characteristically thinned by some unspecified process at a hot spot. Clearly,

$$\bar{q} = f\eta q_0 + (1 - f)q_0 + q_v \tag{4}$$

where q_v is the contribution to the global heat flux delivered by volcanism.

If volcanically delivered heat is small compared with conducted heat at hot spots and elsewhere (i.e., $q_v \ll \bar{q}$), then q_0 is given by

$$q_0 = \frac{\bar{q}}{1 - f + f\eta} \tag{5}$$

Under the assumption that the Hawaiian hot spot is a guide to the characteristics of possible hot spots on Venus, we take $\eta \simeq 2$–3 [*Detrick and Crough*, 1978; *Crough*, 1978; *Detrick et al.*, 1981; *Sandwell*, 1982; *von Herzen et al.*, 1982]. For $\eta = 2$, $q_0 \gtrsim \bar{q}/2$. That is, the lithospheric thickness far from hot spots can be increased by a factor only as large as 2 compared with the global average derived in the last section, with the factor of 2 approached only for the case where hot spots cover most of the surface of Venus ($f \simeq 1$). For $\eta = 3$, $q_0 \gtrsim \bar{q}/3$, again with near equality only if $f \simeq 1$. Lithospheric thicknesses approaching typical terrestrial values would be possible, but only in a few areas of very limited spatial extent.

If, in contrast, lithospheric heat transfer on Venus occurs dominantly by magma transport at individual hot spots (i.e., $q_v \simeq \bar{q}$ in equation (3)), the average lithospheric thickness is not constrained by global heat flow [cf. *O'Reilly and Davies*, 1981] and can be considerably greater than estimates obtained in the last section. In particular, the average lithospheric thickness can be greater than the 100-km depth of isostatic compensation inferred from the gravity anomalies over a number of topographically distinct features on the planet [*Phillips et al.*, 1979, 1981; *Reasenberg et al.*, 1981]. Thus large topographic relief could be supported passively and on nearly a global basis either by local isostatic compensation or by regional compensation and lithospheric strength.

The hypothesis that hot spot volcanism dominates lithospheric heat transfer on Venus (Figure 5) cannot be excluded on the basis of our present knowledge of the surface. The hypothesis carries important implications for the interpretaton of surface physiographic features (Table 1). The Venus surface, if most of the heat loss occurs by volcanism, should be densely covered with thousands of distinct centers of current or recent volcanic activity. Most of the physiographic features would have surfaces less than 10 m.y. old, though a few areas of older terrain may have escaped recent resurfacing. If the majority of the heat delivered at hot spots is due to lithospheric thinning, then hot spots would nearly have to cover the surface of Venus for the lithospheric thickness far from hot spots to be substantially greater than the globally averaged value. Much of the surface material should, in either case, consist of volcanic deposits. In particular, the Venus highlands would most likely have been formed by volcanic construction. Tectonic activity in the absence of large-scale horizontal motions should be principally restricted to that associated with vertical motions of the lithosphere.

The *Phillips and Malin* [1982] model for hot spot tectonics on Venus includes both volcanic transport of heat and lithospheric thinning beneath major volcanic centers, with the latter process making a greater contribution to the global heat loss. This model may be viewed as a combination of the mechanisms of lithospheric conduction and hot spot volcanism as considered in this paper, and the implications of their model involve a combination of aspects of the scenarios depicted in Figures 4 and 5.

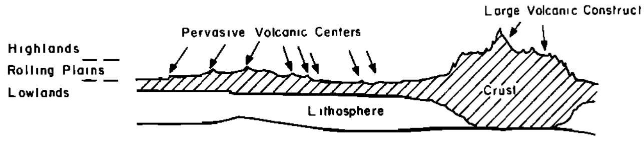

Fig. 5. A schematic illustration of the hot spot volcanism hypothesis for lithospheric heat transport on Venus. Volcanism carries the majority of the heat through the lithosphere, and active volcanic centers on the surface of Venus should be widespread. The highland terrain consists of large volumes of volcanic deposits and probably thickened crust. The surface material is generally volcanic and geologically young.

CONCLUSIONS

Without more detailed information on the Venus surface, all of the mechanisms for lithospheric heat transfer considered here (lithospheric recycling, conduction, and hot-spot volcanism) should be regarded as potentially important for Venus. Though each of these mechanisms has been treated individually in this paper, weighted combinations of mechanisms must, of course, also be considered [e.g., *Phillips and Malin*, 1982]. The possibility that the dominant mechanism early in the history of the planet was different from that at present [e.g., *Phillips et al.*, 1981] should be recognized as well.

Each of the possible end-member models for lithospheric heat transfer on Venus carries different implications for the detailed characteristics of Venus landforms. The predicted characteristics (Table 1) should serve as a guide to the interpretation of existing and future imaging and topographic data on the Venus surface. For each of the hypothetical models for heat transfer, however, there is a clear implication that either many of the surface geological units or much of the surface topography is geologically youthful.

A common presumption in discussions of comparative planetary evolution has been that planetary size plays a crucial role in controlling the internal heat budget and the volcanic and tectonic responses to global heat loss. The comparison of Venus and earth holds a key spot in the test of this presumption [*Phillips et al.*, 1981; *Head and Solomon*, 1981]. Establishing the nature of the tectonic and volcanic history of the Venus surface and inferring the dominant mechanisms for lithospheric heat transfer on that body remain elusive goals of the highest priority for our understanding of the evolution of the terrestrial planets, including our earth.

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