ERUPTION HISTORY OF THE THARSIS SHIELD VOLCANOES, MARS:
J. B. Plescia, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

The Tharsis Montes volcanoes and Olympus Mons are giant shield volcanoes (1). Although estimates of their average surface age have been made using crater counts, the length of time required to build the shields has not been considered. Crater counts (2, 3, 4, 5) for the volcanoes indicate the constructs are young; average ages are Amazonian to Hesperian (4). In relative terms; Arsia Mons is the oldest, Pavonis Mons intermediate, and Ascreaus Mons the youngest of the Tharsis Montes shields; Olympus Mons is the youngest of the group. Depending upon the calibration (5, 7), absolute ages range from 730 Ma to 3100 Ma for Arsia Mons and 25 Ma to 100 Ma for Olympus Mons. These absolute chronologies are highly model dependent, and indicate only the time surficial volcanism ceased, not the time over which the volcano was built.

The problem of estimating the time necessary to build the volcanoes can be attacked in two ways. First, eruption rates from terrestrial and extraterrestrial examples can be used to calculate the required period of time to build the shields. Second, some relation of eruptive activity between the volcanoes can be assumed, such as they all began at a specific time or they were active sequentially, and calculate a the eruptive rate. Volumes of the shield volcanoes were derived from the topographic/volume data of (7, 8).

Using known eruption rates, the time necessary to build the shields is illustrated in Figure 1. At one extreme, the eruption rate of the Imbrium flows (31500 km^3 yr^-1 (10)) would build the volcanoes in tens of years. Although single flows might be erupted at such rates, it seems unlikely that the whole shield would be built at these rates. Such large rates have not been observed for terrestrial central vent volcanoes. In addition, an important aspect of large eruption rates for flood basalts is their extremely low viscosity which would not tend to favor shield building. A rate consistent with the Cretaceous super plume (30 km^3 yr^-1 (10)) would result in construction times of a few hundred thousand years. These rates are associated with plumes that fed mid ocean ridges and produced oceanic basalt which is consistent with terrestrial shield building. Perhaps, the most relevant example comes from the long-term Hawaiian rate (0.1 km^3 yr^-1 (11, 12)), because it represent a typical value for a central vent volcano. Using this rate, tens of millions of years are required to build the shields. Carr (13) originally estimated that Olympus Mons was built in 10^8 years assuming an eruption rate of 0.02 km^3 yr^-1.

On the other hand, if one assumes that the volcanoes were built over periods of 10^8 to 10^9 years, such that they all began at the same time (e.g., 3.5 Ga) then the implied mean eruption rates are extremely low, 0.01 to 0.001 km^3 yr^-1. Such low rates are not typical of terrestrial basaltic provinces; rather they usually occur for small volume constructs having silicic compositions. An additional problem with low eruption rates is maintaining the same conduit over long time periods for a central vent and producing a magma chamber large enough for caldera formation. Under extremely low eruption rates, maintaining an open conduit or a thermally weakened zone as a pathway from the mantle source would be difficult. The zone would cool over such long time scales and it might be expected that numerous, regionally distributed vents would occur, rather than a single vent. Additionally, under low magma production rates, it would be impossible to create the large magma chambers required to produce the observed caldera. Estimates of the volume of the Olympus Mons magma chambers are of the order 10^4 km^3 (14), which would require 10^6 - 10^7 years to fill at the lowest magma production rates. Under
these conditions, the magma would solidify before the chamber became large enough to produce a caldera. Thus, the presence of a caldera, which requires large magma chambers, in part constrains the magma production rates.

Assuming the shields are built over time spans of $10^7$ to $10^8$ years, the next question is why the absolute ages of the individual shields differ by 0.8 to $3 \times 10^8$ years, with each shield potentially being completed before volcanism at the next shield commenced. These age relations can be understood in the context of a model in which shield building results from mantle plumes.

It is becoming increasingly apparent in the study of flood basalt volcanism, that large eruptions occur over very brief intervals of time under very large eruption rates. The Columbia Plateau, Deccan and Siberian Traps all formed over only a few million years (15-18). Similarly, episodes of significantly increased sea floor spreading also occur (10). These volcanic episodes can be linked to large mantle plumes impinging upon the base of the lithosphere. As the plume rises through the mantle it ultimately encounters the base of the lithosphere, which acts as a barrier to further ascent. The plume then flattens out and high rate eruptions occur over a few million years.

In Tharsis, it can be proposed that each large shield marks the location of an ancient mantle plume which produced an intense, but relatively short lived pulse of volcanism. Early plumes were probably hotter or tapped different source regions such that the magmas were of very low viscosity and produced the large “sheet” flows that characterize the distal margins of Tharsis. Later plumes produced magmas that resulted in the construct of central vent volcanoes. Ultimately each of the plumes died out and volcanism ended.