GRAVITY ANOMALIES AT VENUS SHIELD VOLCANOS: IMPLICATIONS FOR LITHOSPHERIC THICKNESS .

Walter S. Kiefer, *Lunar and Planetary Institute, Houston TX 77058, kiefer@lpi.usra.edu, http://www.lpi.usra.edu/science/kiefer/home.html*, Emma-Kate Potter, *Research School of Earth Sciences, Australian National University, Canberra, Australia, ekp@rses.anu.edu.au*.

The thickness of the elastic lithosphere on Venus can be estimated from short-wavelength gravity anomalies. Such estimates provide indirect constraints on the lithospheric thermal gradient and hence are important clues about the thermal evolution of Venus. Two very different models have been proposed. In one model, mantle convection is vigorous, with a thin lithosphere and roughly Earth-like heat flow [1-3]. Alternatively, a much thicker lithosphere and low heat flow has also been proposed [4,5].

Many previous estimates of elastic lithosphere thicknesses for Venus have been for features where present-day mantle convection may be important. In some circumstances, convection can produce large short-wavelength gravity anomalies which may bias attempts to estimate the elastic lithosphere thickness [1,6]. If this occurs, the estimated lithosphere thickness will be larger than the true thickness. As a result, the heat flow would be underestimated.

Method

In this work, we model the gravity anomalies for several large shield volcanos in the plains of Venus. Active convective upwellings are typically associated with large geoid amplitudes [7,8]. In order to minimize the possible effect of convection on our estimates of lithospheric thickness, we therefore only consider volcanos where the regional geoid anomaly is relatively small. In order to maximize the detectability of the volcano in the gravity field, we only consider volcanos with radii of at least 100 km and central heights of at least 1 km. Because our modeling is done in the spatial domain, we only consider features with uncomplicated regional free-air gravity anomalies, so that it is clear that the observed gravity anomaly corresponds to the modeled volcano.

We model each volcano as the superposition of several axisymmetric Gaussian loads. The load models are based on fits to high resolution (GTDR) topography data, although the short-wavelength details of the topography (see Figure 1 a,c) are not important to the gravity results. Flexure is calculated using the method of Cyr and Melosh [9,10]. We assume a Young's modulus of 10^{11} Pa and a basaltic crust that is 25 km thick with a density of 2900 kg m^{-3}.

Model gravity anomalies are calculated by summing the contributions from the topography and from deflection of the crust-mantle interface. The model gravity anomaly is then filtered to correspond to the resolution of the observed gravity field. In this work, we have used the spherical harmonic degree 120 representation of the gravity field. Although a degree 180 field is also available [11], many of the terms above degree 120 are not well determined. We therefore consider it safer to use the degree 120 field for this work. The actual resolution of the gravity field varies with location. We use the degree strength map and the width of the observed gravity anomalies as guides in selecting appropriate filters for the model gravity anomalies.

The elastic lithosphere thickness is determined from the best fit between observed and model gravity anomalies. Figure 1 shows results for Kali Mons and for Kunapipi Mons. The two volcanos have similar basal radii and central heights and yet differ in their observed gravity anomalies by more than a factor of two. This implies different elastic lithosphere thicknesses in the two areas, 20 km at Kali Mons and 10 km at Kunapipi Mons. For both regions, the observed gravity anomaly is broader in the north-south direction (long dashed lines) than in east-west direction (dotted lines). Because of the near-polar orbit of the Magellan spacecraft, high order terms of a given harmonic degree are better determined than low order terms of the same degree [11]. As a result, east-west variations in the gravity field are probably better determined than north-south variations. The model fits (solid lines) in Figure 1 therefore emphasize the fit to the east-west gravity profiles.

We estimate uncertainties in the elastic thickness by fitting the observed peak amplitude plus and minus twice the estimated uncertainty in the gravity field. Typically, this gives an uncertainty (2 sigma) in the elastic thickness of about 10 km. Konopliv et al. believe that at short wavelengths the estimated uncertainty in the gravity field amplitude may be too large by as much as a factor of two [11]. Because our results are dominated by short wavelengths, our estimated error bars on the elastic thickness determinations are quite conservative. In three instances, we have modeled two volcanos in a given geographic region. In each instance, there is good agreement in the estimated elastic thicknesses. This agreement reenforces our assessment of the overall accuracy of the results.

Results

Eastern Eistla: We estimate elastic thicknesses of 20 km for Kali Mons and 22 km for an unnamed volcano at 3N, 45E. Both volcanos are just outside the region studied by Smrekar and Stofan, who estimated an elastic thickness of 20 km for a long-wavelength, bottom loading admittance model [12].

Dione Regio: We estimate elastic thicknesses of 22 km for Hathor Mons and 17 km for Innini Mons. No other gravity results are available for this region.

Tuulikki Mons: We estimate an elastic thickness of 8 km for Tuulikki Mons. Simons et al. estimated an elastic thickness of 10 to 20 km for the Beta Regio region as a whole [2].

Kunapipi Mons: We estimate an elastic thickness of 10 km for this volcano in Aino Planitia.

Kawelu Planitia: We have modeled Sekmet Mons and Atira Mons. Because the gravity field resolution decreases at high northern latitudes, we have only estimated upper bounds on the lithosphere thickness for these volcanos. For both, we find an upper bound of 10 km.

Implications

All of the elastic thicknesses determined in this study are in the lower range of previous elastic thickness estimates for Venus, supporting the thin lithosphere interpretation of Venus.

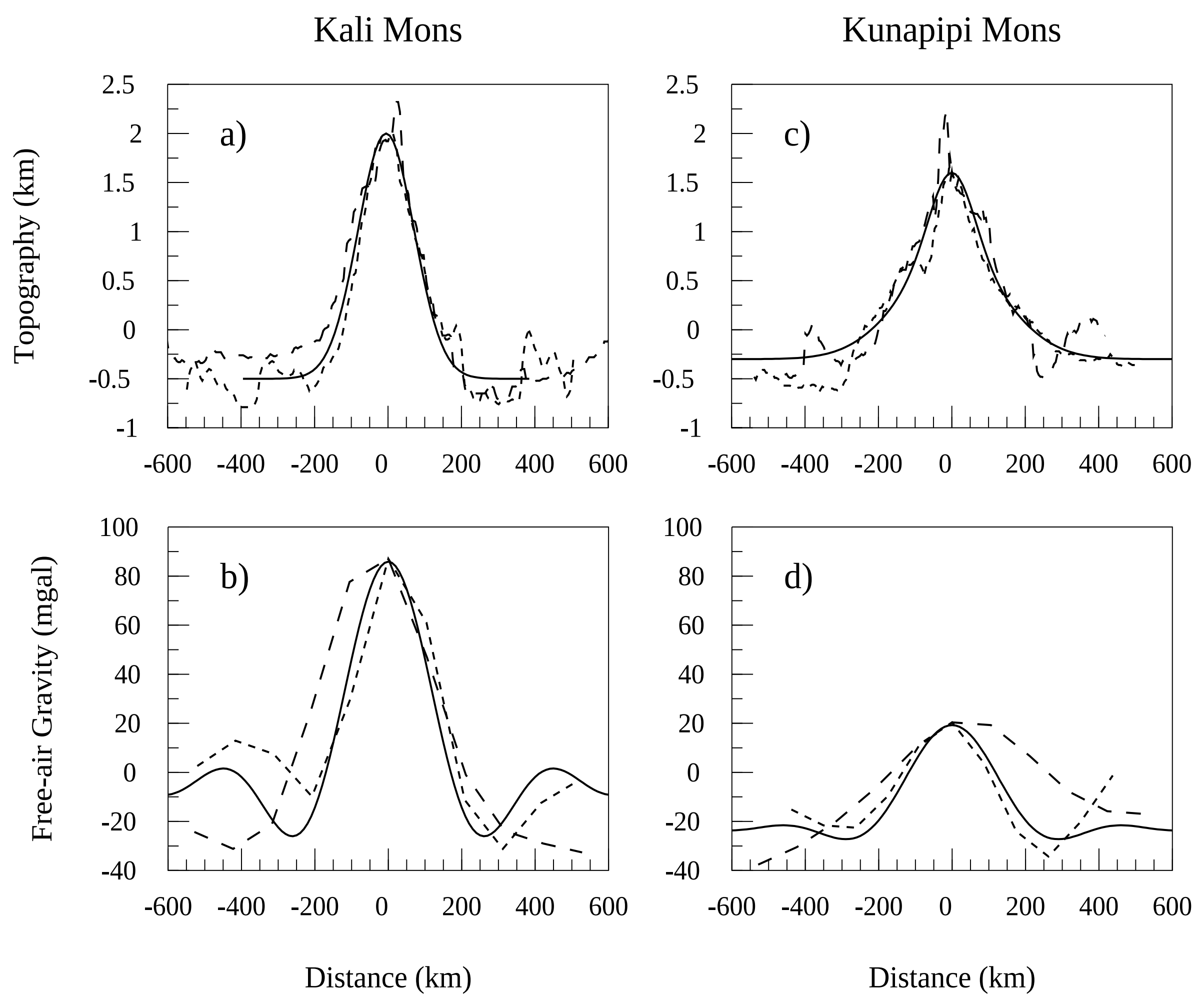

Figure 1: Model results for Kali Mons and Kunapipi Mons. In all cases, the solid lines are the best model fits, the long dashed lines are north-south profiles across the volcano, and the dotted lines are east-west profiles across the volcano. Negative distances are south or west of the volcanic center.

The low values derived here also support suggestions [1,6] that some previous estimates of elastic thickness may have been contaminated by a mantle convection signal and hence overestimated the true elastic thickness.

The elastic strength of rocks disappears at high temperature, so the thickness of the elastic lithosphere is a strong function of the lithospheric thermal gradient. A simple strength envelope analysis shows that a 10 km thick elastic lithosphere on Venus corresponds to a 15 K/km mantle thermal gradient. This implies a heat flux out of the mantle of 60 mW/m^2, which is similar to the present-day average mantle heat flux on Earth. A more precise thermal gradient estimate requires consideration of plastic yielding and conversion of the elastic thickness to a mechanical thickness [13,14].

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