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NASA GRANT NAGW-4784: FINAL REPORT

Bounds on Lithospheric Thickness on Venus from Magellan Gravity and Topography Data

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1. SUMMARY

The primary objective of the work executed under NAGW-4784 is to provide constraints on the thermal and tectonic evolution of Venus. Establishing thermal and tectonic evolution models requires not only geological, but geophysical constraints, in particular the nature of temporal and spatial variations in crustal and lithospheric thickness. The major topics of study completed under NAGW-4784 (described more fully below) are

- detailed analyses of the resolution of Magellan line-of-site (LOS) Doppler data to establish the minimum resolvable wavelength in the gravity data
- calculations of the global strain field in the venusian lithosphere and comparisons with global strain patterns from geological mapping
- study of the geological history of coronae at E. Eistla Regio
- estimation of crustal and lithospheric thickness by modeling of topography at asymmetric and symmetric rift-like chasmata
- preliminary investigations of spatial versus temporal variations in lithospheric thickness

Both the PI and Co-I have presented papers based on these topics at national and international meetings (American Geophysical Union Meetings, Lunar and Planetary Science Conferences, Chapman Confernce on the Geodynamics of Venus). In addition, during the period of funding under this grant, the PI served on NASA's Planetary Cartography and Mapping Working Group, and supervised Planetary Geology and Geophysics summer intern, Eric Hargrave.

The work completed under this grant has resulted in the publications and abstracts listed in the following section.

2. PUBLICATIONS

2.1 Refereed Publications:

Sandwell, D. T., C. L. Johnson, F. Bilotti & J. Suppe, Driving Forces for Limited Tectonics on Venus, *Icarus,* **129**, 232-244, 1997

Phillips, R. J., C. L. Johnson, S. J. Mackell,, P. Morgan, D. T. Sandwell, & M. T. Zuber, Lithospheric Mechanics and Dynamics of Venus, *chapter in Venus II*, University of Arizona Press, in press

Johnson, C. L., S. C. Solomon & D. T. Sandwell, Global and Regional Resolution Analyses of Magellan Gravity Data, *in preparation*

2.2 Abstracts:

Johnson, C. L., P. J. McGovern, S. C. Solomon, D. T. Sandwell & M. Simons, Lithospheric Thickness Variations on Venus, Chapman Conference on Geodynamics of Venus, 1997

Johnson, C. L., S. C. Solomon, D. T. Sandwell & M. Simons, Global and Regional Resolution Analyses of Magellan Gravity Data and Comparisons with Current Gravity Models, Chapman Conference on Geodynamics of Venus, 1997

Johnson, C. L, E. Hargrave, M. Simons & S. C. Solomon, Old and young coronae on Venus: combining regional and global studies to constrain thermal evolution models, LPSC **XXVIII**, 665-666, 1997

Johnson, C. L., S. C. Solomon, D. T. Sandwell & M. Simons, Global and regional resolution studies of Magellan gravity data: Implications for inferring lithospheric thickness, LPSC **XXVIII**, 667-668, 1997

Simons, M., C. L. Johnson & S. C. Solomon, Localization and spectral resolution of Venus gravity data: new constraints on the thickness of the elastic lithosphere, LPSC **XXVIII**, 1321-1322, 1997

Simons, M., C. L. Johnson, P. J. McGovern & S. C. Solomon, Localization and spectral resolution of Venus gravity data: new constraints on the thickness of the elastic lithosphere, AGU Fall Meeting Program (due to an AGU error this abstract was not printed in the abstract volume), 1996

Johnson, C. L. & S. C. Solomon, Variations in lithospheric properties on Venus from coronae and chasmata; *LPSC* **XXVII**, 607-608, 1996

Sandwell, D. T. & C. L. Johnson, Driving Forces for Limited Tectonics on Venus, *EOS Trans AGU*, **76**, 333, 1995

Johnson, C. L. & D. T. Sandwell, Regional Resolution Analyses of Magellan Gravity Data, *LPSC* **XXVI**, 681-682, 1995

3. RESEARCH DESCRIPTIONS

3.1 Resolution Analyses of Magellan Line Of Site (LOS) Gravity Data

Collaborative work with Co-I, Professor David Sandwell. Global and regional multi-taper spectral analyses of the Cycle 5 and Cycle 6 LOS Doppler velocity residuals indicate substantial spatial variation in the resolution of Magellan gravity data. As expected, major factors influencing resolution are spacecraft altitude, viewing geometry, and noise levels; our analyses enable us to empirically quantify these relationships. Extracting the maximum resolution from the gravity data is extremely difficult, because of the inherently red spectra and the short time series (a typical 3000 km LOS orbit arc is only 250 points). The best resolution in the data over large areas is at Ovda, Ishtar and Bell and is greater than spherical harmonic degree 120. Locally, the resolution can be significantly greater than the regional average; at Mead Crater the local resolution in the data is degree 140. Our results indicate spherical harmonic field models to degree and order 180 - 200 are justified by the LOS data and would permit the interpretation of localized spectra (which always have a resolution less than the maximum degree of the spherical harmonic model) everywhere out to the maximum resolution inherent to the dataset.

3.2 Driving Forces for Limited Tectonics on Venus

Collaborative work with Co-I, Professor David Sandwell, and also Professor John Suppe and his former graduate student Frank Bilotti (Princeton University). Poster presented at the 1995 Fall AGU Meeting, and manuscript published in Icarus.

This work involved the development of a model for stresses in the venusian lithosphere using the degree and order 90 spherical harmonic model for the geoid. For isosatic and particular classes of dynamic models of compensation of topography, the geoid height uniquely determines the magnitude of the body forces within the venusian lithosphere. This allows the calculation of the global strain field, predicted by the geoid. We have compared this with global strain maps of wrinkle ridges and rifts produced by Suppe and Bilotti. The calculated stresses provide an estimate of the overall strength of the venusian lithosphere and can be compared with predictions with rheological models of yield strength, in regions where rifting of the lithosphere is evident (e.g. Atla and Beta Regiones). The stresses predicted by our model constrain the temperature gradient in these regions to be at least 7°K/km.

3.3 Geology of Eastern Eistla Regio Coronae

PGGURP intern, Eric Hargrave, was involved in mapping the geology of six major coronae of Eastern Eistla Regio, under the supervision of the PI. E. Eistla Regio (30°-60° E, 5°-25° N) was mapped at the scale of the C1-MIDR SAR images, with the aid of F-MIDRs and topography. The motivation behind this study was to compare surface geological units and temporal extent of formation of coronae in a region which appears to have been thermally rejuvenated, and where from a geophysical standpoint, one might expect the coronae to have formed relatively recently. Mapping concentrated on six major coronae in the region. The simplified geologic history of eastern Eistla Regio consists of: tessera formation, emplacement of regional plains and formation of two "old" corona, regional deformation, formation of four major "young" coronae and volcanism from intermediate-sized volcanoes, and the formation of a rift zone (possible new corona). There are significant overlaps in timing among many of these events.

3.4 Application of Asymmetric and Symmetric Rift Models to Chasmata on Venus

Preliminary work involving the application of asymmetric and symmetric rift models (e.g. *Weissel and Karner*, 1988), developed for terrestrial rifts to rift-like chasmata on Venus indicates effective elastic lithospheric thicknesses of 23 - 37 km. These have been integrated with other estimates of elastic thickness from coronae to investigate spatial versus temporal variations in lithospheric thickness.

3.5 Preliminary Studies of Spatial versus Temporal Variations in Lithospheric Thickness

Estimates for elastic thickness fom topographic flexural signatures on Venus come mainly from coronae and chasmata. These estimates of elastic thickness can be subdivided into three groups, those obtained from coronae in the plains (5 - 24 km), those from coronae in corona chains (15 - 18 km) and those from coronae in chasmata and from chasmata themselves (23 - 37 km). One of the main disadvantages of lithospheric thickness estimates obtained from topography data alone is that we cannot distinguish between temporal and regional variations in our estimates. To address this question we have re-classified coronae according to their association with plains regions, chasmata or corona chains. We then investigated impact crater densities for these classes of coronae, in order to investigate whether the variations in lithospheric thickness correlate with variations in surface age. The results indicate that coronae in the plains have an age indistinguishable from the age of the global resurfacing event (GRE). Coronae in the chasmata and in coronae chains have an age approximately half that of the time to the last GRE, when all the impact craters are considered. As noted in other studies, the chasmata regions contain a significant fraction of the tectonized and embayed craters; if these craters are assumed to predate the formations of chasmata and the cornae within the chasmata, then the age of these features is on average less than half the age of the GRE. These age estimates and estimates of mechanical thickness can be combined and compared with the predictions for lithospheric thickness assuming that the lithosphere had zero thickness at the time of the last GRE, and that heat loss has been solely due to conduction since then. These results have some important implications. First, the processes which generate coronae have persisted since the last GRE. Second, recent spatial variations in lithospheric thickness are at least as great as temporal variations since the last GRE. Third, the last global resurfacing event did not correspond to an event in which the lithosphere was completely destroyed.