Fig. 16. Exposure of a slab pahoehoe flow surface about 4000 years old in the Snake River Plain (from *Greeley and King* [1977]; photos by J. King and J. Karlo). Abundant fractured plates are reminiscent of bedrock exposures at the Venera 10, 13, and 14 sites.

nature and distribution of various types of horizontal layering (platy jointing, sheeting, and flow layering). *Macdonald* [1972, p. 93] describes the formation of sheets in block lava flows, noting that the

> moving liquid higher up tends to separate into a series of sheets slipping over each other like a series of cards in a deck when the deck is bent. The same sort of motion (laminar flow) is present in aa and pahoehoe flows, but the separation into sheets shearing over each other is less pronounced. The movement of the sheets is predominantly nearly parallel to the underlying surface, and in solidified flows the shear surfaces are visible as planes of separation (joints) essentially parallel to the top and bottom of the flow. The sheets may be very thin. Sometimes they are only a fraction of an inch thick, and then the lava resembles the platy sedimentary rock, shale.

Macdonald further notes that occasionally shear planes may bend upward at the front or top of the flow.

Vertical fractures, or joints, are ubiquitous in lava flows (Figure 14) and are due primarily to tensional stresses associated with volume reduction due to cooling. The nature of jointing commonly changes at subunit boundaries, and vertical joints often stop abruptly at these boundaries (Figure 14). The patterns of joints may range from rectangular to polygonal and blocks derived from jointed flows are commonly angular in form. The extensive vertical fractures seen at Venera 14, and the shape of bedrock exposures at Veneras 10 and 13, are interpreted to be related to joint patterns. The angularity of blocks visible at Venera 9 may also be related to jointing.

Thus we find a number of strong morphological similarities between the bedrock and blocks at the Venera 9, 10, 13, and 14 sites and terrestrial basaltic lava flows. We believe that this interpretation based on morphologic characteristics is supported by geochemical analyses indicating basaltic compositions, the low albedo of surface rocks, comparison to surface images of outcrops of known (moon) or suspected (Mars) volcanic origin, the high density, the extreme similarity between sites separated by thousands of kilometers, and the strong likelihood that extrusive volcanism has been a significant mechanism of heat transfer throughout the history of Venus [*Solomon and Head*, 1982; *Morgan and Phillips*, 1983], and in the Beta-Phoebe region [*Saunders and Malin*, 1977; *McGill et al.*, 1981; D. Campbell et al., unpublished manuscript, 1983].

The present Venus environment is considerably different in terms of temperature, pressure, and atmospheric composition than the present terrestrial subaerial environment. The high Venusian upper crustal and surface temperatures would favor greater effusion rates and less efficient lava cooling, both of which are factors that would produce long extensive flows relative to comparable terrestrial eruptions [*Wood*, 1979; *Garvin et al.*, 1982; *Head and Wilson*, 1982; *Wilson and Head*, 1983]. Although many earth analogs [cf. *Green and Short*, 1971; *Greeley*, 1974; *Greeley and King*, 1977] can be found which show similarities to the Venera panoramas (Figures 15 and 16), we are presently concentrating on an analysis of the flow and cooling behavior of lavas with compositions of the Venera site materials, under Venus conditions, in order to provide a framework for further investigation of terrestrial analogs in the subaerial and subaqueous environment.

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REFERENCES

Barsukov, V. L., V. P. Volkov, and I. L. Khodakovsky, The crust of Venus: Theoretical models of chemical and mineral composition, *Proc. Lunar Planet. Sci. Conf. 13th*, Part 1, *J. Geophys. Res.*, *87*, suppl., A3, 1982.

Bazilevski, A. T., N. N. Bobina, V. P. Shaskina, Y. G. Shkuratov, Y. K. Kornienko, A. Y. Usikov, and D. G. Stankevich, On geological processes on Venus: Analysis of the relationship between altitude and the degree of surface roughness, *Moon Planets*, *27*, 63–89, 1982.

Binder, A. B., R. E. Arvidson, E. A. Guinness, K. L. Jones, E. C. Morris, T. A. Mutch, D. C. Pieri, and C. Sagan, The geology of the Viking lander 1 site, *J. Geophys. Res.*, *82*. 4439, 1977.

Bokshteyn, I. M., M. A. Kronrod, P. A. Chochia, and Y. M. Gektin, Processing of the television panoramas of the surface of Venus, preliminary structural analysis by the automatic stations Venera 13 and Venera 14 (in Russian), *Kosm. Issled.*, *21*, 190, 1983.