Discussion of

An alternative Venus

by

Warren B. Hamilton

24th December, 2006, G.J.H. McCall

Warren Hamilton's article is clearly the result of very detailed study of Venusian surface features. Venus is the only planet in our solar system for which we have to rely on radar images and this in itself provides additional constraints on interpretation. Hamilton has carefully considered the likely radar image obtained from different geological materials: e.g. basalt, sediments, breccias etc. He readily admits that his interpretations conflict with the interpretations of the conventional school of J.W. Head and others. It is a remarkable fact that, whereas for the Moon, Mercury, Mars and the many planetary satellites the conventional wisdom is virtually to apply Impact (rather than volcanism) as an 'a priori' or 'default' explanation for any craters or circular structures of disputed origin, the reverse is the case for Venus. Volcanic processes are invoked except for about 1000 'undisputed young pristine' Venusian craters. Hamilton rightly suggests that 'pristine' has been in many cases incorrectly used, and many are by no means pristine.

In this space age, conventional interpretations tend with the passage of years to be taken as 'graven in stone', but of course they are not. I remember well a meeting in London at which Dan McKenzie put forward a quite different interpretation of Venus, rejecting the conventional resurfacing model and calling for anomalies in crater counts.

I feel that so little is really known for certain about Venus that no careful interpretations such as that of Hamilton should be rejected out of hand. As Lichtenberg said, "question everything once". I myself am an independent thinker, like Hamilton. Indeed I think that there is yet room for such unconventional statements about Mars, even though we know much more for certain about Mars than about Venus. Take, for example, Venusian craters Aurelia, Lachapelle and Barton, illustrated by Hamilton. They are surely the radar-image analogs of the type of Martian crater, including the delightfully named Tooting Crater, illustrated and discussed by Barlow (2006) and Hartmann and Barlow (2006). Such Martian craters are surrounded by what appear to be successive thin flows, possibly of slurry, which conventionally are interpreted as 'ejecta blankets'. But are they? 'Spirit' and 'Opportunity' have completely revolutionised Martian 'geology', by recognising wholesale alteration of early Martian volcanic rocks to carbonates and sulphates, under an early hydrous regime, in which the water likely occurred as transient emissions. These craters could equally well be volcanic. There is absolutely no certainty that they are impact craters and there must have been early volcanism which produced the basaltic parents of these altered rocks and the clasts in the aeolian sediments imaged by 'Opportunity'. The associated heat could have mobilised the alteration products into several generations of slurries, for instance, in Tooting Crater (see cover illustration. Meteoritics & Planertary Science 41(10)). Impact origin is only an a priori assumption. Less is known for certain about Mars than is popularly supposed, it is early days yet, and our knowledge of Venus is in its infancy. Meanwhile let us allow divergent interpretations of both to see the light of day.

I am not myself in any way versed in interpretation of the surface of Venus. I do not know whether Hamilton's interpretations are correct or not. That is not the point. I do have greater interest Mars, especially from the meteoritic and eruptive viewpoints, and there can be no doubt that Olympus Mons is an ultrasized shield volcano with a caldera (McCall, 2006). Experience of mapping Menengai, Suswa, Kilombe, Silali and Ambrym caldera volcanoes in Africa and Vanuatu led me to recognise many of the classic features of such volcanoes, albeit highly magnified. In general also, my wide experience of volcanic terrains and extensive examination of Mars images, suggests that there will prove to be far more volcanic craters on Mars than is now conventionally supposed. There must be an earlier generation of volcanic rocks to have been altered to carbonate and sulphate minerals, and many simple younger craters may have been misidentified.

On Venus there are some quite unarguable volcanic structures (e.g the bun-like tholoids) and, considering the nature of its atmosphere, Venus must have had a history of major volcanism. Nevertheless, Hamilton's arguments are convincing and cannot be dismissed out of hand, and impact may have been much more important in shaping that planet's surface than is conventionally supposed.. The state of knowledge is that many of the Venusian craters and circular structures are ambiguous, and our knowledge of the geochronology of the planet is at present comparable with that of pre-Curie Victorian terrestrial geology - sequence known but no vestige of knowledge of a time scale.

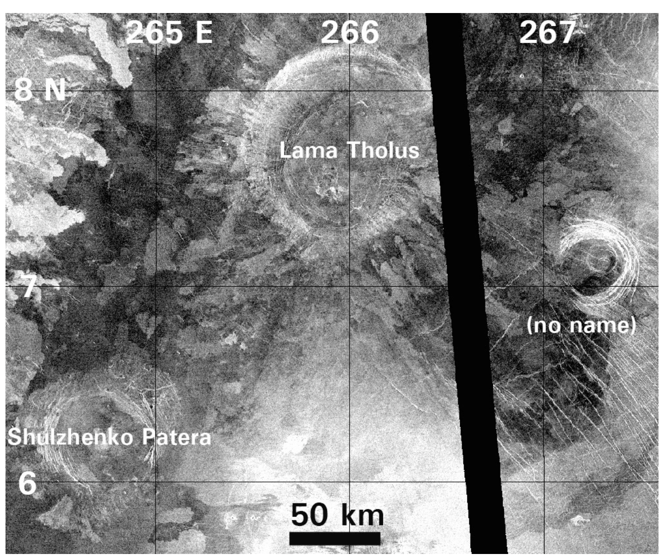
Hamilton has identified sediments and mud-volcanoes. In doing this he is relying on radar contrasts and other observed relationships, but, drawing on imagery from other planets and the Moon, I suspect that the plains are composed of volcanic material. I personally doubt whether Venus ever had transient oceans. My experience of mud-volcanoes related to hydrocarbons in the Makran of Iran suggests that what Hamilton is envisaging is something quite different to those small features, which would defy detection in the radar imagery of Venus.

3rd January 2007, Warren B. Hamilton

Joe McCall provided helpful comments on the manuscript for this paper, and I thank him for his continuing interest. We disagree on the nature of the venusian plains. He shares the overwhelming-majority view that the plains are volcanic, whereas I regard them as formed of sediments metamorphosed thermally by a runaway-greenhouse atmosphere. McCall makes few specific statements for discussion, so I list some of my reasons; see my present book chapter and Hamilton (2005) for elaboration.

- The plains are radar-dark, hence smooth-surfaced at centimeter and decimeter scale.
- Soviet-lander images show thinly slabby laminated material.
- Turbidite channels and lobes can be inferred from radar imagery.
- The plains show no fissures or other obvious lava sources.
- Old circular-rimmed basins (the older of the "pristine impact structures" agreed upon by all, plus my superabundant ancient impact structures) formed concurrently with deposition of plains materials, which progressively flooded the fretted topography of the structures, buried them, and compacted into and over them.
- Many wet-sediment and underwater impacts can be inferred.
- Thermal wrinkling and contraction structures, imposed only on plains material, are explicable by top-down heating and desiccation.
- The million or so smooth small, low, gentle-sided "shields" strewn about the plains resemble terrestrial mud volcanoes, not rough, steep-sided, fissure-following lava cones, and plausibly relate to top-down heating.

McCall terms the "bun-like tholoids" "unarguable volcanic structures"; but they are arguable. "Tholus", defined vaguely as "small domical mountain or hill", is applied to 55 venusian structures from 15 to 300 km in diameter in the U.S. Geological Survey Gazetteer of Planetary Nomenclature (http://planetarynames.wr.usgs.gov). Most have raised circular rims, many of which, like Lama Tholus illustrated here, enclose broad, shallow basins. I regard most of them, like venusian circular-rimmed structures given other designations, as ancient impact structures. Figure 1 shows two other circular rim-and-basin structures that I also see as impacts. Lama's radial debris-flow lobes are deflected against the aprons of the other two, and also against the lobate apron (in the northwest corner) of a large out-of-view doublet crater, Aruru Corona, so Lama is youngest. Everything in view is conventionally deemed endogenic.



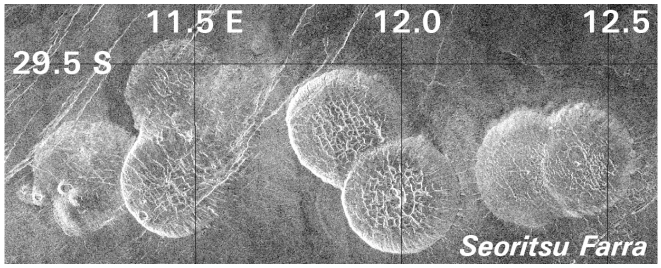


Figure 1

Or perhaps McCall means the "farra" (singular, farrum) of specialist terminology: rare low, flat-topped circular "pancake domes", typically several tens of km in diameter and several hundred meters high, mostly in elongate clusters. The domes have been casually likened to terrestrial silicic lava domes—but their "morphology and dimensions... make them unlike any type of terrestrial subaerial volcano" (Bridges, 1995), and their radar response is utterly unlike that of terrestrial lava domes (Plaut et al., 2004). Note the circularity of the Seoritsu Farra, and the superposition of younger domes on older, without deflection required by magmatic origins. Perhaps these are submarine impacts, of fragments of a large bolide disrupted by gravity and superdense atmosphere, into soft, water-saturated sediments.

31st January 2007, Suzanne E. Smrekar & Ellen Stofan

The study of impact craters is now 50 years old, and was developed in support of the Apollo program.

Impact craters are defined by their shape and ejecta blanket. They are depressions; the shape follows a transition from smaller, bowl-shaped craters to those with smaller depth-to-diameter ratios and central peaks, to larger multiring basins with even smaller depth-to-diameter ratios. The transition between these shapes is a function of planetary gravity. The eject blankets result from the shock wave that hurls the fragment surface on to the surrounding area. The effects of atmospheres and target properties on crater morphology are well understood, through studies of craters on Earth, the Moon, Mars, Mercury, and the icy satellites of the outer solar system. The physics of the processes that form these shapes has been examined via fieldwork on terrestrial craters, morphologic studies of craters on other planets, experimental studies, and theoretical modeling. Impact cratering is a well-understood process (e.g. Melosh, 1989).

Coronae are defined by their concentric fracture rings (Stofan et al., 2001). They typically also have radial fractures. They have a wide range of topography morphologies, with similar numbers of topographically high and topographically low features (Stofan et al., 2001; Glaze et al., 2002). All coronae have at least minor associated volcanism, and many have extensive volcanism. They are commonly interpreted to form above either mantle upwelings or downwellings, due to the radial and concentric fracturing and range of topographic morphologies (e.g. Smrekar and

Stofan, 1997; Hoogenboom and Houseman, 2006). They are enigmatic in that they are unique to Venus. One explanation is that either the thick continental lithosphere or the low viscosity asthenosphere prevents the formation of coronae on Earth (Smrekar and Stofan, 1997). Alternatively, interior thermal boundary layers are affected by a stagnant lid as compared to plate tectonics, and may generate more small-scale plumes (Parmentier and Sotin, 2000; Jellinek et al., 2002). Arguments as to why an impact origin for coronae is unlikely are well laid out in Jurdy and Stoddard (this volume), and generally ignored in the paper by Hamilton (this volume).

Throughout his paper in this volume, Hamilton ignores the physics of impact cratering in attempting to explain characteristics of coronae; in fact, he cites little of the relevant literature on the topic. We do not intend to refute Hamilton's paper point by point, but simply point out examples of major inconsistencies. First, Hamilton completely ignores the issue of transition of shape as a function of size. As on all planets, Venusian craters transition to multi-ring basins at a given size (e.g. McKinnon et al., 1997). All coronae have concentric rings. To suggest that the concentric fractures seen at coronae are in fact multiring basin structures is to completely ignore both the morphology and physics of impact basin rings, which form via slumping of the crater walls and thus never exceed 3 rings. In contrast, corona concentric rings are narrow, closely spaced fractures, with typically a dozen or more at a given coronae. To suggest that the radial fractures seen at most coronae can be formed through debris flow processes ("flow lines or channels) has no basis. The appearance of tectonic features in radar images is well understood through decades of radar studies of Earth. The radial features at most coronae are grabens, with steep walls and flat floors. Their location and morphology is completely consistent with a tectonic origin, and completely inconsistent with formation by flow processes.

Additionally Hamilton applies his explanations for corona characteristics selectively, not to mention with the use of phrases like "I think…" and "I presume…", rather than offering sound evidence. For example, he states "Venusian aprons are dominated by ground-hugging lobate debris flows, rather than by ballistic ejecta as on the airless Moon, because of the dense atmosphere and high gravity." This statement ignores both the observed ejecta blankets on Venus, which bear characteristics of both ballistic and flow emplacement. The physics of how the atmosphere affects ejecta on Venus has been analyzed and modeled, using actual examples of venusian impact craters (Schultz, 1992). The ejecta around craters bear no resemblance to the flow aprons around coronae, which are lava flows that can be traced to the fractures and edifices from which they originated. Hamilton (this volume) rejects a volcanic origin for nearly every type of feature, despite the morphologic evidence. Again, we refer him to the extensive literature on terrestrial radar studies (e.g., Ford et al., 1989; Ford et al., 1993), which provide excellent analogues for the volcanic edifices and lava flows seen in Magellan images.

Controversial ideas serve a key role in the advancement of science through challenging our assumptions and paradigms. Hamilton's proposal goes too far in that he ignores basic physics and makes selective observations in the service of his hypothesis. The details of corona formation is still debated in the literature, but the impact hypothesis was rejected long ago on the basis of sound, scientific, unbiased research. For an informed discussion of the origin of coronae, see Jurdy and Stoddard (this volume).

4th February 2007, Warren B. Hamilton

The scores of papers published by Smrekar and Stofan, with various co-authors, over the past 20 years have been dominated by speculations regarding the origin, always assumed to be endogenic, of the fraction of old circular venusian structures that they term “coronae”. Their comment above, of 31st January, 2007 (henceforth, S&S07) continues their consideration of these structures in isolation from the thousands of other old structures, mostly ignored, from which coronae are discriminated arbitrarily. As I show in my paper in this volume (henceforth, H07) and in Hamilton (2005), the infrequent mentions, and prompt dismissals, of exogenic origins by Smrekar and Stofan in their papers prove only that their assumptions of endogenesis are incompatible with impact origins. S&S07 approvingly cite the anti-impact paper by Jurdy and Stoddard (this volume); but, as I show (see the discussion following that paper, and H07), the arguments of Jurdy and Stoddard (this volume) also are irrelevant because, among other disqualifications, they address hypothetical endogenic blobs rather than the rimmed circular structures abundant in their own study area. The statement by S&S07 that coronae “form either above mantle upwellings or downwellings” illuminates the lack of constraints on endogenic conjectures.

The ejecta aprons of small, young venusian impact craters (agreed upon by all) are distinctively lobate. Diverse ground-hugging and atmospheric-interaction mechanisms have been proposed (e.g., Herrick et al., 1997; Barnouin-Jha and Schultz, 1998), although long-runout fluidized flows can only be ground-hugging (e.g., Purdie and Petford, 2005). These lobate aprons much resemble the lobate aprons of coronae (compare Figs. 4-6 of H07 with Figs. 7 and 18), with appropriate scaling of lobes for diameters of structures (cf. Barnouin-Jha and Schultz, 1998). The assertion in S&S07 that “the ejecta around craters bear no resemblance to the flow aprons around coronae” is false. The assertion that corona aprons “are lava flows that can be traced to the fractures and edifices from which they originated” is based only on interpretations of rare and ambiguous relationships; dike eruptions, for example, have not been documented. The physics of large impacts cannot be extrapolated from small ones and can only be modeled. Although shock fluidization probably is a major process (e.g., Pierazzo and Collins, 2003), S&S07 state that “radial features [for which I infer a surficial origin consequent on shock fluidization] at most coronae are grabens”—an assertion that is disproved because the required extensions along concentric circles about the structures are 100 times too great to be explicable by the very slight doming possible with inflation models (Grindrod et al., 2005).

S&S07 assert that analogies with modern terrestrial features require endogenic volcanic interpretations for many features of coronae. In fact, no modern terrestrial features resemble venusian “volcanoes”, which are hundreds to many hundreds of km in diameter but mostly only 1 or 2 km high, typically rise from rimmed circles, and mostly have only single central peaks, either broad plateaus or exceedingly gentle summits, with broad sags but not calderas. These venusian constructs (of shock melt and shock-fluidized material?) may be analogous to those once present atop the terrestrial Precambrian proved-impact structures of Vredefort and Sudbury, and possible-impact Bushveld and Stillwater, and such features may have been abundant on the pre-3.8 Ga Earth. That Ford et al. (1989, p. 27-54) presented radar images of various young terrestrial volcanic features does not confirm the interpretation by Ford et al. (1993, p. 109-134) that the very different features of Venus also are volcanic. Thus, the great 800 x 300 km stream of rough-surfaced lobate flows (termed lava by Ford et al., 1993, although in scale, source, and character they resemble nothing on modern Earth) of Mylitta Fluctus originates in what appears to me to be a complex of simultaneous(?) impact structures (Jord Corona, Tarbell Patera, and Alcott Crater) and thus is analogous to, but appropriately larger than, the fluidized-ejecta stream of similar appearance from Isabella Crater (H06, Fig. 6).

I agree with S&S07 that the concentric fractures in many of their coronae lack common conspicuous analogues in known impact structures elsewhere, but I have not confused these with multiring craters. That no endogenic process yet conceived could produce the concentric structures has not influenced conjectures by Smrekar and Stofan. The impact regime, by contrast, makes it easy to visualize formation of shock-induced concentric features in bedrock targets, whereas they could not form in the deep-rubble targets of Mars and the Moon, and I suspect that such structures are abundant but commonly unseen in terrestrial bedrock structures. In Figure 2 I show two images of Aorounga Crater, the impact origin of which is confirmed by shatter cones and shock metamorphism (McHone et al., 2002), in the Sahara Desert. The optical image (Figure 2a) is dominated by eolian features, whereas the satellite synthetic-aperture-radar image (Figure 2b; analogous to venusian imagery) sees through the thin cover and shows abundant concentric fracturing of coronal type.

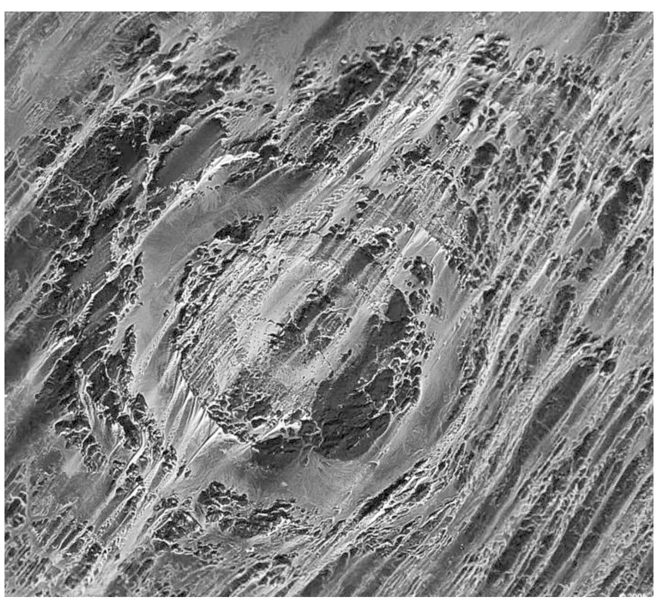


Figure 2a. Optical image of Aorounga Crater, northern Chad, courtesy of Google Earth. Structure is centered near 19.2˚E, 19.1˚N. North at top. Wind-sculpted ridges and narrow sand sheets are aligned with prevailing wind, and minor concentric structures are obscure. [permission to publish requested].

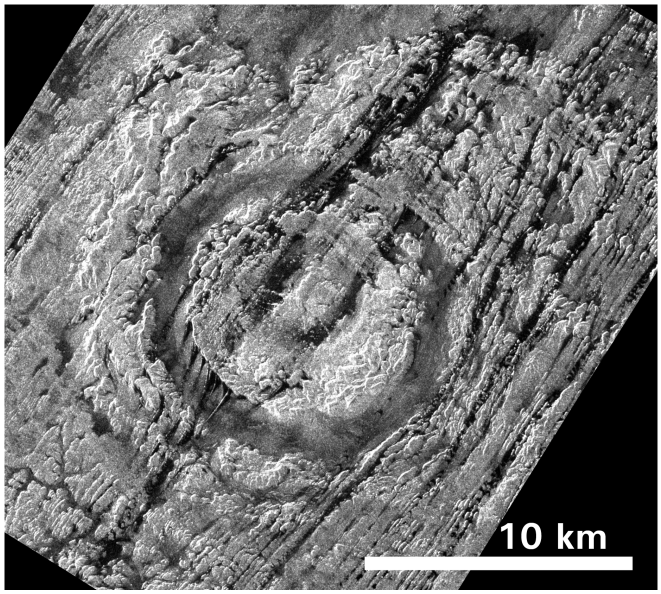


Figure 2b. Radar image of Aorounga Crater, courtesy of NASA. Smooth sand too thick to see through is radar-dark. Corona-like concentric fracturing is obvious. Illuminated from northwest; apparent small triangular facets are due to slant-radar hogback illusion. Black corners are areas with no data.

Coronae, as hypothetical endogenic structures, "are unique to Venus" (S&S07), whereas impact structures are ubiquitous on solid bodies in the Solar System. This contrast justifies skepticism of endogenic-corona conjecture, and consideration of the obvious option that the thousands of small to huge old circular structures of Venus are ancient impact structures.

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