TESTS OF CRUSTAL DIVERGENCE MODELS FOR VENUS. Robert E. Grimm and Sean C. Solomon, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139; Larry S. Crumpler and James W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912.

Introduction. On the basis of elevated topography, free air gravity anomalies [1], and volcanic and rift structures inferred from radar observations [2], the equatorial highlands of Venus are likely sites of upwelling and horizontal divergence of mantle convective flow. Two hypotheses for the near-surface form of this divergence may be considered: *(1)* rigid plate motion, with deformation confined to narrow spreading centers and transform faults, as proposed by Crumpler and Head [3,4], and *(2)* broadly accommodated deformation of a non-rigid surficial layer. We determine whether a plate rotation model, described by a single Euler pole, provides an adequate description of inferred fracture zone traces [3]. This test provides the strongest discriminant between the two models for crustal divergence. Following Kaula and Phillips [5], we also examine the topography of Aphrodite Terra for characteristics of a conductively cooling thermal boundary layer, given the spreading direction suggested by the Crumpler-Head analysis. While the presence of boundary layer topography is not in itself a discriminant between the two models of divergence, the variation in derived spreading rate with position serves as an additional test of the rigid plate hypothesis. The results of these tests on Venus topography are compared with similar analyses of the bathymetry of the Mid-Atlantic Ridge under the assumption that the same restrictions on information apply.

Euler Pole. By Euler's theorem, the relative motion of two rigid plates on the surface of a sphere may be described by a rotation about an axis passing through the center of the sphere [6]; the intersection of this axis with the surface is known as the Euler pole. Transform faults follow small circles about this pole, so that given the locations and azimuths of transform faults a best-fitting Euler pole may be calculated by a least squares criterion [7]. Crumpler and Head have suggested that cross-strike discontinuities (CSDs) in Aphrodite Terra are analogs to terrestrial fracture zones and that axes of bilateral topographic symmetry are analogs to terrestrial spreading centers. Using the segments of CSDs located between offset centers of symmetry (i.e., the hypothesized active transform portions of fracture zone analogs) and weighting the fit by the inverse estimated measurement variance, the Euler pole for Aphrodite is 21 ± 4°N, 208 ± 12°E.

Figure 1 shows the axes of symmetry and CSDs rotated into the Euler-pole coordinate system. CSD segments near the symmetry axes are well described by parallels in this projection. Indeed, a good fit extends to about 30° from the symmetry axes for the region 5 to 35°N in this coordinate system. The axes of symmetry fall approximately along lines of longitude (great circles) for Euler latitudes 40°S to 35°N.

The CSD traces more than 30° distant from the symmetry axes at 50°N and 35°S depart significantly from small circles about the Euler pole. If changes in the location of the pole with time have occurred, all fracture zone traces on one side of the ridge system should shift in the same sense, and the shifts on the opposite side should be in the opposite sense, giving a sigmoidal shape to individual fracture zones. The opposing curvature of the CSDs on the same sides of the symmetry axes, therefore, is strong evidence against a simple two-plate model. In addition, CSDs near 40°S, 65°E tend to strike north of east, instead of the south of east direction expected were a pole shift invoked to explain the change in CSD azimuths near 35°S, 20°E. Unfortunately, the lack of Pioneer Venus imaging radar data further to the east (in Euler coordinates) precludes testing of more complicated time-dependent multiple-pole models.

Thermal Boundary Layer Topography. The long-wavelength variation in elevation of the terrestrial seafloor is well understood in terms of buoyancy differences due to conductive cooling of the lithosphere; for ages less than 80 m.y., depth varies approximately as the square root of age [8]. For a constant spreading rate, that rate may be inferred directly from the variation of elevation with distance [e.g., 5]. We have applied this method to Aphrodite Terra to test the Crumpler-Head spreading model. Least-squares fits of elevation versus square root of distance were determined for 39 profiles in Aphrodite Terra from 63°E to 179°E, to distances of 800 km and 1500 km along small circles about the Euler pole. For comparison 45 profiles across the Mid-Atlantic Ridge between 51°N and 25°S were examined in similar fashion; the terrestrial data were analyzed about individual poles for the appropriate plate pair [9] as well as a single mean Euler pole. The latter approach reflects the effect of a possible misidentification of additional plate boundaries in Aphrodite. The rms misfit σ and linear correlation coefficient r were calculated for each profile as measures of goodness-of-fit and are summarized in Table 1. The increased information on plate geometry has little effect on the terrestrial fit, so only the result for the mean pole is given. The excellent match of the Atlantic seafloor topography to the model is apparent even to 1500 km distance. For Aphrodite, however, the topography to 800 km in the Crumpler-Head spreading model is poorly characterized by a thermal boundary layer; the fit is somewhat better if the profiles are extended to 1500 km, but this may simply reflect an 'averaging out' of the blocky, convex shapes of the profiles in the Ovda and Thetis regions.

Geographical Variation of Spreading Rate. The angular velocity ω between two plates varies with angular distance Δ from the Euler pole as $\omega = (v_0/R)\sin\Delta$, where v_0 is the full-spreading rate at $\Delta = 90°$ and R is the planetary radius. For the Earth, it is possible to recover angular velocities to within 20% from topographic data alone, but this requires detailed knowledge of plate boundaries. The inferred crustal divergence rates in Aphrodite are poorly fit by a sin Δ relation, but considering potential errors in the number and positions of additional plate boundaries and the possible contributions to topography from sources other than thermal buoyancy, this result is not surprising.

Conclusions. We have examined the topography and CSD geometry of the Aphrodite region in terms of the plate divergence hypothesis [4]. Several conclusions may be made: *(1)* A two-plate model may be rejected. The system considered, however, is over 12,000 km in length; the longest plate boundaries on Earth are less than 10,000 km long. *(2)* A model of nonrigid, distributed deformation does not readily account for the distribution of CSDs; if these features are the traces of large-offset faults, a spatially coherent pattern of crustal motion is implied. *(3)* The topography of Aphrodite is not well described in general by a simple thermal boundary layer model. In addition to any thermal boundary layer component to topography, significant contributions must arise from lateral variations in crustal thickness and the mantle flow field.

References. [1] R. J. Phillips et al., *Science, 212,* 879, 1981; [2] G. G. Schaber, *GRL, 9,* 499, 1982; [3] L. S. Crumpler et al., *GRL*, 14, 607, 1987; [4] J. W. Head and L. S. Crumpler, *Science, 238*, 1380, 1987; [5] W. M. Kaula and R. J. Phillips, *GRL, 8,* 1187, 1981; [6] Bullard et al., *Phil. Trans. R. Soc., A263, 41,* 1965; [7] X. Le Pichon, *JGR, 73,* 3661, 1968; [8] B. Parsons and J. G. Sclater, *JGR, 82,* 803, 1977; [9] J. B. Minster and T. H. Jordan, *JGR, 83,* 5331, 1978.

Table 1. Summary of Thermal Boundary Layer Tests

Planet	Profile Length, km	Rms σ, m	Median r
Earth	800	310	0.87
Earth	1500	560	0.81
Venus	800	690	0.05
Venus	1500	730	0.54

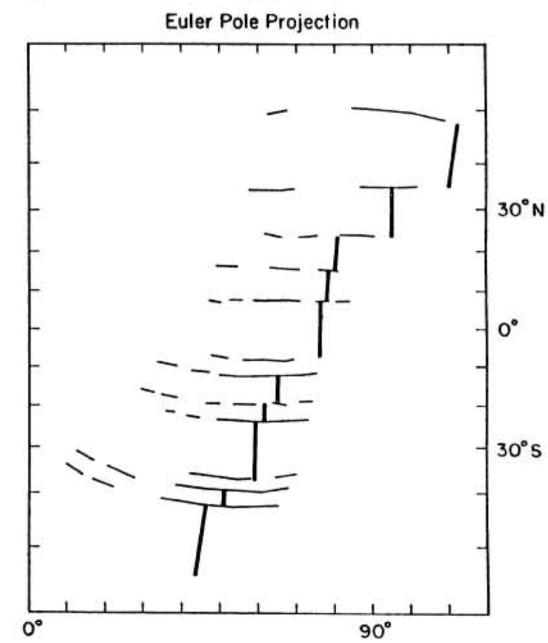

Fig. 1. CSD traces and axes of bilateral topographic symmetry (heavy lines) in Aphrodite, plotted in a Mercator projection about the best-fitting Euler pole. For a fixed pole, fracture zones should follow lines of latitude in this projection.