GEOPHYSICS AT MARS: ISSUES AND ANSWERS; R.J. Phillips, Dept. of Geological Sciences, Southern Methodist University, Dallas, TX 75275

Introduction. The tectonic and volcanic evolution of Mars is strongly coupled to the evolution of the martian mantle, which has delivered mass and heat to the martian lithosphere over geological time. Understanding the evolution of the martian mantle and unraveling the tectonic and volcanic history are tightly coupled because in the absence of seismic data, surface information and gravity data are the major ways to constrain interior processes. The overall problem is highly underdetermined, but some progress has been made in the sense that there are not an infinite number of interior models that will satisfy the topographical, gravitational and geological constraints available.

Model results for the Global Dichotomy Boundary (GDB) are limited. There is general agreement that this boundary is isostatically compensated, and any scenario that attempts to explain the gross differences between the two hemispheres must include processes that extend to at least the crust-mantle boundary. The global center-of-figure to center-of-mass offset is explained by a combination of an isostatically compensated GDB and a nearly compensated Tharsis.

Most geophysical modeling of Mars has concentrated on the Tharsis and Elysium provinces. Central to these considerations are the relative roles of structural uplift and volcanic construction in the creation of immense topographic relief [1,2]. The origin, classification, and relative timing of tectonic features has also been a subject of focused study [3,4].

Stress Modeling. The observation of grossly organized tectonic patterns associated with Tharsis (and to a lesser extent Elysium) have led to the formulation of a number of theoretical elastic and isostatic models of the interior [5-8]. Such models are constrained by the observed gravity and topography, satisfy the equations of mechanical equilibrium, and are used to predict stress type, magnitude, and direction in the lithosphere. The results depend on the estimate of the nonhydrostatic component of the second zonal harmonic of gravity, J_2. This estimate and the corresponding estimate of the mean moment of inertia have been the subject of recent debate [9,10].

If tectonic features on Tharsis can be separated into stratigraphic groups with relative age firmly established [3], and if these groups can be related to specific mechanical models of the interior, then scenarios for interior evolution can be worked out. Generally, three types of mechanical models have been recognized: (i) isostatic, (ii) flexural loading, and (iii) flexural uplift. In model (i) the flexural rigidity D is set to zero and the stress distribution is governed solely by membrane and gravitational forces. Addition of a non-zero D leads to a different stress distribution, which depends on whether the lithosphere is loaded from above [model (ii); e.g., volcanic piles] or loaded from below [model (iii); e.g., buoyant uplift]. Model (i) cannot distinguish isostatic loading from isostatic uplift.

Graben in the Claritas Fossae region of Tharsis are mapped as Early Noachian in age [3]. Flexural uplift models predict extensional stresses at Claritas Fossae [8] that are approximately orthogonal to the mapped tectonic features [11]. This suggests that flexural uplift was an early phase in the tectonic evolution of Tharsis. To first order, radial graben and fractures on the periphery of Tharsis are consistent with flexural loading models [5-7], while tectonic features in the immediate Tharsis area are best explained by isostatic models [6,7]. *Detailed* matching of stress predictions with tectonic features is more problematical. This is partly due to the extremely poor knowledge of martian topography and partly because all modeling efforts have no choice but to use the present-day values of the gravity field and topography to predict ancient stress fields. The most complete modeling to date uses spherical harmonic coefficients of the field quantities to degree and order eight [8]. While this model has more resolution than earlier fourth degree models, it may also be noisier. Locally, predictions are successful in some regions but do not match as well as earlier models do in other regions (e.g., Valles Marineris). Attempts to match stratigraphically assigned fracture/graben sets to either flexural loading or isostatic models have also not been successful because of inadequate azimuthal resolution of the stress trajectories in the two types of models.

Petrological Models Related to Geophysics. All of the mechanical models carry an interior density distribution required to match the gravity and topography boundary conditions. Isostatic models, for example, are composed of a low density Pratt-like region in the upper mantle and a thinned crust beneath Tharsis. Flexural loading models carry a thickened crust. The Pratt zone in the isostatic model can be interpreted in terms of a low density mantle residuum formed by partial melting that produced basaltic magmas [12]. Isostatic models have been formulated that satisfy the gravity and topography boundary conditions and conserve mass in a partial melting sequence. More recent work [11] has concentrated on the implications of a requirement for uplift, as suggested by the fault distribution and elevation of Claritas Fossae. While most of the buoyancy for uplift is provided by a low density residuum, a crustal extrusive load will strongly counteract this effect unless it is only a small portion of the melt products generated beneath Tharsis. Thus most of the Tharsis magmas may have ended up as intrusive bodies in the crust and upper mantle. During the period of intense tectonism of Tharsis (Hesperian time and earlier), volcanism was not as active at Tharsis as it was on other parts of Mars [13]. Later (Late Hesperian, Amazonian), Tharsis accounted for about half of the planet's volcanism. The picture that is emerging is that early in the history of Tharsis, massive intrusion led to tectonic disruption of the surface. Subsequently, magmas made their way to the surface and tectonism waned. The reason for this evolution may have been decreasing melt density as the partial melting process evolved toward lower iron content of basaltic magmas. The concept of massive intrusion leading to the immense relief of Tharsis blurs the distinction between uplift and constructional models.

Future Directions. While geological mapping of Tharsis has reached a high level of maturity, there are major areas of geophysical modeling yet to be carried out. Time-dependent thermoelastic modeling has not been considered, nor has stress modeling with the majority of the flexural load in the form of intrusive bodies. Considerable work on the spatial and temporal variation of elastic lithospheric thickness [14] and inferred temperature gradient [15] has not been incorporated into the regional-scale stress modeling described above. The accuracy and resolution of stress modeling will undergo marked improvement with the topography and gravity field information to be acquired by Mars Observer. Finally, some of the models for the origin and evolution of Tharsis, which predict specific differences in magma composition as a function of age, can possibly be tested with data acquired by the remote sensing instruments on Mars Observer.

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