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Elysium Region, Mars: Tests of Lithospheric Loading Models for the Formation of Tectonic Features

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The second largest volcanic province on Mars lies in the Elysium region. Like the larger Tharsis province, Elysium is marked by a topographic rise and a broad free air gravity anomaly and also exhibits a complex assortment of tectonic and volcanic features. We test the hypothesis that the tectonic features in the Elysium region are the product of stresses produced by loading of the Martian lithosphere. We consider loading at three different scales: local loading by individual volcanoes, regional loading of the lithosphere from above or below, and quasi-global loading by Tharsis. A comparison of flexural stresses with lithospheric strength and with the inferred maximum depth of faulting confirms that concentric graben around Elysium Mons can be explained as resulting from local flexure of an elastic lithosphere about 50 km thick in response to the volcano load. Volcanic loading on a regional scale, however, leads to predicted stresses inconsistent with all observed tectonic features, suggesting that loading by widespread emplacement of thick plains deposits was not an important factor in the tectonic evolution of the Elysium region. A number of linear extensional features oriented generally NW-SE may have been the result of flexural uplift of the lithosphere on the scale of the Elysium rise. The global stress field associated with the support of the Tharsis rise appears to have influenced the development of many of the tectonic features in the Elysium region, including Cerberus Rupes and the systems of ridges in eastern and western Elysium. The comparisons of stress models for Elysium with the preserved tectonic features support a succession of stress fields operating at different times in the region. While the order in which those stress fields operated cannot be determined from present geological observations, thermal and mechanical arguments favor the hypothesis that any flexural uplift of the lithosphere by a mantle thermal anomaly preceded or occurred contemporaneously with emplacement of the largest volcanic loads.

INTRODUCTION

The tectonic history of the planet Mars has been dominated by the formation and evolution of several major volcanic provinces, notably those in the regions of Tharsis and Elysium. The Tharsis province, because it is the largest, has received the most attention. Two general categories of models have been proposed to explain the topography, gravity, and tectonic features of the Tharsis region. According to the first type of model, uplift of ancient lithosphere by a chemical or thermal anomaly in the crust or mantle created a broad topographic dome and led to widespread fracturing and to the emplacement of relatively thin volcanic plains units and isolated volcanic shields [*Hartmann*, 1973; *Carr*, 1974; *Sleep and Phillips*, 1979; *Wise et al.*, 1979*a*, *b*; *Plescia and Saunders*, 1980]. This uplift may have occurred isostatically or by a flexural uplift of the lithosphere [*Banerdt et al.*, 1982]. In the second type of model the Tharsis rise was created primarily by volcanic construction, and the tectonic features of the province are a signature of the response of the lithosphere to loading by these volcanic units [*Solomon and Head*, 1982; *Willemann and Turcotte*, 1982; *Banerdt et al.*, 1982]. The distribution of preserved tectonic features in the Tharsis region appears to rule out flexural uplift as a significant source of lithospheric stress and instead favors distinct episodes of local isostatic support of the Tharsis rise and partial support of the downward load by the finite strength of the Martian lithosphere [*Banerdt et al.*, 1982]. The temporal ordering of these episodes is not presently resolvable from geological observations [*Banerdt et al.*, 1982; *Sleep and Phillips*, 1985].

Like the Tharsis region, the Elysium volcanic province is marked by both a topographic rise and a broad free air gravity anomaly [*Sjogren*, 1979; *Janle and Ropers*, 1983]. The Elysium region also exhibits a complex assortment of tectonic and volcanic features. In this paper we test whether the competing models for the origin of tectonic features in Tharsis can be distinguished on the basis of how well they account for the tectonic evolution of Elysium. Specifically, we compare the characteristics of tectonic features in the Elysium region with the stress fields predicted both by volcanic loading and by uplift of the Martian lithosphere.

We begin with a brief description of the physiographic features in the Elysium region which are of probable tectonic origin. We then test the hypothesis that these features are the product of loading of the lithosphere. We consider loading at three different scales: local volcanic loading (individual shields), regional loading (at the scale of Elysium Planitia) of the lithosphere from above (volcanic plains) or below (flexural uplift), and quasi-global loading by Tharsis. By comparing the predicted stress fields from such models with the distribution and orientation of tectonic features, we evaluate the relative importance of loading at these different scales, we constrain the mechanical properties of the Martian lithosphere, and we offer a further step toward a general understanding of the evolution of major volcanic provinces on Mars.

GEOLOGIC SETTING

The Elysium region (Figure 1) is the second largest volcanic province on Mars [*Carr*, 1973; *Malin*, 1977]. It consists of a broad topographic high, 2400 by 1700 km in extent and centered at about 25°N, 212°W, rising about 4 km above the

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