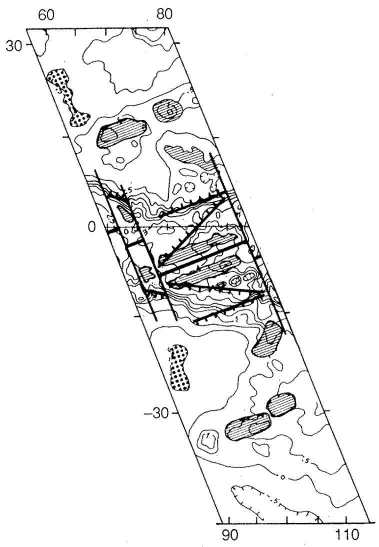

Fig. 6. Morphology and location of topographic elements symmetrical to the ridge crest within domains between cross-strike discontinuities 1 and 3 (Fig. 4) in the western Aphrodite Terra region, Venus. Solid lines are CSD's and rise-crest axis, linear scarps are shown by hachured lines, positive topography (mountains and linear and arcuate ridges) by a ruled pattern, and negative topography by a stippled pattern. Compare this map with the series of parallel profiles between CSD 2 and 3 in Fig. 4C.

the ridge crest and then rifted and moved laterally apart to their present position equidistant from the ridge crest.

Future tests for divergence and crustal spreading on Venus. Western Aphrodite Terra is characterized by many features that are similar to those present in terrestrial oceanic divergent plate boundary environments. In addition, the Venus data indicate: (i) the existence of bilateral symmetry of topographic elements even at great distances (>1500 km) from the ridge crest, (ii) similarities to terrestrial divergent boundary topography in terms of broad symmetric evolving thermal boundary layer profiles linked to, and consistent within, the individual domains rather than to Aphrodite Terra as a whole, and suggesting spreading rates of several centimeters per year, and (iii) a relationship of topography across transform-like structures (topographic step-down) consistent with spreading age relationships. We thus conclude that fundamental aspects of the plate tectonics process occur on Venus, and that plate creation and divergence is a probable mechanism of lithospheric heat loss. Preliminary assessment indicates that the process is not limited to the western Aphrodite region, and that it occurs elsewhere in the equatorial highlands of Venus (*34*). The positive correlation of gravity and topography in this area (*5*) may indicate that large-scale mantle convection processes are more directly linked to divergence on Venus than on Earth.

If divergence and crustal spreading occur in the equatorial regions of Venus, as we suggest, then there are a number of predictions that can be made, and we can propose a number of tests of this hypothesis based on these predictions. First, as a consequence of equatorial divergence in western Aphrodite Terra, we would expect to see evidence for convergence and compressional deformation at higher latitudes. Data for northern mid-to-high latitudes show abundant evidence of compressional and strike-slip deformation (*7, 9, 35, 36*) and high topography, in contrast to the equatorial regions that appear to be dominated by extensional deformation (*37*). Second, the age of the surface should increase away from western Aphrodite Terra toward the poles; lower latitudes should be younger on the average than the higher latitudes. At present there is insufficient high-resolution data in the western Aphrodite region to provide crater-count ages. However, if the process is widespread in the equatorial region, and rates of spreading are in the range of a few centimeters a year, then the average age of the surface of Venus should be relatively young, certainly less than 1.5 billion years. On the basis of crater counts for the northern mid-to-high latitudes, Ivanov *et al.* (*38*) suggest an age of 0.5 to 1.0 billion years for that region, similar to the average age of the Earth's surface (*39*). Existing data and global high-resolution data from the upcoming U.S. Magellan mission to Venus can be used to test this hypothesis further, and to determine the extent to which it may be operating on Venus.

REFERENCES AND NOTES

1. J. W. Head and S. C. Solomon, *Science* **213**, 62 (1981); J. G. Sclater *et al.*, *Rev. Geophys. Space Phys.* **18**, 269 (1980).
2. S. C. Solomon and J. W. Head, *J. Geophys. Res.* **87**, 9236 (1982).
3. G. H. Pettengill *et al.*, *ibid.* **85**, 8261 (1980).
4. J. W. Head, A. R. Peterfreund, J. B. Garvin, S. H. Zisk, *ibid.* **90**, 6873 (1985).
5. W. L. Sjogren *et al.*, *ibid.* **88**, 1119 (1983).
6. H. Masursky *et al.*, *ibid.* **85**, 8232 (1980).
7. D. B. Campbell, J. W. Head, J. K. Harmon, A. A. Hine, *Science* **221**, 644 (1983); *ibid.* **226**, 167 (1984); D. B. Campbell and B. A. Burns, *J. Geophys. Res.* **85**, 8271 (1980).
8. R. M. Goldstein, R. R. Green, H. C. Rumsey, *ibid.* **81**, 4807 (1976).
9. V. L. Barsukov *et al.*, *ibid.* **91**, D378 (1986).
10. D. B. Campbell, J. W. Head, J. K. Harmon, *Lunar Planet. Sci.* **15**, 121 (1984).
11. C. P. Florensky *et al.*, in *Venus*, D. H. Hunten *et al.*, Eds. (Univ. of Arizona Press, Tucson, 1983), p. 137.
12. R. J. Phillips, W. M. Kaula, G. E. McGill, M. C. Malin, *Science* **212**, 879 (1981).
13. W. M. Kaula and R. J. Phillips, *Geophys. Res. Lett.* **8**, 1187 (1981).
14. R. J. Phillips and M. C. Malin, in *Venus*, D. M. Hunten *et al.*, Eds. (Univ. of Arizona Press, Tucson, 1983), p. 159.
15. P. Morgan and R. J. Phillips, *J. Geophys. Res.* **88**, 8305 (1983).
16. W. J. Ehmann, thesis, Brown University, Providence, RI (1983); W. J. Ehmann and J. W. Head, *Lunar Planet. Sci.* **14**, 171 (1983).
17. V. L. Sharpton and J. W. Head, *J. Geophys. Res.* **91**, 7545 (1986).
18. L. S. Crumpler, J. W. Head, D. B. Campbell, *Lunar Planet. Sci.* **17**, 1029 (1986).
19. ——, *NASA Tech. Mem.*, in press.
20. ——, *Lunar Planet. Sci.* **18**, 217 (1987).
21. L. S. Crumpler and J. W. Head, *ibid.*, p. 215.
22. J. W. Head and L. S. Crumpler, *ibid.*, p. 409.
23. L. S. Crumpler, J. W. Head, J. K. Harmon, *Geophys. Res. Lett.* **14**, 607 (1987).
24. D. L. Anderson, *ibid.* **8**, 101 (1980).
25. ——, *ibid.*, p. 309.
26. W. M. Kaula and L. M. Muradian, *Geophys. Res. Lett.* **9**, 1021 (1982).
27. B. T. Lewis, *ibid.* **6**, 753 (1979); R. D. Ballard and H. Van Andel, *Geol. Soc. Am. Bull.* **88**, 507 (1977).
28. G. G. Schaber, *Geophys. Res. Lett.* **9**, 499 (1982).
29. P. J. Fox, E. Schreiber, H. Rowlett, K. McCamy, *J. Geophys. Res.* **81**, 4117 (1976); P. A. Rona and D. F. Gray, *Geol. Soc. Am. Bull.* **91**, 485 (1980); Z. Garfunkel, *J. Geol. Soc. London* **143**, 775 (1986).
30. B. Parsons and J. G. Sclater, *J. Geophys. Res.* **82**, 803 (1977).
31. L. S. Crumpler and J. W. Head, *ibid.*, in press.
32. N. Kumar and R. W. Embley, *Geol. Soc. Am. Bull.* **8**, 683 (1977).
33. E. E. Davis and J. L. Karsten, *Earth Planet. Sci. Lett.* **79**, 385 (1986).
34. J. W. Head and L. S. Crumpler, in preparation.
35. L. S. Crumpler, J. W. Head and D. B. Campbell, *Geology* **14**, 1031 (1986).
36. R. W. Vorder Bruegge, J. W. Head, D. B. Campbell, *Lunar Planet. Sci.* **18**, 1046 (1987).
37. J. W. Head, *ibid.* **17**, 325 (1986).
38. B. A. Ivanov, A. T. Basilevsky, V. P. Kryuchlov, A. L. Sukhanov, M. S. Markov, *J. Geophys. Res.* **91**, D413 (1986).
39. G. Schaber, E. Shoemaker, R. C. Kozak, *Sol. Syst. Res.* **21**, 144 (1987).
40. *World Data Center A for Marine Geology and Geophysics, Report MGG-2* (National Oceanic and Atmospheric Administration, Boulder, CO, 1985).
41. We appreciate constructive discussions with M. Parmentier, S. Solomon, D. Forsyth, D. Campbell, and M. Talwani. The help of P. Fisher in programming and display of altimetric data is gratefully acknowledged. M. E. Murphy, A. Hilliard, and P. Neivert helped in preparation of the manuscript. This research was supported by grants NGR-40-002-088 and NAGW-713, from the Solar System Exploration Division of the National Aeronautics and Space Administration, Jet Propulsion Laboratory contract JPL-957088, and the William F. Marlar Memorial Foundation.

7 May 1987; accepted 28 October 1987