VFLOW: A COMPUTER MODEL FOR THE MOVEMENT OF GRAVITY FLOWS OVER VENUS TOPOGRAPHY; J.R. Johnson, Department of Geosciences, Lunar and Planetary Laboratory, Space Sciences Bldg., Univ. of Arizona, Tucson, AZ, 85721, and L. Gaddis, U.S. Geological Survey, Branch of Astrogeology, Flagstaff, AZ 86001.

Use of the FLOW computer model [1] modified for application to the study of Venus impact crater fluidized ejecta blankets (FEBs) demonstrates that relatively low viscosities (< 30 Pa-s), yield strengths (< 2300 Pa), and initial velocities (< 100 m/s) are required to duplicate the observed flow paths. The model, renamed VFLOW, calculates the velocities and simulated flow paths of gravity flows over GTDR Magellan topography. The model determines flow movements from initial conditions, gravitational acceleration, and resistance to motion from Coulomb, viscous, and turbulent resistance forces. Successful duplication of observed FEB flow paths has been achieved during preliminary tests for the FEB craters Addams, Isabella, and Cochran.

Background and Methodology. Computer simulation of flow emplacement processes have been used to study lava flows [2,3], pyroclastic flows, lahars, avalanches [1,4], and most recently Martian fluidized ejecta blankets [5]. McEwen and Malin [1] presented a computer model called FLOW that calculated the velocities and simulated flow paths of gravity flows over digital elevation models (DEMs). They applied FLOW to the several types of gravity flow events that occurred at Mt. St. Helens (MSH) in May, 1980. The model was formulated to determine flow movements from initial conditions, gravitational acceleration, and resistance to motion (τ_r) as described by the generalized equation $\tau_r = (a_0 + a_1 v + a_2 v^2)$ where v is velocity, and the terms a_0, a_1, and a_2 are empirically related to Coulomb, viscous, and turbulent resistance, respectively. In cooperation with Dr. A. McEwen (U.S.G.S., Flagstaff), the FLOW model has been modified for application to the study of Venus FEB impact crater flows. The model is used in combination with Venus DEMs constructed from the GTDR topographic image data collected by the Magellan altimeter. VFLOW is designed to compute three-dimensional flow paths over DEMs by using nonuniform flow models (i.e., those in which the flow acceleration or deceleration varies, depending on the surface slope angle as computed from the DEM) in which the flow direction and velocity are recomputed at each time step. The VFLOW model assumes that: (1) the flow depth stays approximately constant or linearly decreases with time; and (2) the flow is approximately steady state, i.e., changes in the mass flux of the flow materials are not considered. Where these assumptions are valid, the VFLOW model parameters may be related to rheological properties of the flow materials such as yield strength and viscosity.

The viscous resistance term a_1 is characterized by a Bingham rheology such that $\tau_r = k + \eta(dv/dy)$. Here y is the distance below the surface of the flowing material such that dv/dy is the velocity gradient or shear strain rate in laminar flow, η is the viscosity (Pa-s) and k is the yield strength (Pa) which includes both cohesion and frictional strength. Results of the Bingham model test runs are described here.

Results. While some model parameters used by [1] were available from measurements of the MSH flows, the FEB flows are not constrained by such measurements. Initial velocities are calculated using the method of [5]: $v_o = (2/15*gR)^{1/2}$ where R is the crater radius. A series of runs using these initial velocities are followed by runs in which the velocity was arbitrarily set to 100 m/s. Table 1 shows the results of the model runs for Isabella ("a" runs correspond to best fits for the central and western FEB regions, while the "b" runs are for the main eastern FEB lobe). Flow density is kept at a constant 1500 kg/m^3 in the runs presented here [cf. 1], and flow depths are chosen as 10 m and 100 m.

All runs for which a calculated initial velocity is used result in very straight flow lines which do not follow the FEB flow paths very well (runs ISA2, ISA3). Flows at 100 m/s initial velocity respond to topography better and follow the observed FEB flows moderately well. Figure 1 shows an example of the flow lines resulting from model run ISA6b overlain on SAR image of Isabella. For the Bingham models, flow depths of 10 m require yield strengths from 5-30 Pa, and viscosities from 20-60 Pa-s, with the 100 m/s initial velocity runs representing the lowest values. These values are relatively low in comparison to terrestrial basalt lavas and more like some debris flows. More exotic lavas such as carbonatites and komatiites have lower viscosities (< 1.0 Pa-s), and have been proposed as possible components of the FEB flows [e.g., 6]. Flow depths of 100 m require yield strengths from 200-2500 Pa and viscosities from 1400-5000 Pa-s. These values are somewhat more like those of basalt lavas, but still as low as some pyroclastic and debris flow values. Other workers have estimated similar to somewhat larger values for Venus FEB flows [9,10]. Morphologic study of the FEBs has suggested that flow depths are probably on the order of 10 m, especially distally where blocking of the flows by low-relief features is often seen [7].

Discussion. The initial results provide important, although not unambiguous, information regarding the emplacement processes and rheology of the FEB flow materials. Modeling the FEB flows as Bingham materials results in yield strength and viscosity values that are much lower than those for basalt lavas and more similar to pyroclastic or debris flows, depending on the given FEB flow depth. Flows of 100 m depth require higher values of both resistance parameters than 10 m deep flows. The choice of initial velocity has been shown to be very important to appropriately model the FEB flow path. Initial calculated ejecta velocities result in flow lines that do not respond well to the topography. Velocities of ≤ 100 m/s model better the flow lines, although at the expense of requiring lower resistance parameter values.

The complicated nature of many of the flow lines derived from VFLOW using lower velocities results from their response to the topography and low resistance. Overlap and intersection of flow lines emphasizes that the FEBs were probably emplaced under conditions where transitions between laminar and turbulent flow occurred often, especially at lower velocities where the effects of the underlying topography would influence both the direction and energy of the flow materials. Future work with VFLOW will include other FEB craters in different topographic settings. Better DEMs would allow more accurate modeling of the FEB flow paths using VFLOW. This may be possible for some regions using multiple-Cycle SAR stereo images where complete coverage exists for each Cycle.

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Table 1. Selected Isabella VFLOW Runs.

Model Run	v_o (m/s)	k (Pa)	η (Pa-s)	D (m)
ISA2	321	30	60	10
ISA3	321	2500	5000	100
ISA6a	100	10	35	10
ISA6b	100	5	20	10
ISA7a	100	400	2300	100
ISA7b	100	200	1400	100

v_o = initial velocity; k = yield strength; η = viscosity D= flow depth

Figure 1. Isabella (north to left) with run ISA6b flow lines overlain.