



## The Tectonics of Venus and Creation

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### Abstract

Venus has a nearly perfectly random distribution of craters on its surface. This implies that the Venusian surface is the same age. Astronomers have not found tectonic plates on Venus. How does the planet release its internal heat. One solution proposed by astronomers is lid tectonics. The Venusian surface is similar to one giant plate. This plate thickens over time from underplating. Astronomers have suggested that this lid eventually reaches a dynamically unstable situation and will quickly be pulled into the interior of the planet. The reasons for this idea will be explored and evaluated within a creationary history. The relationship between Venusian tectonics and catastrophic plate tectonics will be discussed.

### Keywords

Venus, Tectonics, Subduction, Craters

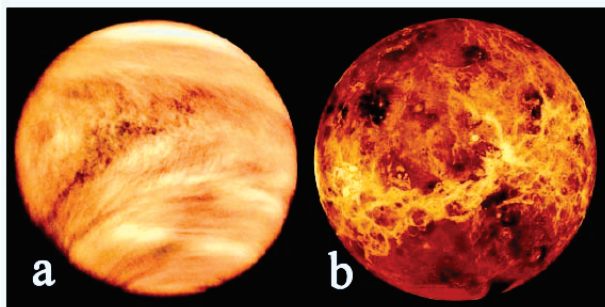
### Introduction

Venus is the second planet from the Sun with a mean orbital distance that is 72% of the distance from the Sun to the Earth (Basilevsky & Head, 2003). Venus has often been called a sister planet to the Earth because of its similar size and mass as well as having an atmosphere. The thick clouds of Venus have provided evidence for an atmosphere ever since the first telescope was used to observe the planet (refer to Figure 1a), but the surface of Venus has been a mystery. That is until the arrival of space probes during the latter half of the twentieth century.

The first space probe sent to Venus was *Venera 1*. This was sent by the former Soviet Union, but it failed before reporting any data back to earth (Basilevsky & Head, 2003). The first space probe that sent data

back from Venus was the *Mariner 2* space probe, but, it was only a flyby mission. *Mariner 2* was sent by the United States (Basilevsky & Head, 2003). The first space probe that actually made it to the surface of the planet and sent data back to Earth was *Venera 7*. It was sent by the former Soviet Union (Basilevsky & Head, 2003). Since then, several other space missions to Venus have been undertaken by the United States and the former Soviet Union. More was learned about Venus since the 1960s than all of history to that time.

The large-scale tectonics of Venus can begin to be evaluated because of all the data from the *Magellan* space probe. The *Magellan* spacecraft was able to pierce the thick clouds of Venus by using synthetic aperture radar (Nimmo & McKenzie, 1998). The *Magellan* spacecraft was able to resolve images down to about 100m (refer to Figure 1b). It could also resolve altimetry data down to 80m in the vertical (Phillips & Hansen, 1994). Large scale images of Venus became possible for the first time. It was soon realized that Venus was not a sister planet to the earth when it came to tectonics. It was obvious from the synthetic aperture radar images that Venus does not have surface features that are similar to those associated with plate tectonics on the Earth (Nimmo & McKenzie, 1994). Researchers have concluded that if Venus has tectonic activity that activity isn't like tectonic activity on the Earth. Tectonic activity on the earth is thought to be a slow and constant process by conventional earth scientists. The planetary



**Figure 1.** The Venusian atmosphere and surface. (a) Venus in UV light taken by Pioneer Venus orbiter in 1979. (b) This image is a computer construction of Venus based on the synthetic aperture radar data from the *Magellan* space probe. (Basilevsky & Head, 2003).

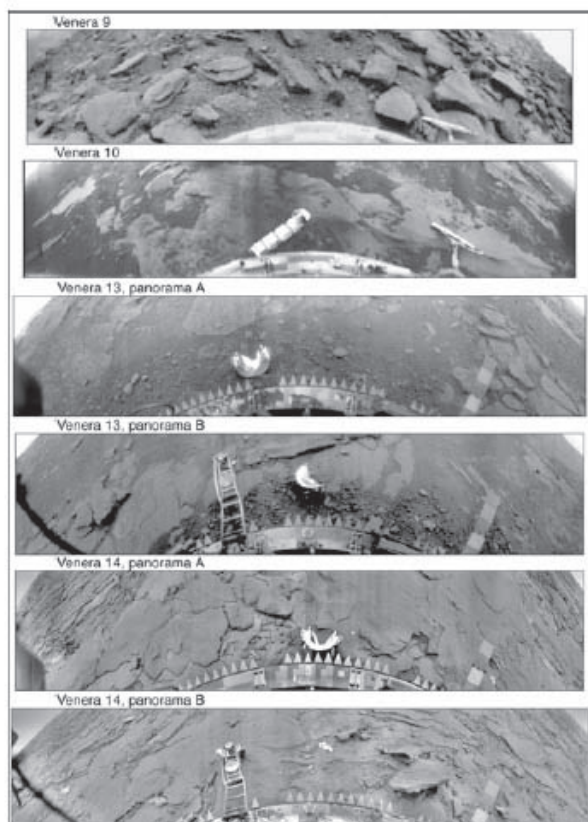
scientists studying Venus have come to the conclusion that if Venus has tectonic activity, it is episodic. That is, it goes through times of catastrophic subduction followed by times of virtually no subduction.

First, this paper will review the basic geologic structure found on Venus. Second, it will review the evidence that is in favor of catastrophic subduction on Venus. Third, this paper will evaluate the evidence in terms of a creationary model for Venus. The implications for solar system history within a creationary model will also be addressed.

## Observations

### Surface rocks

The surface rocks of Venus have been analyzed using x-ray fluorescence spectroscopy by the *Venera 13* and *Venera 14* landers (Surkov, Moskaleva, Shcheglov, Kharyukova, Manvelyan, & Smirnov, 1982). Figure 2 contains examples of images from the surface of Venus taken by the *Venera* probes. The rolling upland terrain rocks analyzed by the *Venera 13* lander are consistent with potassium alkali basalts. The flat lowland rocks analyzed by the *Venera 14* lander are consistent with tholeiitic basalts, but Kaula (1995) has pointed out that the inherent dryness of Venus would also affect the physical properties of rocks on Venus. The extreme lack of water on Venus was first



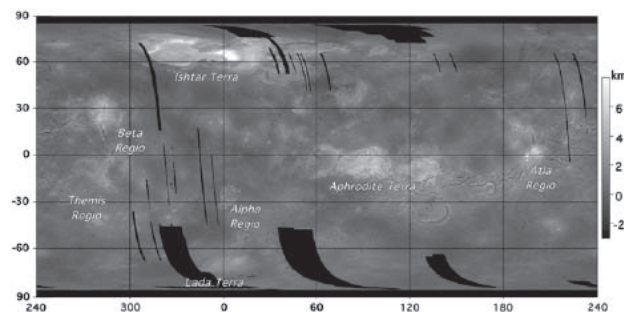
**Figure 2.** Venus surface rocks. Photographs taken by the *Venera* landers. The rocks are similar to basalts found on earth but very dry (Basilevsky & Head, 2003).

measured by *Venera 4*. This probe was sent from the former Soviet Union (Basilevsky & Head, 2003). Experiments were done with diabase that has had most of its water removed. The viscosity of the dry diabase was higher than for diabase that would be typically collected on earth.

The implications of dry crustal rocks are clear. The lithosphere of Venus should be more difficult to break (Kaula, 1995). This would explain the lack of spreading centers and subduction zones on Venus. A more rigid lithosphere would tend to stay in place until it fails catastrophically.

### Plains

Volcanic plains cover about 80% of the Venusian surface (refer to Figure 3). These plains are very close to the mean planetary radius (Basilevsky & Head, 2003). Many of these volcanic plains have wrinkle ridges that suggest compressional deformation. Wrinkle ridges are the most common structure on the volcanic plains (Phillips & Hansen, 1994). These volcanic plains also have very highly deformed terrains that resemble islands and continents. These islands and continents form about 8% of the Venusian surface (Basilevsky & Head, 2003).



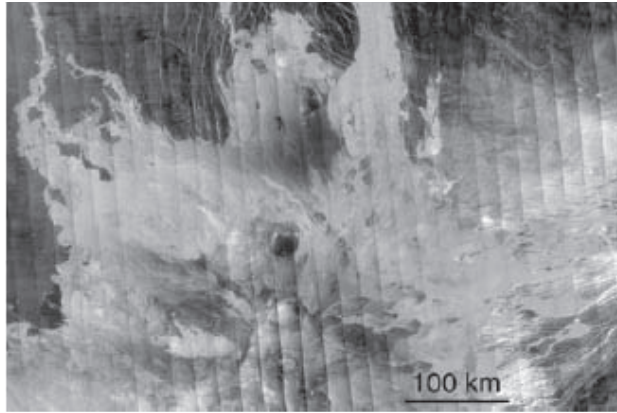
**Figure 3.** Hypsometric map of Venus. The Terraes are similar to continents in size and are elevated above the mean planetary radius. However, hypsometry on Venus is unimodal, while it is bimodal on the earth (Basilevsky & Head, 2003).

### Volcanoes

Volcanoes on Venus are numerous and are not distributed on the surface in a linear pattern as they are on the earth (Phillips & Hansen, 1994). Volcanoes on Venus, have gentle slopes and lobate flows (Basilevsky & Head, 2003). They appear to be similar in structure to basaltic shield volcanoes on the earth. Figure 4 is a typical volcano on Venus.

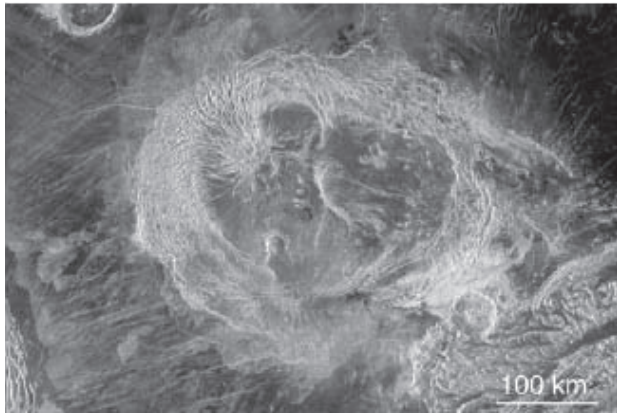
### Coronae

Venus also possesses volcano-like structures called corona. Over 360 coronae have been identified on the surface of Venus (Phillips & Hansen, 1994). They are nearly circular structures with tectonically deformed annuli around them. Corona are thought to be caused by rising mantle diapirs. When the diapirs cool the



**Figure 4.** The volcano Maat Mons. The volcanoes on Venus are structurally similar to shield volcanoes on earth (Basilevsky & Head, 2003).

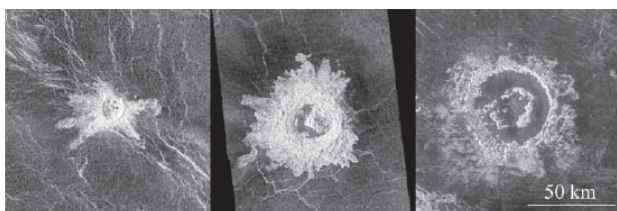
uplifted surface collapses causing the deformed annuli (Basilevsky & Head, 2003). Figure 5 is a typical corona.



**Figure 5.** Pomona Corona (Basilevsky & Head, 2003).

### Craters

Over 900 impact craters have been identified on the surface of Venus (Strom, Schaber, & Dawson, 1994). Examples of the different types of craters on Venus can be seen in Figure 6. The atmospheric pressure at the surface of Venus is 93 times the atmospheric pressure of the earth at the surface (Basilevsky & Head, 2003). The thick atmosphere of Venus reduces the number of impacters that reach the surface. The *Magellan* space probe did not detect any impact craters with diameters less than 1.5 km, even though the space probe could resolve crater diameters down to 500 m (Strom, Schaber, & Dawson, 1994).



**Figure 6.** Types of impact craters on Venus. (Basilevsky & Head, 2003).

### Internal structure

The internal structure of Venus is thought to be similar to the earth. However, the iron core takes up about half the radius of the planet. The entire crust is thought to be about 70 km thick (Basilevsky & Head, 2003).

The elastic thickness of the lithosphere is the effective thickness that can support elastic stresses over geologic timescales. The elastic thickness for Venus can be estimated by modeling lithosphere flexure associated with structures found around volcanoes. Large-scale lithosphere flexure can be determined from topography and gravity anomalies. The coherence function between topography and gravity anomalies is calculated. The coherence function is determined by dividing the two Fourier transforms of the two data sets. The elastic thickness is then calculated from the coherence function. After looking at 34 structures on Venus, Barnett, Nimmo, and McKenzie (2002) concluded the elastic thickness of the regions studied was 20–60 km.

The mantle of Venus is thought to be similar in composition to the earth. This assumption is based on the similar densities of the two planets. It probably has radiogenic isotopes as does the earth (Turcotte, Morein, Roberts, & Malamud, 1999). These radiogenic isotopes will add thermal energy to the mantle and will tend to cause convection in the mantle. (Phillips & Hansen, 1994).

### Unusual Observations

The distribution of craters is independent of elevation (Strom, Schaber, & Dawson, 1994). That is, they are distributed randomly on the surface of Venus (Strom, Schaber, & Dawson, 1994; Turcotte et al. 1999).

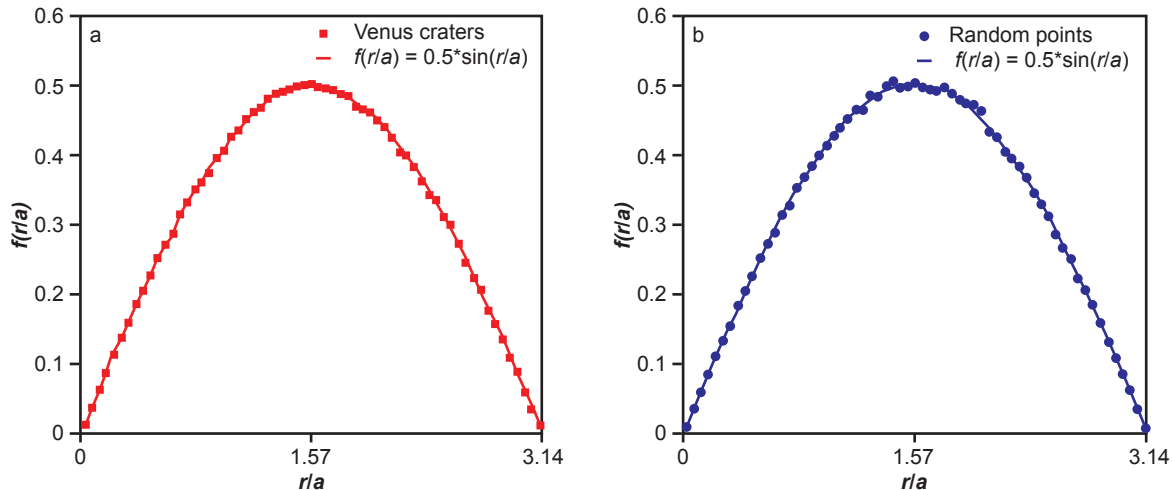
Turcotte et al. thoroughly established the random distribution of craters on the surface of Venus. They used pair-correlation statistics.

Their method followed the following procedure.

- (1) Pick a crater.
- (2) Model a set of rings around that crater along the planet surface.
- (3) Count the number of craters within each ring.
- (4) Divide the number of craters within each ring by the total number of craters.

The maximum number of craters will be found halfway around the planet from the chosen crater because the ring at the halfway point will have the largest surface area. The minimum number of craters will be found in the ring closest to the chosen crater and the ring farthest from the chosen crater.

Turcotte et al., (1999) simulated a random set of craters on a sphere. They used the method outlined above on Venus and on the simulated set of craters. The two were indistinguishable, as can be seen in Figure 7.



**Figure 7.** Crater distribution on Venus compared to a random distribution. The two graphs are indistinguishable (Turcotte et al., 1999).

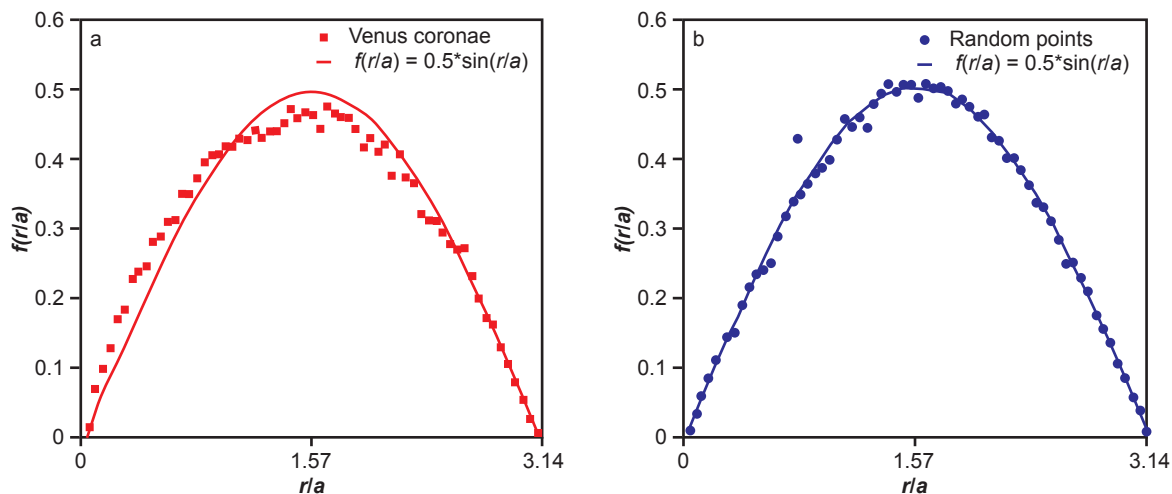
Turcotte et al. (1999) also analyzed the distribution of coronae on the surface of Venus using the same approach. Coronae are not randomly distributed, as can be seen in Figure 8. Coronae are fractally distributed. Hotspots on the earth are also fractally distributed. This lends credibility to the conclusion that coronae are related to rising mantle diapirs (Turcotte et al., 1999) the coronae are not truly randomly distributed. (Turcotte et al., 1999).

Another unusual feature about craters on Venus has to do with the degradation of craters over time. The craters on Venus have experienced very little degradation since they were formed. The crater rims appear to be pristine. Only 3.4% of crater rims on Venus demonstrate lava embayment (Strom, Schaber, & Dawson, 1994). Only 8.5% of craters on Venus have been slightly fractured (Strom, Schaber, & Dawson, 1994).

The random distribution of craters on the surface of Venus implies that the entire surface of Venus is the same age (Strom, Schaber, & Dawson, 1994). The lack of crater degradation implies that the entire surface

of Venus is geologically young. Based on cratering rates, the surface of Venus has been estimated to be between 190Ma and 600Ma by planetary scientists (Strom, Schaber, & Dawson, 1994). As creationists we reject the long ages, but it should be recognized that Venus doesn't have as many craters as expected by evolutionary models of the solar system.

Some have suggested that volcanoes alone could resurface the planet and produce the observed distributions and character of Venusian craters without invoking a catastrophic event. Strom, Schaber, and Dawson (1994) examined this equilibrium-resurfacing model by developing Monte Carlo simulations of cratering and volcanic eruptions. They concluded that the equilibrium-resurfacing model was not supported because the number of volcanoes required for the equilibrium-resurfacing model to work was three times the observed number of volcanoes on Venus (Strom, Schaber, & Dawson, 1994). The Monte Carlo simulations also did not produce randomly distributed pristine craters, which is true of Venus (Strom, Schaber, & Dawson, 1994).



**Figure 8.** Coronae distribution on Venus compared to a random distribution. The two graphs are similar, but the coronae are not truly randomly distributed (Turcotte et al., 1999).

### Episodic Subduction

The brittle lithosphere of Venus can be treated as a stagnant lid that rides on top of a mobile mantle. The lithosphere moves very little for long periods of time. Mars, Mercury, and the Moon can be described as stagnant lid tectonics as well. The lithosphere on these solar system bodies behaves as a single lithospheric plate (Moresi & Solomatov, 1998). The stagnant lid will catastrophically fail catastrophically when conditions are right. Moresi and Solomatov found that catastrophic failure occurs when the mantle underneath the lithosphere changes to plastic deformation during a mantle upwelling.

Turcotte et al. (1999) have suggested that catastrophic subduction begins when the thermal Rayleigh number,  $Ra_{cr}$ , reaches a critical value. The critical value of the thermal Rayleigh number is shown in equation (1):

$$Ra_{cr} = \frac{\rho_m g \alpha [T_m(t) - T_s] Y_L^3}{\eta(t) \kappa} \quad (1)$$

where  $\rho_m$  is the average mantle density,  $g$  is the surface gravity,  $\alpha$  is the thermal expansion coefficient,  $T_m(t)$  is the mean mantle temperature as a function of time,  $T_s$  is the mean surface temperature,  $Y_L$  is the lithosphere thickness,  $\eta(t)$  is the mantle viscosity as a function of time and  $\kappa$  is the thermal diffusivity (Turcotte et al., 1999).

The mantle viscosity is affected by temperature. It is assumed that it follows an Arrhenius functional dependence as shown in equation (2),

$$\eta(t) = C e^{\frac{E_a}{RT_m(t)}} \quad (2)$$

where  $C$  is the reference viscosity,  $E_a$  is the activation energy,  $R$  is the ideal gas constant, and  $T_m(t)$  is the mean mantle temperature as a function of time (Turcotte et al., 1999).

Turcotte et al. (1999) assumed that Venus has a similar rate of heat production per unit mass to the earth. They assumed the rate of heat production decayed exponentially with time (Turcotte et al., 1999). This is reasonable since radioactive decay is inherently exponential in nature. The heat production equation can be written as shown in equation (3) (Turcotte et al., 1999),

$$H(t) = H_0 e^{-\lambda(t-t_0)} \quad (3)$$

where  $H(t)$  is the heat production per mass,  $H_0$  is the reference heat production per mass,  $\lambda$  is the decay constant and  $t_0$  is the reference time. Radiogenic heat production will heat the mantle during subduction events.

The temperature of the mantle will then be shown as in equation (4) (Turcotte et al., 1999),

$$T_m(t) = T_m(t_s) + \frac{H_0 e^{\lambda t_0}}{C\lambda} \left( e^{-\lambda t_s} - e^{-\lambda t} \right) \quad (4)$$

where  $C$  is the specific heat, and  $t_s$  is the time of the last subduction event.

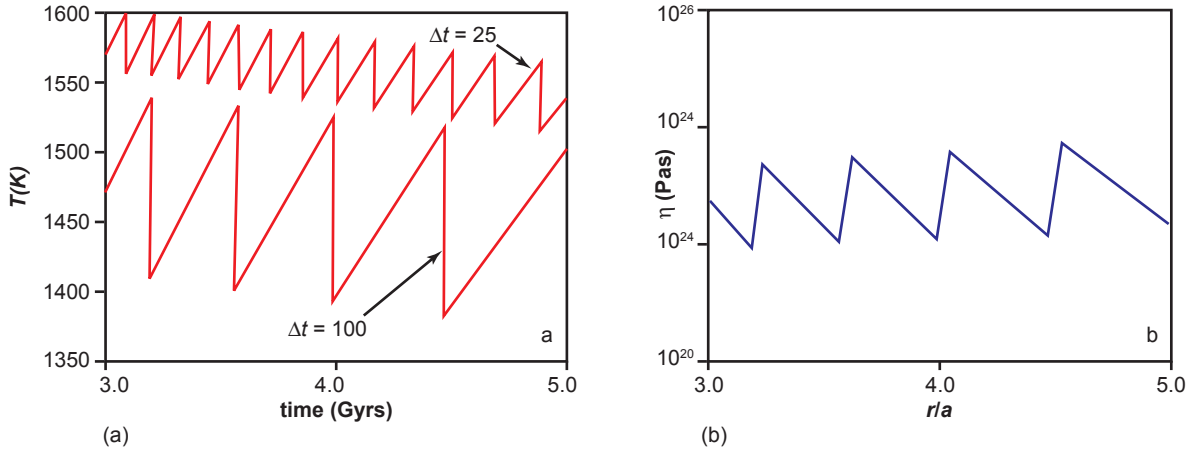
Turcotte and Schubert (1982) derived an expression for the thickness of the lithosphere as a function of time under these assumptions as shown in equation (5) (Turcotte & Schubert, 1982),

$$Y_L(t) = 2.32 [\kappa(t-t_s)]^{1/2} \quad (5)$$

Plate tectonics is an important mechanism for cooling of the earth. About 75% of the thermal energy transferred from the interior of the earth is due to subduction of lithospheric plates (Turcotte, 1993). However, Venus does not have continuous tectonic activity. This allows heat to build up under the Venusian lithosphere. Eventually a critical situation develops and subduction takes place catastrophically releasing enormous amounts of heat from the planet interior. After a catastrophic subduction event, the rate of thermal energy transfer from the interior of Venus decreases drastically. With this drastic reduction in thermal energy transfer mantle convection in Venus decreases dramatically (Turcotte, 1993).

During the time when the Venusian lithosphere is not going through active tectonics, the lithosphere thickens by underplating (Turcotte, 1993). The thicker lithosphere acts as a thermal insulator. This causes the temperature of the mantle to increase. As the mantle temperature increases, the viscosity of the mantle decreases. The thicker lithosphere also becomes unstable due to its negative buoyancy (Turcotte, 1993). Eventually, this negative buoyancy becomes so unstable, that catastrophic failure of the Venusian lithosphere occurs and rapid subduction occurs (Turcotte, 1993). A rapid subduction event will occur when the  $Ra_{cr}$  value occurs. The cycle then repeats itself in his model. It is doubtful that more than one rapid subduction event can occur within a creationary time frame.

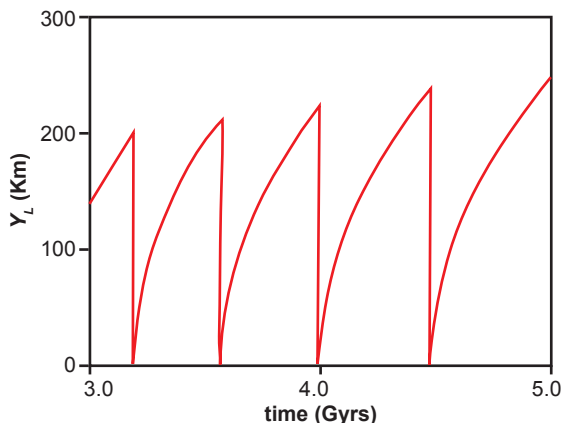
There is virtually no evidence of subduction or plate spreading going on today. However, there is some evidence for mantle convection from gravity and topography data. McKenzie (1994) concluded that some of the larger topographic features of Venus are supported by convective circulation in the mantle. He based this conclusion on the admittance spectra from topography and free air gravity anomaly (McKenzie, 1994).



**Figure 9.** Mantle properties over time. (a) shows the mantle temperature as a function of time. (b) shows viscosity as a function of time (Turcotte et al., 1999).

Figure 9(a) shows how mean mantle temperature will vary over time. The mean mantle temperature builds up until the critical value of the thermal Rayleigh number is achieved. Then catastrophic subduction occurs which releases heat from the mantle. The mean mantle temperature drops and begins to build back up again. The top curve in the temperature versus time graph shows how the mantle will behave if it cools by 25 Kelvin during each catastrophic subduction event. The bottom curve in the temperature versus time graph shows how the mean mantle temperature will vary when the mantle cools down by 100 Kelvin during each catastrophic subduction event. The larger the temperature drop between subduction events, the longer the time interval to the next catastrophic subduction event.

Figure 9(b) shows how the viscosity varies over time (the right graph). The viscosity drops as the mantle heats up between catastrophic subduction events. Then, when the mantle releases a great deal of heat and the mean mantle temperature drops, the viscosity rises again. This rapid rise in viscosity towards the end of the catastrophic subduction event will also hasten the end of the subduction event by making it



**Figure 10.** Lithosphere thickness as a function of time (Turcotte et al., 1999).

more difficult for the lithosphere to subduct.

Figure 10 shows how the lithosphere thickness changes over time given the assumptions that were discussed above. This graph is based on the assumption that the mean mantle temperature decreases by 100 Kelvin during a catastrophic subduction event. At the end of a catastrophic subduction event, the entire lithosphere has been subducted into the mantle of Venus. As the surface of Venus cools, the lithosphere thickens with time. The lithosphere thickens until the critical value for the thermal Rayleigh number is reached. Then, the lithosphere catastrophically subducts again into Venus. The process then repeats itself.

Another approach to developing a mathematical model of the catastrophic resurfacing of Venus is to use the Nusselt number. This was the approach by Moresi and Solomatov (1998). They first solved Stokes equation for fluid flow using a finite element code involving stress and strain rate tensors. Then they related the Rayleigh number to the Nusselt Number (Moresi & Solomatov, 1998).

Parameterized fluid models use the following relation for the Rayleigh number which can be seen in equation (6) (Nimmo & McKenzie, 1997):

$$Ra = \frac{g\alpha Fd^4}{k\kappa\nu} \tag{6}$$

where  $g$  is the gravitational strength,  $\alpha$  is the thermal expansivity,  $F$  is the heat flux across the layer,  $d$  is the layer thickness,  $k$  is the thermal conductivity,  $\kappa$  is the thermal diffusivity, and  $\nu$  is the dynamic viscosity.

The Nusselt number ( $Nu$ ) is the ratio of heat flux in the presence of convection to the heat flux in the absence of convection (Nimmo & McKenzie, 1997). As long as the viscosity of a fluid is approximately constant, then  $Nu = Ra^\beta$ , where  $\beta$  is a constant between 0.1 and 0.3 (Nimmo & McKenzie, 1997).

Figure 11(a) shows how the Nusselt number varies over time (Moresi & Solomatov, 1998). The

Nusselt number is a good measure for Venus episodic subduction events because it is a direct consequence of thermal energy transfer during convection. The Nusselt number in the graph is fairly constant over time until it spikes. These spikes occur when the critical value of the Rayleigh number is reached and catastrophic subduction begins to take place. Then, after the catastrophic subduction event is over, the thermal energy flow drops and convection slows down. This causes the Nusselt number to drop back down to its quiescent value.

Figure 11(b) represents the root mean-squared velocity of the mantle over time (Moresi & Solomatov, 1998). It follows a similar pattern to the Nusselt number. It is fairly slow and steady most of the time. But, as heat builds up and the critical Rayleigh number is reached, it rises dramatically and spikes. This rapid convection would enable the lithosphere to be rapidly subducted into the mantle.

One event that has been proposed as the initiator of the catastrophic resurfacing of Venus is the resonance between the core and the mantle of Venus due to solar tides (Touma & Wisdom, 2001). This event would transfer rotational kinetic energy to thermal energy in the mantle and could destabilize the mantle enough to start a resurfacing event. The transfer of rotational energy during resonances between the core and mantle can also happen on the earth. But, the retrograde rotation of Venus makes the core-mantle resonances stronger for Venus than for the earth (Touma & Wisdom, 2001). Therefore, the heating effect due to the transfer of rotational kinetic energy to thermal energy will be stronger for Venus than for the earth.

Strom, Schaber, and Dawson (1994) concluded that the global resurfacing event probably took less than 10Ma. They based their conclusion on the results of their Monte Carlo simulations and the estimated

cratering rate on Venus. This global resurfacing event is very similar to the idea presented by Austin, Baumgardner, Humphreys, Snelling, Vardiman, and Wise (1994) that has come to be called catastrophic plate tectonics.

### Conclusions

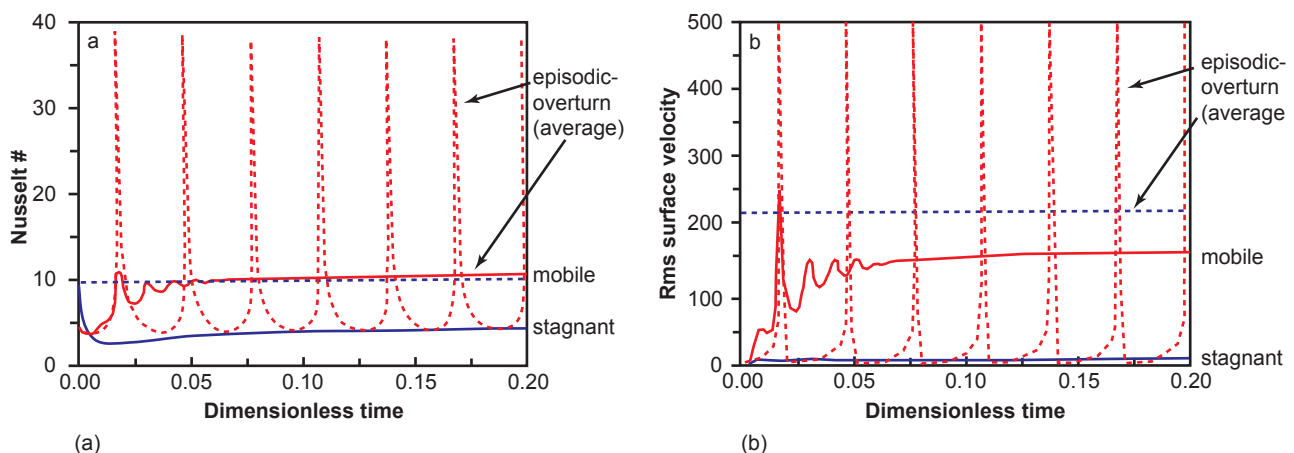
Venus isn't much of a sister planet to the Earth. It has features that Earth does not have, such as coronae. Also, earth has abundant water and Venus does not. The absence of water on Venus had a dramatic impact on the development of Venus over time. The lithosphere and mantle properties of Venus are different from the same properties on the Earth.

One consequence of the lack of water on Venus is the way in which the planet transfers thermal energy from the mantle to the surface. Earth transfers a most of the thermal energy from the mantle to the surface along plate boundaries. Venus does not have plate boundaries because its lithosphere has more strength. The viscosity of the mantle of Venus is also stiffer. The result of both of these factors combined makes plate tectonics on Venus impossible.

Instead Venus transfers thermal energy from the mantle to the surface by catastrophic subduction events. Venus catastrophically dumps thermal energy to the surface when the lithosphere is catastrophically subducted in a short time.

Evidence in favor of this catastrophic subduction is the random distribution of craters on Venus. This would not be possible unless the crust was the same age everywhere. The craters on Venus are not degraded over time by lava flows or other geologic activities. This implies that the surface of Venus is relatively young in the geologic sense.

One implication for creationary science is straight forward. Venus has been recognized by evolutionary planetary scientists as having experienced



**Figure 11.** (a) shows the variation of the Nusselt number with time. Catastrophic subduction would take place at the spikes. (b) shows how the mantle velocity varies with time. The two graphs spike at the same times (Moresi & Solomatov, 1998).

catastrophic plate tectonics. It would be very interesting to model Venusian tectonics using TERRA because it uses more sophisticated models for viscosity. This should be worth investigating further.

The second implication Venus has for creationary science has to do with the extreme randomness of the craters. Creationists at different times have proposed astronomical triggers for the Flood. One proposed trigger has to do with the solar system passing through a large asteroid swarm. This model would explain the non-random crater distribution of some solar system objects. This model would be hard pressed to explain the crater distribution on Venus. Venus has a very long sidereal day. An asteroid swarm would not cause the random distribution of craters on Venus. If the asteroid swarm trigger is to be used, it needs to be modified to explain the crater distribution on Venus. One possible solution would be for the rapid subduction event on Venus to take place after the Flood.

The random crater distribution of craters on Venus also has implications for proposals that a planet in between Mars and Jupiter exploded or was destroyed by a large impacting body. This idea has been proposed to explain the asteroid belt between Mars and Jupiter. An exploding planet and an large impacting body on a planet would probably not produce a random distribution of craters on Venus. Again, one possible solution for this issue would be for Venus to have the rapid subduction event after the planetary explosion or impact.

The third implication this has for creationary science has to do with the RATE project. A burst of radioactive decay would be an ideal trigger for the rapid subduction event on Venus. This should be explored further.

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