COMPARISON OF THE DISTRIBUTION OF LARGE MAGMATIC CENTERS ON EARTH, VENUS, AND MARS; L.S.CRUNPLER, Department of Geological Sciences, Brown University, Providence, RI 02912

INTRODUCTION. Volcanism is widely distributed over the surfaces of the major terrestrial planets Venus, Earth, and Mars. Anomalous centers of magmatic activity occur on each planet and are characterized by evidence for unusual concentrations of volcanic centers, long-lived activity, unusual rates of effusion, extreme size of volcanic complexes, compositionally unusual magmatism, and evidence for complex geological development. The purpose of this study is to compare the characteristics and distribution of these magmatic anomalies on Earth, Venus, and Mars in order to assess these characteristics as they may relate to global characteristics and evolution of the terrestrial planets.

DISTRIBUTION OF MAJOR CENTERS. Global maps showing the location of all major volcanic centers were prepared based on the Magellan volcanic feature catalog [1] and from existing compilations of volcanism on Earth [2] and Mars [3]. The centers and regions of volcanism included for each planet were selected because they are in each case among the largest in size, greatest in volume, or most active with respect to volcanism elsewhere (Figure 1, 2, and 3). For Venus this consists of volcanoes exceeding 100 km in diameter [1]; for Mars, the selection is simple as this includes all known volcanic centers greater than a few kilometers in diameter; and for Earth, the residual of all active [4] volcanoes is taken for comparison after removal of the volcanic centers related to plate boundaries as discussed below.

Venus. Volcanism is nearly ubiquitous on Venus and ranges from small shield volcanoes near the limit of resolution [5] of Magellan data to large rises and major volcanic complexes [6]. Although widespread, the annual volume rate of volcanism is estimated [1] to be \(-1\) km\(^3\)/yr globally, or about that of the intraplate volcanism on Earth. The global history of Venus volcanism volume-rates is currently debated, but a net decline in the magmatic budget from an initial high rate with a half-life of 2Ga is a reasonable approximation. Many of the smaller centers occur in association with the larger volcanic centers and coronae [1,7], and to first order the distribution of major centers on Venus may be taken as representative of the distribution of anomalous melting and corresponding interior anomalies. Based on the distribution of large volcanoes and coronae in the global volcanic catalog [1] the distribution of anomalous magmatism on Venus occurs in regional concentrations, groupings, and clusters. Regional (Eistla) [6] concentrations as well as hemispheric-scale (A-T) concentrations are known to occur and have been correlated to several characteristics of global tectonism [1]. The Beta-Atlas-Themis concentration anomaly [1] comprises (and probably influences) a significant (~25%) fraction of the global surface area.

Linear arrangements of the pattern of magmatic center are rare, despite the abundance of linear deformation belts, extensional fractures, and rifts, despite the correlation of volcanism with extensional fracture belts [1] at regional scales. Volcanism appears not related to plate boundary processes at any scale and must arise through other mechanisms. However, some of the largest centers of volcanism occur in association with major topographic rises and are accompanied by significant positive gravity anomalies attributable to dynamic support [8]. In this respect, the processes associated with major centers of volcanism on Venus are analogous to those frequently ascribed to mantle plumes, particularly large rises.

Earth. On Earth the global distribution of volcanism is widespread and occurs in both plate boundary and intraplate settings. Plate boundary volcanism arises through instabilities introduced at the divergent boundaries through crustal thinning and corresponding mantle upwelling, and at convergent boundaries through complex processes associated with the introduction of water into the deep lithosphere and upper mantle during subduction.

Intraplate or "hot spot" volcanism differs from plate boundary volcanism in several respects. The total volume rate of intraplate volcanism is exceeded by an order of magnitude by divergent and convergent plate boundary volcanism. Unlike the frequently silica-saturated, calc-alkalic, and hydrous-phase rich composition of plate boundary magmas, intraplate volcanism is typified by silica-undersaturated, alkalic, large-cation enriched melts derivable from relatively undepleted mantle. Centers of intra-plate volcanism are also known to be long-lived (>10\(^7\) m.y.), relatively stable with respect to the motion of the lithosphere, and often occur in association with significant evidence for plume-like, possible deep mantle upwelling. In addition, the global distribution of intraplate volcanism is non-random, occurs in two global concentrations ("African" and "Pacific") [2] with some evidence for synchronicity of activity within global concentrations [9] and, and has been correlated with a variety of characteristics of the global patterns of mantle structure, interior convection [10], and global tectonism [11]. The African hot spot concentration encompasses an area of about 25% of the global surface and accounts for a large fraction of the known hot spots.

The pattern of distribution, relative stability, intraplate setting, and association with dynamic plumes of hot spots on Earth is comparable to many of the characteristics of volcanism on Venus. For this reason, the mapped distribution of "hot spots" on Earth (Figure 2) is considered appropriate for comparison with the distribution of volcanism on Venus.

Mars. The total number of volcanoes as well as the estimated global volume-rate of magma production [12] on Mars are about two orders of magnitude less than on Earth or Venus. Most of the central volcanism consists of relatively low, but physically large shield volcanoes thought to have formed through dominantly effusive processes, but with locally important components of volatile-rich magmatic activity [ref]. The rate of magmatism on Mars associated with the emplacement of major volcanic surface units has apparently decreased steadily over Martian history [12], and the same is likely of magmatism associated with the known volcanic centers. Volcanic centers occur in three settings, Tharsis, Elysium, and Hellas, and the later two are approximately antipodal to Tharsis such that there are two global occurrences (Figure 3). In either division, the global distribution is dominated by the Tharsis concentration. The origin of the Tharsis tectonism and volcanism are the subject of previous detailed studies [13]. Whatever the origin, it...
clearly represents a major anomaly influencing the tectonic and magmatic activity in an area exceeding 25% of the global surface.

**INTERPRETATION/DISCUSSION.** Subtraction of those volcanic centers directly attributable to plate boundary processes from the mapped distribution of volcanism on Earth results in global pattern of major volcanic centers similar in several respects to the distribution of major volcanic centers on Venus and Mars. The most striking characteristic of the distribution of volcanic centers on Venus, Earth, and Mars is that it occurs in global concentrations and that each planet is characterized by a dominant globally anomalous area of unusually concentrated volcanism and/or tectonism. In addition, on both Earth and Mars there are two fundamentally antipodal concentrations.

In terms of scale, association with global tectonic processes, location with respect to the inertial equator, and association with possible convective anomalies, the Beta-Atlas-Themis Region of Venus, the African hot spot concentration on Earth, and the Tharsis region of Mars all share some characteristics in common. Several observations suggest that the BAT concentration on Venus and the African hot spot cluster on Earth might reflect global upwelling anomalies. Many discussions have recently centered on the possible origin of the two antipodal global hot spot concentrations on Earth [10], its relationship to global patterns of tectonism, and its possible origin through deep-seated broad-scale mantle upwelling. And many previous interpretations of Tharsis on Mars [14] have cast this topographic and volcanic anomaly on Mars as a consequence of similar deep mantle processes. The antipodal correlation in arrangement of hot spot concentrations and subduction zones on Earth, and the observed anti-correlation of volcanic concentrations and crustal shortening in the lowlands of Venus may be manifestations of similar convection cycles characterized by integrated patterns of deep welling and broad regions of isolated upwellings.


**Figure 1.** Distribution of large volcanoes and coronae, Venus. **Figure 2.** Distribution of intraplate volcanism on Earth. **Figure 3.** Distribution of major volcanoes on Mars.