earth is a consequence of its relatively cooler temperature and also a result of phase changes which occur at shallower than normal depth in the cooler slab [*Toksöz et al.*, 1971; *Turcotte and Schubert*, 1971]. The argument has been advanced that a Venus lithosphere similar in crustal thickness and other physical properties to oceanic lithosphere on earth would have less negative buoyancy because of the higher surface temperature and smaller lithospheric thickness on Venus [*Anderson*, 1981; *Phillips and Malin*, 1982]. *Anderson* [1981] has argued further that an additional factor which might make the Venus lithosphere positively buoyant is the enhanced depth range of the basalt stability field on Venus compared with that on earth, thereby opening the possibility for crustal thicknesses substantially greater than in terrestrial ocean basins.

These buoyancy calculations are sensitive to the assumptions made about parameters which are at best poorly known for Venus, including the thickness of a crustal layer, the location of the mantle residuum remaining after extraction of partial melt to produce the crust, and the partitioning of planetary heat loss among plate recycling and conduction. Thus the uncertainty attached to an individual result is large, and both positive and negative values for net lithospheric buoyancy are possible results at our present stage of understanding [*Phillips and Malin*, 1982].

That the Venusian lithosphere is less negatively buoyant than old oceanic lithosphere on earth is likely, yet even this conclusion is not a strong argument against some form of subduction on Venus. On the earth, oceanic lithosphere with seafloor as young as 10 m.y. is subducted [*Menard*, 1978], yet such lithosphere is certainly less negatively buoyant than unsubducted oceanic lithosphere 150 m.y. old. *Parsons* [1982], in fact, has demonstrated that the distribution of ocean floor area versus age on the earth is consistent with the hypothesis that plate consumption is uniformly distributed with age except for seafloor younger than 10 m.y. old. Subduction of young seafloor may, of course, be sustained by a finite-amplitude instability; i.e., 10 m.y. old oceanic lithosphere may be only marginally unstable or even stable gravitationally yet continue to subduct if attached to a negatively buoyant slab. Such a finite-amplitude instability might equally well be invoked to sustain subduction on Venus. Once subduction of an aging piece of Venusian lithosphere is initiated, by this argument, the subduction process may be sustained by thermal anomalies and elevated phase transitions in the subducted slab, and the characteristic age of subducted material may be substantially younger than that initially subducted. If, as suggested earlier, lithospheric delamination occurs on Venus, then the mantle portion of the lithosphere would be negatively buoyant even if the crustal portion is not. Thus a thicker crust on Venus compared with terrestrial ocean basins [*Anderson*, 1981] need not restrict subduction of the mantle portion of the lithosphere where such delamination occurs. To the extent that the mantle residuum complementary to a basaltic crust resides in the lithosphere, in fact, the net lithospheric buoyancy may be largely insensitive to crustal thickness.

On the Kaula-Phillips Arguments on Heat Removal by Lithospheric Recycling on Venus

Kaula and Phillips [1981] estimated an upper bound on the fraction of the global heat loss on Venus contributed by plate tectonics. While not an argument against plate recycling on Venus per se, their conclusion that the heat transported by plate tectonics is 15% or less of the global heat flux on Venus compared with 65% on earth [*Sclater et al.*, 1980] would, if true, provide an important contrast between the two planets.

We do not regard the 15% result of *Kaula and Phillips* [1981], however, as necessarily valid. Their calculation was based on an identification of candidate spreading ridges on Venus, a measurement of the rate of decrease in elevation with distance from each segment of the ridge, an application of thermal boundary layer theory to scale the physical parameters of mantle convection in the earth to those of Venus, and a conversion of the measured rates of change in elevation to estimates for the heat delivered along each spreading ridge segment. Further elaboration of the boundary layer scaling arguments is given by *Phillips and Malin* [1982].

The candidates for ridges chosen by *Kaula and Phillips* [1981] include Beta Regio and Aphrodite Terra. Both of these features contain large regions which, together with Ishtar Terra, compose the highlands province of Venus [*Masursky et al.*, 1980]; terrestrial continents rather than ocean ridges may provide a preferable analog to much of the Venus highland terrain [e.g., *Head et al.*, 1981]. Having made this selection of ridges, Kaula and Phillips then note that the Venus ridge heights do not show a narrow distribution about a mode as do terrestrial ocean ridges well removed from hot spots [*Parsons and Sclater*, 1977] and that these ridges do not form an interconnected global system. While these observations may be sufficient to rule out either Beta Regio or Aphrodite Terra as Venusian analogs to terrestrial mid-ocean ridges [cf. *Schaber*, 1982], neither observation is a compelling argument against lithospheric recycling on Venus in general.

Having posed the hypothesis that plate recycling dominates lithospheric heat transport on Venus, we should consider the expected form of Venusian spreading centers. A reasonable guide to the rate of heat loss per length of spreading ridge follows from the spreading-plate model of oceanic lithosphere [*Williams and von Herzen*, 1974; *Kaula and Phillips*, 1981]:

$$q_r = \rho C_p L v \, \Delta T \qquad (1)$$

where ρ and C_p are the density and specific heat of the lithospheric plate, L is the lithospheric thickness, v is the average half spreading rate, and ΔT is the difference in temperature between the bottom and top of the lithosphere. Subduction of the lithosphere before it has reached thermal equilibrium will reduce q_r from that given by (1). Because of the higher surface temperature on Venus, ΔT will be less for Venus than for the earth's ocean basins, though boundary layer scaling arguments suggest that the difference in ΔT between Venus and earth may be somewhat less than the difference in surface temperatures [*Kaula and Phillips*, 1981; *Phillips and Malin*, 1982]. For a spreading ridge system on Venus to deliver to the surface an amount of heat comparable to that delivered by ridges on earth, either the characteristic spreading rate or the total length of ridges (or both) must be greater on Venus than on earth. Because either possibility would likely be accompanied by a lesser characteristic age of subducted lithosphere on Venus than on earth, the product of ridge length and mean spreading rate would exceed that quantity for the earth by a ratio greater than simply the ratio of the values of ΔT for the two bodies.

These considerations suggest that the most likely candidates for spreading ridges on Venus should be characterized by rapid rates of spreading and correspondingly small rates of change in topographic height with distance from the ridge axis. *Phillips and Malin* [1982] have shown that a fast spreading ridge, such as the East Pacific Rise, would have only modest topographic