Fig. 2.

ated with Mead's interior probably indicate flooding of the topographically lower and relatively flat basin floor, with fracturing (mainly toward the center) producing locally radar-bright returns.

Isabella, with a diameter of ~170 km, is a ringed crater of the same scale, but its interior has been extensively flooded. A partially concentric arrangement of isolated peaks defines the remnants of an inner ring and a possible intermediate ring, both within the well-defined crater rim. The diameter ratio of the crater rim to the inner ring of peaks is roughly 2. If the intermediate ring, or a remnant thereof, can be shown to be scarplike in nature, then Isabella would also be a multiringed basin as interpreted here.

The ring diameter ratios of the three unequivocal multiringed impact basins are distinctly different from peak-ring craters (Fig. 1), although they follow the trend of decreasing ring ratios with increasing diameter. The ring diameter ratios for the two most distinct rings for Klenova, Meitner, and Mead are ~1.6, ~1.6, and ~1.4 respectively. Also, ring ratios for Klenova's intermediate ring to peak ring is ~1.4, as is Meitner's partial ring to main ring. These ring ratios are close to the $\sqrt{2}$ ratio suggested for Orientale and other lunar multiring basins, thus supporting the multiringed basin analogy. Finally, theoretical arguments [1,2] support the formation of multiringed basins on Venus at these scales (>100–150-km diameter).

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IS ISHTAR TERRA A THICKENED BASALTIC CRUST?

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The mountain belts of Ishtar Terra and the surrounding tesserae are interpreted as compressional regions [1,2,3]. The gravity and surface topography of western Ishtar Terra suggest a thick crust of 60–110 km [4,5] that results from crustal thickening through tectonic processes. Underthrusting was proposed for the regions along Danu Montes [6] and Itzpapalotl Tessera [7]. Crustal thickening was suggested for the entire Ishtar Terra [8]. In this study, three lithospheric models with total thicknesses of 40, 75, and 120 km and initial crustal thicknesses of 3, 9, and 18 km are examined. These models could be produced by partial melting and chemical differentiation in the upper mantle of a colder, an Earth-like, and a hotter Venus having temperatures of respectively 1300°C, 1400°C, and 1500°C at the base of their thermal boundary layers associated with mantle convection. The effects of basalt-granulite-eclogite trans-

formation (BGET) on the surface topography of a thickening basaltic crust is investigated adopting the experimental phase diagram [9] and density variations through the phase transformation [10].

Figure 1a shows the thermal evolution of the lithosphere of the cold Venus model with a linear crustal thickening of 0.5 km/m.y. followed by an exponential thickening for only 20 m.y. starting at 100 m.y. with a characteristic time of 20 m.y. (the main results are not very sensitive to these values; see below). Figure 1b shows the stability field of different phases that basalt enters. The BGET begins when the crust reaches a thickness of 7 km, and eclogite appears when the crust thickens beyond 70 km. Geologically speaking, the BGET is assumed to be instantaneous. Ahren and Schubert [11] suggested that cold basalt may take several tens of millions of years to transform to eclogite, and based on this suggestion Vorder Bruegge and Head [5] proposed that Maxwell Montes are 65 m.y. old. However, the recent crater distribution obtained from Magellan data suggests that the average age of Ishtar Terra is similar to that elsewhere on Venus, 500 m.y. [12,13]. To assess the effects of the time lag in the phase change, the crustal thickening is halted at 120 m.y. and the crust is allowed to reach thermal equilibrium for the next 80 m.y. The temperature increase does not significantly reduce the volume proportion of eclogite.
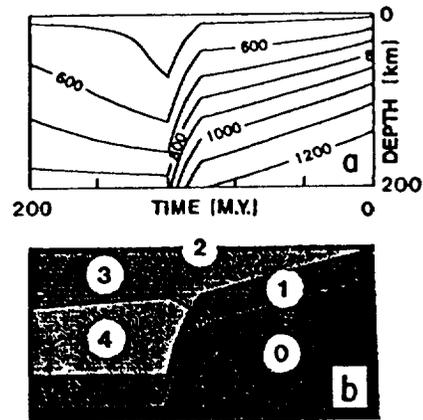

Fig. 1. Thermal evolution of the cold Venus model with a thickening crust. The numbers on the curves are temperatures in °C. Figure 1b shows the existing phases. 0 = undepleted peridotite, 1 = depleted peridotite, 2 = basaltic crust, 3 = granulite, and 4 = eclogite.

The surface topography produced by crustal thickening is determined assuming Airy isostasy with a compensation depth at 150 km as suggested for the western part of Ishtar Terra [14]. Figure 2 shows the resulting topography with (curve 1) and without (curve 2) taking into account the BGET. The density of basalt is 2900 kg/m³ at room temperature. That of granulite increases linearly and reaches ~3500 kg/m³ when eclogite appears. Also taken into account is the density decrease with temperature. The constant density model in Fig. 2 is similar to that of Bindschadler et al.'s [8] at steady-state condition, taking into account the density differences of the two models. However, in a more realistic model with the BGET, the surface topography attains a maximum of 1.8 km with a total crustal thickness of 38 km, beyond which the topography decreases due to sinking of the denser assemblages into the mantle. Halting the crustal thickening causes a rebound of the crust, but not enough
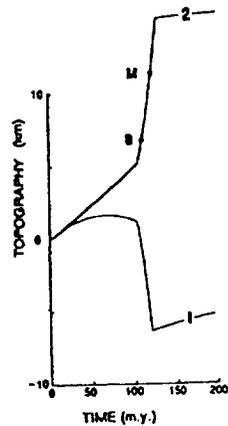
Fig. 2. The surface topography produced by the crustal shortening of the cold Venus model with (curve 1) and without (curve 2) taking the BGET into account. Point B approximates Bindschadler et al.'s [8] model and point M is the approximate height of Maxwell Montes.
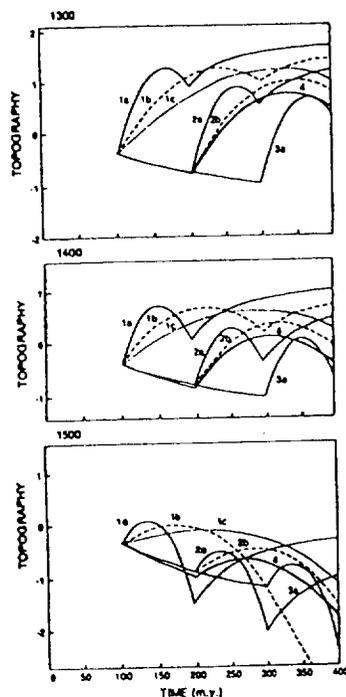

Fig. 3. The surface topography produced by the crustal thickening of the cold (1300), the Earth-like (1400), and the hot (1500) Venus models. The curves a, b, and c denote the thickening rates of 0.5, 0.25, and 0.167 km/m.y., respectively. The compensation depths are at 150 km, except for the curve 4 whose compensation depth is at 200 km.

rebound to produce a significant surface elevation. Not only is it impossible to produce a high plateau, but it is quite possible to produce a basin.

The factors that could affect the surface topography of a thickening crust are (1) the initial temperature distribution in the lithosphere, (2) thickening rate of the crust, (3) depth of compensation,

and (4) total thickness of the crust. Figure 2 shows the surface topography produced by lithospheric models assuming linear thickening of the crust. There are three sets of curves in each figure. Sets 1, 2, and 3 show the effects of the initial temperature distributions corresponding to lithospheres 100, 200, and 300 m.y. old. Within a given set, the curves a, b, and c are for thickening rates of 0.5, 0.25, and 0.167 km/m.y. respectively. In 1a and 2a the thickening was halted after 100 m.y., and in 1b after 200 m.y., allowing the lithosphere to reach thermal equilibrium. Curve 4 shows compensation at 200 km depth. None of these factors have a significant effect on the maximum height of the surface topography. The controlling factor, however, is the total thickness of the basaltic crust. The maximum topographic height is achieved when the crust reaches its critical thickness of ~38 km, beyond which the crustal shortening actually depresses the surface due to creation of high-density granulite and eclogite in the deeper parts that readily sink into the mantle. The crust of the cold Venus model requires significant thickening before it reaches the critical thickness, whereas those of the Earth-like and especially the hot Venus models need less thickening. Consequently, the cold Venus model produces a surface topography that is ~1.5 times higher than that of the Earth-like Venus model and ~3 times higher than that of the hot Venus model.

Lakshmi Planum is higher than 4 km above the mean surface of Venus and Maxwell Montes stand ~6 km higher. These prominent features are ~2-6 times higher than the maximum height that could be achieved by thickening a basaltic crust, no matter which lithospheric model is used. These features probably contain relatively less dense materials and represent analogues of continental masses on Earth.

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CONSTRAINTS ON THE THERMAL EVOLUTION OF VENUS INFERRED FROM MAGELLAN DATA. J. Arkani-Hamed[1],G.G. Schaber[2],and R. G. Strom[3],[1]Department of Geological Sciences, McGill University, Montreal, Canada, H3A 2A7, [2]U.S. Geological Survey, Flagstaff AZ 86001, USA, [3]Department of Planetary Sciences, University of Arizona, Tucson AZ 85721, USA.

A surface topography produced through viscous deformation of a mantle by internal loadings correlates with the resulting gravity anomaly if the mantle has an almost uniform viscosity [1]. The high correlation over low-degree spherical harmonics of surface topography and gravity anomalies of Venus and the greater apparent depth of compensation of the topography imply a high-viscosity upper mantle for Venus [2] that probably results from dehydration effects of the high surface temperature [3] and from the colder interior of