the Venera 15/16 probes [Barsukov et al., 1984a, b, 1986] has revealed only one candidate for a large pyroclastic deposit. In view of the evidence for slow erosion rates on Venus [Head et al., 1985b], this implies that large explosive eruptions are not common at the present time and hence that magma volatile contents do not commonly exceed about 4 wt %. Impact crater counts [Barsukov et al., 1984a, b, 1986] show that the average age of the surface mapped lies between 500 and 1000 Ma. Since the likely trend of evolution of availability of magmatic volatiles on Venus is toward smaller amounts of volatiles being present in magmas at later times as the planet degasses, we take this to imply that large explosive eruptions have not been common for at least the last 500 m.y., even though magmatic volatiles may have been more plentiful in the past. This, in turn, implies that the atmospheric pressure has been at least as large as the present-day value for a time of at least this order.

6.3. Relation of Volcanism to Tectonism and Lithospheric Structure

On Earth, volcanism is closely linked to tectonism in terms of areal distribution, style, and tectonic characteristics of the crust and lithosphere. Furthermore, volcanic activity is one of the major potential mechanisms of planetary lithospheric heat transfer [Solomon and Head, 1982]. In addition, it is known that fissure width, a fundamental aspect of local and regional tectonic environment, is a major factor in determining effusion rates on the planets [Wilson and Head, 1983]. On the basis of theory and observations discussed in this paper, we can offer several tentative conclusions about the relation of volcanism and tectonism on Venus.

6.3.1. Volcanism and tectonic environment. Although the nature of the surface of Venus is only partly known, preliminary observations show that many of the volcanic features are related to crustal and lithospheric structure. Theia Mons, the prominent shield volcano in Beta Regio, is situated on the western bounding fault of Devana Chasma, a major extensional rift structure [Campbell et al., 1984]. Several other large volcanic edifices [Stofan, 1985] are located along regional structural trends, although it is unknown whether they are in extensional or compressional environments. The cone/dome structures reported by Barsukov et al. [1984a, b, 1986] occur in extensive fields in the plains and may reflect the structural fabric of the upper crust and lithosphere in these regions [e.g., Settle, 1979b]. Larger shield structures southeast of Ishtar Terra are related to preexisting linear trends, and their density may also contain information on lithospheric structure [Head et al., 1985a].

When magma is able to pass completely through a planetary lithosphere to the surface, the heat transfer can be regarded as advective (though volcanic deposits in the form of lava flows or ash layers carry out the final stages of their cooling by conduction). When magma only partially penetrates the lithosphere and cools in intrusive dikes or sills, the activity represents a hybrid of advection and conduction and is effectively a way of increasing the average value of the temperature gradient in the outer layers of the planet. Intrusion of low-viscosity basaltic material in narrow, linear dikes which can cool quickly is a more effective means of heat loss than the formation of more equant high-level magma bodies. It is tempting, therefore, to assume that regions of Venus having high heat flow rates will be preferentially associated with linear surface patterns of volcanism and tectonism. Linear tectonic patterns are linked on Earth with other processes besides rifting and intrusion, and so the best chance of understanding these relationships on Venus will probably come from identifying and mapping the global distribution of volcanic centers.

6.3.2. Volcano heights and lithospheric properties. The height to which volcanoes can grow depends in part on the depth of origin of the magma and the density contrast between the lava and the rocks between the source and the surface. Eaton and Murata [1960] and Carr [1973, 1981] have applied these concepts to Earth and Mars and have suggested that the source depths for the approximately 9-km-high Hawaiian shields are about 60 km, while those for the Martian shields in excess of 20 km altitude are at least 160 km. Even the largest and relatively youngest of the identifiable shield volcanoes on Venus (e.g., Theia Mons) do not appear to attain as great topographic heights as analogous structures on Earth and Mars, yet their diameters are more similar to those of the largest shields on Mars. Even though viscous relaxation must be an important process in the present environment [Weertman, 1979; Solomon et al., 1982], these youngest volcanoes do not appear to have structural or topographic features associated with these processes. This observation of volcano height may be related to the structure of the Venus lithosphere.

Magma may ascend from a source region below (or within) the lithosphere through a continuous fissure joining the source to the surface [Shaw and Swanson, 1970] or via an isolated crack of finite vertical height that opens ahead of the magma and closes behind it [Weertman, 1971; Secor and Pollard, 1975]. The essential requirement for magma migration is that the density of the magma should be less than the mean density of the surrounding rocks obtained by integrating over the vertical extent of the region occupied by the magma. Cooling constraints dictate that there is always a minimum fissure width required to allow a magma with a given viscosity to rise through a given vertical height [Wilson and Head, 1981].

On Earth, direct magma ascent from deep sources in the upper mantle is aided by the high density difference between typical partial melts and mantle rocks. If magma sources on Venus are located at systematically shallower depths than on Earth, a likely consequence of a higher temperature gradient if heat transfer through the lithosphere occurs mainly by conduction [Solomon and Head, 1982, 1984], then typical density differences driving the eruptions will also be less. Also, magmas ascending through the upper few kilometers of the crust on Earth are assisted by the density decrease due to exsolution of volatiles; the systematically higher pressures on Venus will reduce or suppress this process, again leading to smaller density differences.

When magma sources are connected to the surface by continuous pathways, it is readily shown from hydrostatic arguments [Eaton and Murata, 1960]