isostatic compensation, a typical value mantle density and a thermal anomaly corresponding to a 100°C temperature difference in the plume head yields an apparent compensation depth (ADC) of ~200 km, or ~150 km with an Airy model of compensation. In either case, the depths are much larger than the thickness of the crust. As at other large volcanic rises, the broad topographic rises, the abundant volcanism, and the large GTR and apparent depth of compensation make the presence of a mantle plume at depth a reasonable interpretation. The Bouguer gravity anomaly (Fig. 2) is 150-200 gals lower under the center of QC than at the edges. This magnitude of anomaly is consistent with the presence of a subducted lithospheric slab at depth. Given the available resolution, it is not possible to distinguish contributions from a plume head, subduction (or underthrusting), or a combination of processes.

3. Figures

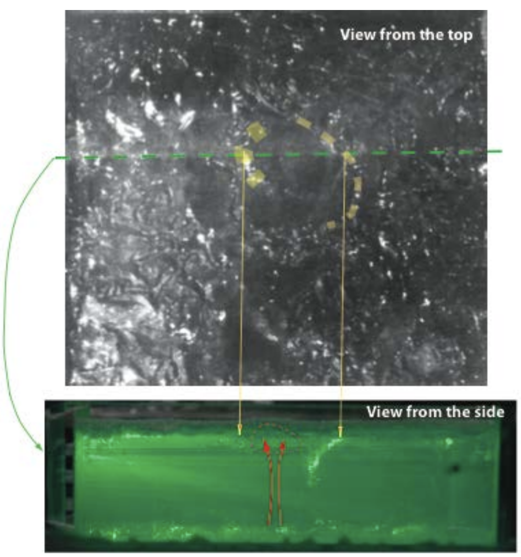

Fig.1: Experiment with a colloidal layer (4.5 cm thick) dried from above and heated from below. The side view shows the vertical cross-section along the green line in the top view. A hot plume has been highlighted in red. Its impact under the surface skin results in a topographic high, 2 circular ridges (in yellow on the top view) and two nascent subduction zones along those ridges (in fluorescent green on the side view).

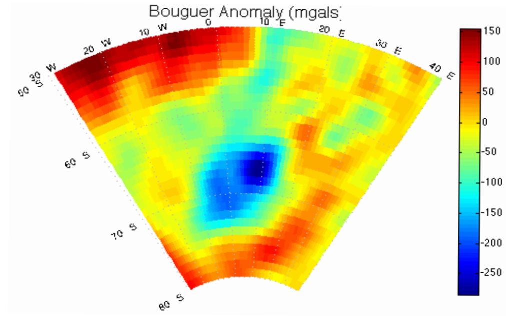

Figure 2: The Bouguer gravity at Lada Terra shows an anomaly of >100 mgals over the possible subduction site, consistent with the presence of a slab.

4. Summary and Conclusions

Laboratory experiments offer a means of linking convection and lithospheric deformation for realistic rheologies. Experiments with weaker lithosphere produce features with many similarities to Venus. One phenomenon observed in the lab is initiation of subduction at the rim of a plume head. Interpretation of geophysical data sets suggests that the trough at Quetzelpetlatl is likely an example of such limited subduction. If this is correct, Venus is an example of a sluggish rather than stagnant lid planet in that convection can produce failure and subduction of the lithosphere. Since subduction appears to be only limited, this process is distinct from terrestrial style plate tectonics.

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