VENUS IMPACT CRATERS: IMPLICATIONS FOR ATMOSPHERIC AND RESURFACING PROCESSES FROM MAGELLAN OBSERVATIONS

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Introduction. Observations of impact craters on Venus by Magellan yield important insights into (i) atmospheric effects on the formation of impact craters and their attendant ejecta deposits and (ii) the resurfacing history of the planet [1].

Atmospheric Processes. Most craters smaller than 15 km are classified as "irregular"; they possess irregularly shaped rims, and multiple hummocky floors. The irregular nature of these craters is interpreted to be the consequence of breakup and dispersion of incoming meteoroids by the dense atmosphere [2].

Two major ejecta facies of venusian impact craters are "hummocky ejecta" and "outer ejecta". The latter is akin to "continuous ejecta" seen on other planets, except that on Venus azimuthal sectors of ejecta are often missing, and this is attributed to the effects of oblique impact amplified by an atmospheric cushion. The distal edge of the outer ejecta of complex craters on Venus is sharp and lobate to slightly pointed, often with a petal-like appearance suggesting emplacement by flow. Schultz and Gault [3,4] have described a mechanism that may explain this observation. They showed that below a critical size, the ballistic paths of ejecta material are significantly modified by an atmosphere. In particular, small particles are decelerated and form an ejecta cloud that is deposited as turbulent ejecta and flows outward as a base surge from the crater rim.

A number of craters documented in the Magellan images possess often non-radial, "flow-like ejecta" indicative of a low viscosity material. Typically the flows extend up to two crater diameters from either beneath or within the crater's hummocky and outer ejecta deposits. The origin of the flow-like ejecta is problematical, and there is more than one form of this unit (e.g., uniformly radar bright, or bright just along the boundaries), and multiple origins are possible. Three hypotheses for the origin of flow-like ejecta are: (i) turbidity flows of very-fine-grained ejecta, (ii) flows consisting of a mixture of ejecta and magma released during the impact event, and (iii) flows of impact melt.

Approximately half of the impact craters observed with the Magellan radar are partially or wholly surrounded by areas with low radar backscatter cross sections, σ_0; we term these areas "dark margins". In most cases these regions are irregularly shaped and extend up to 3 or 4 crater diameters from the crater center; in a few cases the dark areas are much more extensive. The interface between this dark area and the surrounding brighter terrain occurs over a relatively short distance but, in general, it is not a sharp, well-defined boundary. The crater Stephania, for example, has dark margins that extend from about 25 km west of the crater to approximately 60 km to the east. The dark margins appear to be areas that are very smooth, with little wavelength-sized roughness to diffusely scatter the incident radar signal.

Hypotheses for the origin of dark margins include ablated meteoroid material, ejecta sorting, seismic shaking, and surface pulverization by the shock/pressure wave associated with the incoming meteoroid. Energy considerations show that the last mechanism is quite feasible [1].

Resurfacing Processes. Venera 15/16 imaging data showed that impact craters are not uniformly distributed on the surface of Venus [5,6,7], and this is evident in the Magellan data. Particularly apparent are regions that do not have any impact craters at all, for instance, the Sappho Patera region in central Eistla Regio. The hypothesis that the observed areal distribution of craters is random can readily be tested. The area around Sappho that is devoid of impact craters comprises approximately 5×10^6 km^2. We consider 135 (the total number of impact craters observed in the first 277 mapping orbits) Bernoulli trials for impact into the Sappho region. A "success" occurs when a crater is formed at Sappho and the probability of success for a spatially random process must be the ratio of the Sappho area to the total area surveyed, or 1/14. The resulting probability distribution must be binomial, b(x,135,1/14), with $\mu = 9.6$ and $\sigma = 3.0$. This meets the criterion, $\mu \geq 3\sigma$, that ensures the sampling area is large enough to have at least 1 crater [6]. In fact, the compliment of this outcome, the probability of observing *no* craters at Sappho under a random spatial distribution is 4.5×10^{-5} (b(0,135,1/14)). Thus it is highly unlikely that the "event" of no craters at Sappho can occur. However, this does not reject the hypothesis that the null occurrence of craters can belong to a random process because the Sappho area is part of a larger sampling population. If this experiment is repeated a sufficient number of times (i.e., other 5 million square kilometer areas are examined), the probability that at least one such area will be found with no craters will approach unity. The maximum number of experiments possible is 92, the surface area of the planet divided by 5×10^6. The expected number of 5 million square kilometer areas with no craters is approximately 92xb(0,135,1/14) = .004. Therefore, if Venus truly has a spatially random distribution of impact craters, the probability of finding a region the size of the Sappho area with no craters is essentially nil.

Those areas on Venus with few or no impact craters must have young surfaces undergoing rapid resurfacing on a geological time scale. At Sappho, volcanism is playing a major role; elsewhere, tectonic processes may also be important. A hypothesis that might explain the impact crater distribution on Venus is that cratering occurs randomly in space and time, whereas resurfacing has a spatial and temporal dependence [8]. In this case, craters are preserved in relatively pristine form in tectonically and volcanically quiescent regions. Areas of recent volcanism and tectonism have completely removed craters because resurfacing rates have been so high. This hypothesis appears to account for the seemingly contradictory observations that: (i) very few impact craters are observed to be in the process of removal by resurfacing, yet (ii) there are areas of the planet where no impact craters are observed, and thus *there must be* processes removing craters on a regional basis.

A simple, end-member model for this hypothesis is one of "regional resurfacing". This model is an end-member construction because it is binary: either craters are pristine, or they are completely removed; there are no craters in the process of removal. In a production model, for a surface of age τ, the cumulative size-frequency distribution, C_p, is given approximately by $C_p = R_p \tau D^{-\alpha}$, where R_p is the present cratering rate, D is crater diameter, and α is the power-law exponent that determines size distribution. For a regional resurfacing model, the information that can be gleaned from cumulative crater statistics is not surface age (production model) or retention age/resurfacing rate (equilibrium model), but instead the *areal resurfacing rate of the planet*. With the binary assumption, the cumulative size-frequency distribution, C_r, is given by $C_r = 0.5(R_p/f_r)D^{-\alpha}$, where f_r is the fraction of the planet resurfaced in one year. The reciprocal of f_r is T_r, the average time it takes to resurface the planet once. The portion of the cumulative size-frequency distribution curve unaffected by the atmosphere ($D \geq 25$ km) is well matched by $T_r = 0.8$ Ga. In this model there is no one unique age of the surface; surface ages span the range from 0 to 800 Ma, with Sappho, for example, representative of one of the youngest regions on the planet. We consider that this is the most realistic interpretation of the crater data, in terms of both the cumulative statistics and the appearance of individual craters.

References. [1] R.J. Phillips *et al.*, submitted to *Science* (1991); [2] G.G. Schaber *et al.*, this volume; [3] P.H. Schultz and D.E. Gault, *J. Geophys. Res.* **84**, 7669 (1979); [4] P.H. Schultz and D.E. Gault, in *Geological Implications of Impacts of Large Asteroids and Comets on the Earth, GSA Special Paper 190*, 153 (1982); [5] G.A. Burba, *Lunar and Planet. Sci. XX*, 123 (1989); [6] J.J. Plaut and R.E. Arvidson, *J.Geophys. Res.* **93**, 15339 (1988); [7] G.G. Schaber, *U.S. Geological Survey Open-File Report* **90-468** (1990); [8] R.E. Arvidson *et al.*, *Geophys. Res. Lett.* **17**, 1385 (1990).