Maxwell Montes. At the then achievable spatial resolutions of about 100 km, the measured ratios for Alpha and Beta were approximately 0.5 while that for Maxwell Montes was closer to unity. More recent measurements with the Arecibo system in 1983 and 1988 indicate that the ratios for parts of Maxwell Montes are very close to unity and may exceed unity in some areas. Very high cross sections and inverted polarization ratios have been observed for the icy Galilean satellites and the south polar region on Mars. All models attempting to explain the phenomenon invoke internal scattering in a very low-loss ice medium.

Results from the Pioneer-Venus [2] and Magellan missions [3] showed that Theia and Rhea Montes in Beta Regio and Maxwell Montes are areas with low thermal emissivities and high Fresnel reflectivities. Pettengill et al. [3] invoked the presence of very high dielectric constant material and Muhleman [4] has pointed out that volume scattering could play an important role. However, if further analysis of the current data and future measurements confirm that the polarization ratio exceeds unity, then the current models to explain the low emissivities and high reflectivities will need to be revised.

With no new missions currently planned, the only method to obtain additional data for the surface of Venus in the post-Magellan era will be with groundbased telescopes. Improvements to the Arecibo radar system currently underway will increase its sensitivity for radar mapping of Venus by about a factor of 7, allowing high-quality imaging at 1- to 2-km resolution over approximately 40% of the surface. This resolution and sensitivity are more than adequate for mapping of the polarization properties of selected areas aimed at studies such as the wavelength-scale roughness properties of volcanic flows for comparison with terrestrial data and the understanding of the high-emissivity/low-reflectivity areas.

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BRIGHT CRATER OUTFLOWS: POSSIBLE EMPLACEMENT MECHANISMS. D. John Chadwick[1], Gerald G. Schaber[1], Robert G. Strom[2], and Darla M. Duval[3], [1]U.S. Geological Survey, Flagstaff AZ 86001, USA, [2]Department of Planetary Sciences, University of Arizona, Tucson AZ 85721, USA, [3]University of North Dakota, Grand Forks ND 58202, USA.

Lobate features with a strong backscatter are associated with 43% of the impact craters cataloged in Magellan's cycle 1 (Fig. 1). Their apparent thinness and great lengths are consistent with a low-viscosity material. The longest outflow yet identified is about 600 km in length and flows from the 90-km-diameter crater Addams. There is strong evidence that the outflows are largely composed of impact melt, although the mechanisms of their emplacement are not clearly understood. High temperatures and pressures of target rocks on Venus allow for more melt to be produced than on other terrestrial planets because lower shock pressures are required for melting [1].

The percentage of impact craters with outflows increases with increasing crater diameter. The mean diameter of craters without outflows is 14.4 km, compared with 27.8 km for craters with outflows. No craters smaller than 3 km, 43% of craters in the 10- to 30-km-diameter range, and 90% in the 80- to 100-km-diameter range have associated bright outflows. More melt is produced in the more energetic impact events that produce larger craters [2]. However, three of the four largest craters have no outflows.

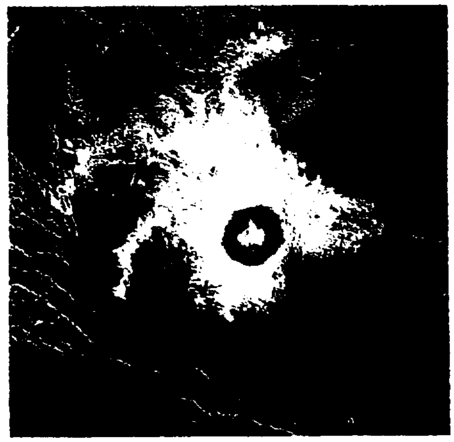

Fig. 1. Hellman, 35 km in diameter. Note position of outflows downrange of missing segment of ejecta.

Outflow occurrence is also correlative with impact incidence angle. Fifty-nine percent of Venus' craters have bilaterally symmetric ejecta: a large concentration on one side and little or none on the other. Such craters were probably formed by oblique impacts; more pronounced asymmetry in the ejecta reflecting a lowering impact angle [3]. Of craters with asymmetric ejecta, those with outflows are more numerous than those without above about 15 km in diameter. This transition occurs in craters with symmetric ejecta patterns above about 35 km, which suggests that oblique impacts are much more efficient at producing outflows than those with higher-angle trajectories. Forty-eight percent of asymmetric-ejecta craters have outflows, compared with only 34% of those with symmetric ejecta. Schultz [3] observed a relation between decreasing impact angle and increasing length and areal coverage of outflows. More impact melt is not expected to be generated in oblique impacts relative to high-angle impacts due to lower energy deposition in the target [4]. Rather, oblique impacts may be more efficient at removing the outflow materials from the crater and may also incorporate a higher percentage of the projectile in the outflows.

Of the 227 venusian craters with outflows and asymmetric ejecta, about 26% have outflow sources centered on the downrange axis, and 87% have outflows originating from within 90° in azimuth of this axis (Fig. 1). These relations suggest that the outflows are transported downrange during the impact. Popigai, a 100-km-diameter Asian impact crater, has an asymmetric distribution of melt glass attributed to oblique impact [5]. This downrange distribution is evident in flows from fresh lunar craters as well [6].

In the following paragraphs we present four possible mechanisms for the emplacement of bright outflows. We believe this "shotgun" approach is justified because all four mechanisms may indeed have operated to some degree.

Model 1: Emplacement by Jetting: There are apparently two types of bright outflows: those deposited after emplacement of the crater rim materials and a rarer form that appears to have been deposited before. Jetting is a very early process that occurs before ejecta emplacement, and jets have velocity usually higher than that of the projectile [4]. Therefore, any jetted materials that remain in the vicinity of the crater would lie stratigraphically below the rest of the ejecta. Impact velocities as low as 1–2 km per second may be sufficient to produce jetting [7].

As impact angle decreases, the speed of the jet increases and the amount of jetted material decreases to conserve momentum [4]. It is unclear whether atmospheric drag could slow the jet enough for local deposition.

Model 2: Emplacement as Lavalike Flows: In this model, impact melt and solid fragments are transported out of the transient crater within a turbulent, radially expanding gas cloud and deposited in a discrete layer atop the crater rim deposits. This same mechanism was proposed to explain the aerodynamic sculpturing and lack of sorting of melt bombs in suevite deposits at Ries Crater [8]. At Ries, glass constitutes about 15% of the suevite volume. Calculations by Basilevsky and Ivanov [9] and Ivanov et al. [10] suggest that a 26-km-diameter crater such as Ries would produce 20% to 50% more melt on Venus; thus a venusian suevite layer may be composed of over 20% melt.

With high melt volumes and inefficient cooling of the melt by hot incorporated clasts, venusian suevites may remobilize after emplacement to form laminar, lavalike outflows. Many outflows are observed to contain sinuous, leveed channels that commonly have complex tributary and distributary systems. Channels in outflows are usually best developed close to the crater, giving way to broad, unchannelized distal lobes. Similar transitions occur in Hawaiian lava flows, apparently due to increasing viscosity of the flows with distance from the source.

Additional evidence for a slow, lavalike emplacement of the outflows is their common inability to surmount topographic obstacles (exceptions are described below). Small volcanic cones surrounded by flows have commonly retained their circular shape; flows of higher velocity would be expected to submerge part of one side of these cones. Alternatively, it is not yet clear whether the melt could remain molten long enough to produce the more lengthy flows.

Model 3: Emplacement by Turbulent Flow: This model requires a low-viscosity fluid similar to that of model 1, but emplacement is at a much higher velocity in a turbulent gas/solid/melt mixture, similar to terrestrial pyroclastic surges. This model would best explain the outflows if the channels observed within many of them are erosional, although it is not clear whether a surgelike mechanism would produce the intricate networks of leveed tributaries and distributaries that are observed.

Some outflows show a marked ability to climb slopes. At Cochran, flow directions follow topographic contours except on the northwestern side of the crater. Here the flow appears to climb as much as 300 m into an elevated tessera region [11]. The northwestern side of the crater is interpreted to be in the downrange direction, so this observation is consistent with a turbulent flow being driven forward along the impactor trajectory. The driving force may be the momentum of the impact itself or a strong drafting created by the impactor wake as suggested by Schultz [3].

Terrestrial pyroclastic flows have been analyzed by using the energy-line model that gives the potential head of a flow along its runout distance [12,13]. For the gravitational collapse of a debris column, H/L is the ratio of column height to runout distance and determines the slope of the energy line. H represents the initial potential energy of the material converted to kinetic energy, which is dissipated as the flow moves along the surface. The vertical distance between the energy line and the subjacent topography is used to calculate the velocity at a given distance from the crater. It is possible for the flows to travel up slopes if they lie below the energy line [12].

Values of H/L for large terrestrial pyroclastic deposits fall in the range of 0.1 to 0.2. These values, coupled with the longest L value (measured at Addams), result in column heights of 60 to 120 km. Using the height of origin for Addams and neglecting the subjacent topography, we derive an initial velocity of the 600-km-long outflow at the crater edge of about 1 to 1.5 km/s. This value exceeds the sonic velocity of the venusian atmosphere. However, the values of H/L in Venus' dense atmosphere are probably quite different from those on Earth. Values of H/L of less than 0.02 are required if the initial velocity of the outflow at Addams were to be below the sonic velocity of Venus' atmosphere.

Kinetic energy may be imparted to the flow by the energy of the impact in lieu of a collapsing column. This is possibly a more likely scenario because of the tendency of the flows to be directed downrange.

Model 4: Slow Ejection of Molten Transient-Crater Lining: Features similar to the venusian outflows, albeit much smaller, are the small flows and ponds on ejecta near the rims of relatively fresh lunar craters. Hawke and Head [6] interpreted these materials to be impact melt that originally lined the transient crater and was ejected at low velocities from the crater interior by rebound and wall slumping during the modification stage of crater formation. This model is supported by the great number of outflows that appear to originate very high on the ejecta blankets of Venus' craters, commonly at the rims. This relation was also noted by Edmunds and Sharpton [14]. The backscatter tone of the floors of many outflow craters indicates that the floors are much smoother than the flows themselves, however, possibly indicating that they are not the same material.

It is possible that a combination of models 2 and 3 may best explain the longer outflows. Schultz [3] observed a significant population of outflows (38% of 253 craters) in which a combination of laminar and turbulent emplacement styles was evident. Thus these flows may have been given initially high velocities by the impact and may have behaved as turbulent, ground-hugging surges. Upon degassing, the solid-melt fraction of the flow would have settled to the surface and continued to flow in a slow, laminar fashion. Secondary flowage of this type has been observed in terrestrial rheomorphic tuffs [15], which probably have a much lower melt fraction than the outflows.

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