**A Solution to the Problem of the Resurfacing of Venus?** R. C. Ghail, Department of Earth Science and Engineering, Imperial College, London, SW7 2BP, United Kingdom. *R.Ghail@ic.ac.uk.*

**The Problem:** How does Venus resurface itself? Turcotte [1] proposed a model of rapid global resurfacing to explain the observed crater distribution on Venus. Despite initial scepticism, and with some modification, this model was accepted as the "standard" answer to the question of Venus resurfacing. Resistance to the model came most strongly from geologists unhappy with a catastrophic model that challenged the accepted belief in uniformitarianism. However, many now see evidence of a global stratigraphy [2] consistant with a past resurfacing event. Critical to this view is the idea that nearly all modern geological activity on Venus is in decline and that, apart from a small amount of extension associated with a few rifts, recent geological activity is entirely plume related with no evidence of plate tectonic behaviour.

The few voices of dissent have in the main argued against a global stratigraphy *sensu stricto* [3] or find evidence for plate-like behaviour [4] and examples of recent or ongoing geological activity. A weakness of the dissenters has been the lack of a plausible geophysical model that explains both the crater distribution and the proposed ongoing tectonic activity. This weakness is addressed here.

**Modes of Resurfacing:** It is generally accepted that Venus has been active since the supposed last resurfacing event; the question is as to its nature and extent. Certainly there has been recent rifting and volcanism but advocates of a global stratigraphic sequence argue that this minor and constitutes less than 10% resurfacing in the last 700 Ma or so, and simply represents the last stages in the rapid decline in activity following the cessation of global resurfacing. A second group [5] argues that the crater distribution is more consistent with a closely spaced (in time) series of regional resurfacing events, followed by a more gradual decline in activity. In both cases, the consensus is that there is a general sequence of global stratigraphy, starting with tesserae units, followed by various plains units associated with the global or regional resurfacing, and subsequently a number of large volcanic provinces, rift systems and coronae. The inference from this is that Venus has two modes of geological activity. The more or less continuous, steady-state, mode of activity is dominated by large volcanic provinces and by rift belts, often associated with coronae, that generate local plate-like behaviour consisting of compressional and strike-slip regimes.

The second mode is intermittant (or possibly happened only once) and consists of a single global, or a closely-spaced series (in time) of regional, plains-forming events. These events are short and end abruptly (within 10 to 50 Ma).

Does the episodic resurfacing model explain these two modes successfully? It appears to successfully predict the intermittant mode of global resurfacing. However, it fails to predict the second mode of activity, though it allows for some plume-related volcanism. Secondly, it does not appear to fit the range of lithospheric thicknesses inferred from gravity and other data. Thirdly, the model suffers from a chicken-and-egg paradox. For the model to work, the lithosphere must slowly thicken (by conductive cooling) until it is thick enough to be negatively buoyant and so start to subduct. For conductive cooling to occur the previous resurfacing event must have over-cooled the mantle so that radiogenic heating does not increase the mantle temperature. But since Venus must have accreted hot, there can have been no first resurfacing event.

**Comparison with Earth:** Plate tectonics is presently the major mechanism of mantle cooling and resurfacing on Earth and has been so for at least the last 2 Ga. However, early in Earth history (~3 Ga ago), the mantle temperature was much higher because of the increased radiogenic heat production at that time. To compensate for this higher heat flow, the size of terrestrial plates must have been smaller [6] and consequently the average age of subduction must have been lower. Exacerbating this, the thickness of oceanic crust produced at spreading centres was greater (20 to 30 km) because of increased melt volumes in the hotter mantle. Subduction would have been inhibited or impossible under these conditions and consequently plate tectonics must have operated in the 'hindered' state (Fig 1).

The debate amongst geologists is to what extent plate tectonics operated at all in the Archaean. There are two competing ideas: a purely uniformitarian one which relates all Archaean geological environments to modern plate boundary settings; and one in which the same geological features are seen in the context of plumes, either hot or wet. Both these ideas have evidence for and against them, though currently the uniformitarian plate tectonic ideas are favoured. This is not unlike the situation with Venus, though here plume models are favoured.

But such hindered plate tectonics is less efficient at removing heat from the mantle, and to compound

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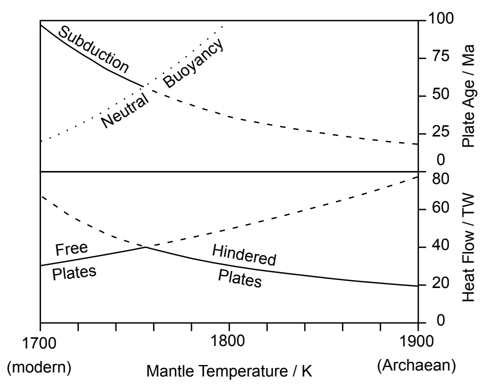


Fig. 1 The Breakdown of Plate Tectonics

matters, its efficiency declines with increasing mantle temperature. In the Archaean hindered plate tectonics was not able to remove heat fast enough. So what happened in the Archaean? Although conjectural, it is possible that, unable to cool itself efficiently by any other mechanism, Earth's mantle may have suffered runaway heating.

Komatiites imply a mantle temperature in excess of 1800 K, close to the peridotite liquidus temperature. A large fraction of Earth's upper mantle may have been flows are found on almost every craton within a 50 Ma period about 2·7 Ga ago, a period of time that also corresponds with the highest rate of continental crust production in Earth history. It is speculation, but might these events have been caused by near-global runaway heating and melting of the upper mantle at that time, caused in turn by the inhibition of subduction by positive lithospheric buoyancy?

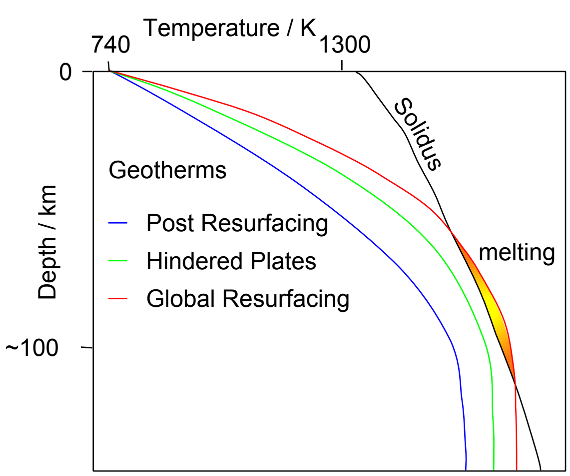


Fig. 2 Mantle Geotherms for Various Stages and Modes of Heat Loss on Venus.

Subduction on Venus is not inhibited by a high mantle temperature but by the high surface temperature, however, the heat loss problem remains the same. Thus Venus may now be operating in the hindered-plate mode, with plate-like behaviour (rifting, collision, wrench movement) driven by underlying mantle convection but without plate generation or destruction. The numerical details of the model in Fig. 1 (adapted from [6]) apply to that particular model of Earth and are regarded as representative. Whilst equivalent modelling has not yet been done for Venus, it seems reasonable that it will behave in a similar way.

Therefore, since the hindered-plate mode is not an efficient mechanism of heat loss, the mantle temperature inside Venus must be slowly increasing until such time as the solidus is crossed (Fig. 2). With the natural variation in mantle temperatures, this may not happen everywhere strictly simultaneously but certainly within a geologically short period of time. Melting on such a massive scale would overwhelm the normal tectonic system (as on Io), leading to regional plains production and volcanism almost everywhere. However, the extreme cooling efficiency of melt advection (essentially allowing material at 1800 K to cool by radiation) allows the Venus mantle to overcool, resetting the clock and allowing a return to the quasi-steady state hindered-plate regime.

Thus the paradox of rapid global plains formation followed by a long period of more limited plate-like activity can be understood as a natural consequence of the inhibition of subduction on Venus and thus inability of its mantle to cool efficiently. Furthermore, in its present state, Venus may offer a valuable insight into the workings of the Archaean Earth.

**References:** [1] Turcotte, D. (1993) JGR 198, 17061-17068 [2] Basilevsky A. T. and Head J. W. (1998) JGR 103, 8531-8544 [3] Hansen V. L. et al. (2000) JGR 105, 4135-4152 [4] Brown C. D. and Grimm R. E. (1995) Icarus 117, 219-249 [5] S.A. Hauck S. A. et al. (1998) JGR 103, 13635-13642 [6] Davies G.F. (1999) Camb. Univ. Press, 458 pp.