MAGELLAN, VENUS, AND THE EARTH; D.L. Turcotte, Department of Geological Sciences, Cornell University, Ithaca, NY 14853

The Magellan Mission has provided a wealth of data on Venus. We now have a far better understanding of the tectonics and volcanism on the planet. This is important in terms of the exploration of the earth's sister planet; but it is also important in that it provides insights into how the earth works. Two major questions concerning the earth are: (1) Why does the earth have continents and (2) why does the earth have plate tectonics? In essence, Venus has neither. These differences can probably be attributed to the presence of liquid water (oceans) on the surface of the earth.

Thanks to the Magellan Mission we now have a fairly comprehensive understanding of how Venus works. The escape of heart from the interior of Venus and the earth dictates how these planets evolve. On the earth mantle convection transports a large fraction of the heat generated by the radioactive decay of the isotopes of uranium, thorium, and potassium and the secular cooling of the planet. The plates of plate tectonics are the thermal boundary layers of mantle convection cells. The subduction of these cold plates at ocean trenches contributes about 75% of the mantle heat flux. The remainder can be attributed to the ascent of hot plumes through the mantle. Alternative mechanisms are partial delamination of the cold lithosphere and as yet undefined forms of secondary mantle convection.

It is now quite clear that active plate tectonics is not occurring on Venus. The surface of Venus is a single plate as is the case for the moon, Mars and Mercury. Prior to Magellan the general consensus was that Venus was in a near uniformatarian state with conductive heat losses through the lithosphere balancing internal heat generation and secular cooling of the planet. This hypothesis implied a thin lithosphere (mean thickness $\approx$ 45 km) and it was recognized that it was difficult to support the high topography and associated gravity anomalies. This led to the concept of dynamic support [1], topography is the result of the dynamic pressure gradients associated with mantle convection.

Crater studies from Magellan images essentially preclude any uniformatarian hypothesis for Venus. [2-4] These studies show that the surface volcanics have a near uniform age estimated to be 500 ± 150 Myrs. In addition, only 4.5%, of the craters show embayment by lava flows and 52% show any tectonic disruption indicating little volcanic and tectonic activity since the global resurfacing event. This is direct evidence for the catastrophic evolution of Venus. One explanation is that Venus died tectonically 500 Myrs ago [5], plate tectonics occurred during the early evolution of the planet but ceased as the radioactive heat production decreased. The primary problem with this hypothesis is that estimates of heat production within Venus indicate that without plate tectonics or other active transfer processes the interior of Venus will be heating up at a rate of about 200°K/Gyr.

An alternative explanation of the observations is that Venus experiences episodic global subduction events [6]. During periods of surface quiescence the global lithosphere thickens by heat conduction and becomes increasingly unstable; also, the interior of the planet heats up increasing the plume flux. Artemis corona has been interpreted as an incipient subduction zone [7-8], one hypothesis is that Artemis is an aborted global subduction zone. Following the global subduction event a period of extensive volcanism and high surface heat flow cools the interior leading to the stabilization of a global lithosphere.

There is also direct observational evidence for episodic subduction in a natural analog to mantle convection. Atmospheric cooling creates a solid crust on Hawaiian lava lakes. This dense crust is gravitationally unstable and episodically the entire crust breaks up and founders [9]. The beginning of foundering is marked by the appearance of a crack in the crust which exposes fresh magma, the foundering propagates along a series of arcs of increasing circumference away from the point of origin until the entire curst has foundered. Then a new crust forms and after a period the process repeats. It is quite possible that this type of episodic subduction is a preferred mode of heat transport in a fluid with a rigid boundary layer and that the Earth is the unusual planet with a near steady-state subduction, rather than Venus.

Although the dominant view of tectonic processes on the earth is uniformitarian, there are many geologists who insist that there is significant long-term episodicity in tectonic processes. This is reflected in the Wilson cycle of supercontinent formation and breakup but there are also important signatures in sea level and continental volcanic activity [10-11]. Stein and Hofmann [12] point out the epicidicity in the radiogenic isotope record and attribute it to episodes of enhanced convective exchange between the lower and upper mantle in which two-layer convection alternates with episodes of penetrative or whole-mantle convection [13]. Nance et al. [10] suggests that peak plume fluxes on the earth occurred at 200, 600, 1,000, 1,500, 2,000, and 2,500 MYBP. Thus the earth appears to have an epicidity very similar to that proposed for Venus.

Two major questions concerning the earth remain largely unanswered, particularly when compared with Venus. (1) Why does the earth have continents? (2) Why does the earth have plate tectonics? A major difference between the earth and Venus is the presence of liquid water (oceans) during much of the evolution of the earth. It has been hypothesized that water is an essential ingredient for the silicic volcanism that produces continental rocks on the earth, the absence of well defined continental masses on Venus supports this hypothesis rather than the alternative hypothesis that these silicic rocks were directly produced from the mantle.

It has long been recognized that plate tectonics cannot evolve in time without internal deformation of plates [15]. Plate evolution in time results in geometrical incompatibilities that require overlaps or gaps. On the earth these incompatibilities lead to broad zones of continental deformation, i.e. the western U.S. and China. The absence of plate tectonics on Venus suggest that reologically soft continents are necessary for plate tectonics. A reasonable conclusion is that the earth is the remarkable planet in terms of tectonics and volcanism, not Venus. How does the near steady-state rate of plate tectonics on earth regulate itself so that it transports the required surface heat flux?

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