LAYERED MAFIC INTRUSIVE COMPLEXES, POSSIBLE TERRESTRIAL ANALOGUES OF VENUSIAN CORONAE.

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Introduction: Preliminary investigations by these authors concerning the comparison and contrast of characteristics associated with terrestrial layered mafic intrusives (LMI's) and Venusian coronae indicate some similarities in morphology and possibly origin. Our premise is that coronae, and processes related to their formation, may not be unique to Venus and that mantle plumes could have been one of the prevalent forms of heat transfer on Earth during the Archean and Proterozoic Eons. Mantle plumes may have also been instrumental in the initiation of primitive plate tectonic processes during the Archean on Earth.

Excellent studies concerning the morphology, structure, distribution, evolution, and origin of coronae based on Magellan data are given in [1,2,3]. Published data and literature on terrestrial LMI's, however, are overwhelmingly dominated by research focused on the origin of compositional layering and origin of economic concentrations of platinum group elements (PGE's), Cu, Cr, V, and Ti, with very little reference to the overall morphology, detailed structure, and ultimate origin. If a correlation between the structures on the two planets is found, then there is potential for huge reserves of PGE's, Cu, Cr, V, Ti, and other metals that may be associated with coronal magmatic deposits.

Diapiric Models on Earth and Venus: It is generally accepted that coronae are formed above mantle diapirs. A model for emplacement of these Venusian diapirs is outlined in [3]; however, the mechanism of the diapiric rise of these magma bodies (compositional, thermal, or melt) is currently ambiguous. The process of diapiric rise of mantle plumes on Earth has been more extensively studied. Models for their emplacement have been discussed by many authors [4,5]. There are several similarities between diapiric models for Earth and Venus; therefore, it may be reasonable to assume that features and structures formed by similar processes would be evident on both planets.

Venusian Coronae: Venusian coronae are interpreted as surface features produced by upwelling diapirs from the Venusian mantle. Coronae can be summarized as circular to elliptical structures with overall diameters between 75 and approximately 2,000 km. Based on Magellan radar imagery, they have an annulus of concentric fractures and exhibit well preserved features, that show minimal affects from weathering and major deformational events. By studying cratering and resurfacing events on Venus, it has been estimated that the latest resurfacing event occurred around 288 Ma [6]. Coronae have been interpreted to be temporally equivalent or subsequent (80-150 Ma [7]) to this event; the age of coronae are interpreted to be somewhere between 80and 288 Ma.

The morphological types of coronae are given in [1,2,3]. These various types include Concentric, Concentric-Double Ring, Radial/Concentric, and Multiple/Asymmetric. For our purposes, Multiple and Asymmetric types have been combined due to their similarities and for the fact that all Multiple types are asymmetric. Statistically, most Venusian coronae are concentrated near chasmata which are interpreted to be extensional features on the Venusian lithosphere; however, they occur in other settings as well [3,6].

Layered Mafic Intrusives (LMI's) On Earth: Terrestrial layered mafic intrusive complexes are circular, lobate, or elliptical surface features on Earth with equivalent diameters of 6 to 300 km, with intrusive ages ranging from Archean to Tertiary, but are dominantly Proterozoic. They are generally found emplaced into Archean age terrains that have, in most cases, been significantly affected by weathering, erosion, deformation, and metamorphism.

The occurrence of LMI's has been documented on every continent; however, some of the largest, most notable, and best exposed of these include the Bushveld Igneous Complex (BIC) in South Africa, Stillwater Complex in Montana, Great Dyke in Rhodesia, and Duluth Gabbro in Minnesota.

LMI's, along with other mafic intrusive systems, have been interpreted to have formed in relatively stable cratonic settings in a plate tectonic context. The majority of LMI's are associated with cratonic-scale crustal separations or rifts [8]. Prime examples of this association are the BIC and the Great Dyke. The Duluth Gabbro Complex is associated with the Midcontinent Rift in eastern North America.

Bushveld Igneous Complex (BIC): The BIC represents one of the most impressive magmatic systems on Earth. Based on present levels of exposure and erosion, it measures 375 km E-W and 300 km N-S, and extends over 67,000 km^2. The complex is characterized as an asymmetric funnel shape in cross-section and morphologically has four lobes as observed in plan [8,9]. The BIC is interpreted to consist of anywhere from four to seven distinct intrusives. If the BIC represents an eroded core of a terrestrial coronae, its shape would classify it as an Asymmetrical/Multiple type. A potential model for the formation of the BIC as related to Asymmetric/Multiple coronae may follow the multiple diapir model of Lopez [10].

Most research on the BIC and most LMI's have been focused on the origin of compositional layering [8,9], very few references address the ultimate origin or source of the magma. Reviews of LMI's [8,9] discuss the impact theory; however, correspondence with major researchers specializing on the Bushveld indicates there is no physical or direct evidence to support this theory. Current petrogenetic models of metavolcanic rocks, as well as rocks comprising the main magmatic suite, associated with the BIC as studied by [11] indicate their geochemistry is consistent with magmatic processes related to a mantle plume and not to multiple asteroid impacts. Gravity surveys of the BIC indicate a relatively complicated structure for the floor rocks of the complex characterized by horst and graben tectonics that run parallel to the contact of the intrusive within the rocks comprising the floor. They have attributed these extensional features to crustal loading by the massive intrusive [12]. Other extensional features that would be the equivalent of an annulus have not been found in the literature and may have not yet been recognized.

Challenges Associated with Terrestrial Interpretations: The majority of Venusian coronae are raised topographic features that are preserved due to their relative young geologic age and insignificant effects of weathering. The effects of weathering and erosion on structural features of exposed LMI's, that appear distinct on Venusian coronae, may have been eroded on terrestrial examples reducing their topographic expressions. Extensive weathering of LMI's, such as in the case of the BIC, may have obliterated any raised topographic expressions if they are equivalent features or related to equivalent processes. Most surface features evident in Venusian coronae such as annular, concentric ridges or rims, inner highs, troughs, moats, or depressions may have been essentially obliterated if they were present on Earth due to deep levels of weathering that would expose the flattened, differentiated, magma chamber of the LMI. This chamber could be the fractionation product of, or may directly represent, the original mantle diapir. Factors affecting possible terrestrial coronae are orders of magnitude more complicated compared to Venusian coronae since erosional and deformational affects on Venus are comparatively insignificant.

Potential Significance: Features currently observed on Venus may be a clue to structures and processes prevalent on Earth during the Archean through the Middle Proterozoic. Coronae are believed by many [1,2,3] to be the surface manifestations of processes associated with rising mantle plumes. In addition, some researchers have indicated that mantle plumes were the dominant form of heat transfer on Venus [13], at least during the period of geologic time in which they formed. There was a period of geologic time on Venus, possibly between 500 and 80 Ma, when the proposed processes associated with mantle plumes were prevalent and formed coronae. Mantle plumes may have had the same significance on Earth during the Archean through Middle Proterozoic, between about 4,000 and 1,000 Ma. Styles of mantle and crustal evolution could be similar on Earth and Venus, but operative during different periods of time on the two planets. Both types of structures appear to be related to extensional tectonism: Venusian chasmata and cratonic rifts on Earth. In addition, all coronae are associated with volcanism and most LMI's are associated with metavolcanic rocks that are spatially and temporally affiliated with the emplacement of the intrusives. If coronae and LMI's are related, being at different stages of mantle evolution at different times could explain the temporal disparity of the mantle processes operating on the two planets.

Our continued research will focus on gathering structural data on LMI's, comparing the data to structural features of Venusian coronae, and drawing conclusions about the relationship of these features.

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