ELEVATION AND IGNEOUS CRATER MODIFICATION ON VENUS: IMPLICATIONS FOR MAGMATIC VOLATILE CONTENT. R.W. Wichman Dept. of Space Studies, Univ. of North Dakota, Grand Forks, ND 58202.

Introduction: Although most impact craters on Venus preserve nearly pristine crater rim and ejecta features [1], a small number of craters have been identified showing clear evidence of either igneous intrusion emplacement (floor-fracturing) beneath the crater floor [2] or of volcanically embayed exterior ejecta deposits [1,3]. Since the volcanically embayed craters consistently occur at higher elevations than the identified floor-fractured craters, I propose that igneous crater modification on Venus is elevation dependent. This abstract describes how regional variations in magmatic neutral buoyancy [4] could produce such elevation dependent crater modification and considers the implications for typical magmatic volatile contents on Venus.

Crater Modification and Elevation: Despite the abundance of surface volcanic features on Venus, only ~4-6% of the recognized venusian impact craters are clearly embayed by exterior volcanic flow units [1,3]. Igneous crater modification may be more common on Venus than this number indicates, however, since episodes of crater-controlled igneous activity should primarily affect the crater interior and not the exterior crater rim or ejecta units used to define the volcanically embayed craters above. Looking at crater interiors, the youngest craters on Venus (those with dark parabolic ejecta deposits) characteristically exhibit a radar bright floor unit [5]. In contrast, nearly two thirds of the recognized venusian craters contain dark floor deposits which might reflect crater-flooding volcanic events. While many of the dark-floored craters also appear to be distinctly shallower than the younger, bright-floored craters [6], however, these dark crater-filling units could as easily reflect fine-grained aeolian deposits emplaced by regional surface winds or impact-induced atmospheric turbulence as volcanic lava flows. Therefore, although the dark-floored venusian craters are consistent with widespread crater-filling volcanism, they do no require such igneous crater modification events.

A few craters, however, show strong resemblances to lunar floor-fractured craters (FFC) [2]. Specifically, three craters on Venus[1] show unequivocal examples of moat-delimited floor plate uplifts comparable to those in extensively modified lunar FFC. At least seven other venusian craters[2] exhibit less distinctive patterns of polygonal or concentric floor fractures which appear to be comparable to fracture patterns in less extensively modified lunar craters. Since the lunar FFC frequently contain ponded mare deposits [7,8,9], and since the best model for crater floor failure and uplift on the Moon requires emplacement of a crater-centered intrusion at depth [8,10,11], these ten venusian craters exhibit the most conclusive evidence on Venus for the interactions of impact structures with sub-surface magma bodies.

As shown by figures 1 and 2, the distribution of FFC on Venus as a function of elevation is distinctly different from the distribution of volcanically embayed craters. Specifically, while the FFC occur almost entirely below the mean planetary radius (MPR) of 6051.8 km and have a mean elevation of ~475 m below MPR, the volcanically embayed craters primarily occur at higher elevations, with a mean of ~340 m above MPR (figures). These two elevation distributions are statistically independent with a p-value of ~0.006, and chi-square tests suggest that the preferred elevation ranges of these distributions do not reflect random modification events within the global crater population.

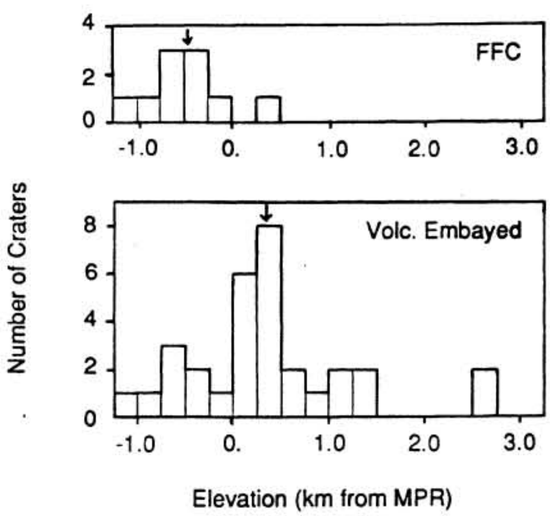
Neutral Buoyancy Model: Igneous crater modification on Venus thus appears to vary systematically with elevation. Since magmatic neutral buoyancy levels on Venus should increase with elevation [4], these changes in regional magma depth provide a possible source for the observed dichotomy between floor-fractured crater modification at low elevations and the peripherally flooded craters at higher elevations. Specifically, if FFC reflect deformation over a shallow, crater-centered intrusion [8,10,11], this dichotomy in post-impact volcanism can result from variations in the depth of regional magmas relative to the breccia lens beneath a crater floor.

To illustrate the effects of such variations in magma depth on crater modification, consider a fresh crater 40 km in diameter with an apparent depth of ~1.0-1.25 km. By analogy to the terrestrial Ries crater [12], the intensity of brecciation beneath such a crater should decrease rapidly with depth and the depth-dependence of breccia densities should define a fairly shallow magmatic buoyancy trap (~0.5-1.5 km beneath the crater floor). Consequently, for magma levels shallower than ~1.5 km beneath a regional surface, magmas entering the crater should be vented directly onto the crater floor. For regional magma depths between ~1.5 and ~2.5 km, magmas entering the crater should be trapped within the impact breccia, thereby allowing floor-fracturing on the surface. Finally, for magma levels much deeper than ~2.5-3.0 km, magmas should not encounter significant brecciation effects, suggesting that volcanism in this case is likely to be independent of the impact structure.

In addition to these effects of NBZ depths on crater modification, however, the effect of atmospheric pressures on magmatic buoyancy also should inhibit FFC formation at higher elevations. Specifically, enhanced volatile exsolution at the higher elevations decreases magma buoyancies relative to the modeled breccia densities, thereby reducing the stability of a breccia-defined magma trap. Since significant crater modification requires magma pressures on the order of 100-200 bar [2,11], such destabilization allows magmas to escape to the surface at higher elevations (presumably within the crater) instead of driving surface failure and floor uplift within the crater.

Magmatic Volatiles: Since the modeled depth of magmatic neutral buoyancy on Venus depends on both elevation and magmatic volatile content [4], this model for the distribution of venusian FFC also can be used to constrain typical magma volatile concentrations on Venus. Based on the calculations of Head and Wilson [4], for example, NBZ should not develop at elevations below MPR on Venus for basaltic magmas with less than ~0.4 wt% combined CO_2 + SO_2. Since the corresponding NBZ depths in the highlands for these magmas range between ~1400 and ~2700 m, the consistently low elevation of FFC on Venus is incompatible with a record of predominantly volatile-poor volcanism. Alternatively, for ~0.4 wt% CO_2 + SO_2, predicted highland magma depths range from ~2500 to ~3200 m and continue to increase for higher volatile concentrations. In the lowland plains, however, such NBZ depths are not attained until ~0.55 wt% CO_2 + SO_2 [4]. Water contents show no significant effect on NBZ depth until concentrations exceed 0.5 wt%, then depths jump to over 2700 m even at the lowest elevations [4].

Summary: Development of lunar-like floor-fractured craters appears to be restricted to lowland plains elevations on Venus, while volcanic embayments outside the crater rim are significantly more common at higher elevations. This dichotomy in igneous crater modification is consistent with predicted changes in regional magma depths relative to a shallow breccia lens beneath the crater floor and suggests that typical magmas on Venus contain between ~0.4-0.5 wt % CO_2 + SO_2 and <0.5 wt% H_2O. Further, since the variation in magmatic neutral buoyancy with elevation should favor crater-filling volcanism at lower elevations, any change in the appearance of dark-floored craters with elevation may provide a basis for distinguishing volcanically flooded crater interiors from fine-grained sedimentary deposits collected within a crater.



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Figures 1 and 2. Histograms showing, respectively, the number of floor-fractured craters (FFC) and volcanically embayed craters at different elevations on Venus. Crater elevation data is separated into 250 m bins and referenced to a mean planetary radius of 6051.8 km. Arrows indicate mean elevation of each crater population; for reference, mean elevation of all craters on Venus is ~50 m.

[1] Venusian craters with moat-defined floor plates are Mona Lisa, Barrymore, and an unnamed crater at (-18.5, 70.5).

[2] Venusian craters with well-developed polygonal or concentric fractures are Leyster, Barrera, Lebrun, Potanina, Yablochkina, Piaf and Wheatley.