**AN EXAMINATION OF THE RHEOLOGY OF MARTIAN DEBRIS APRONS.** M.H.Bulmer[1], B. Zimmerman[1], D.Finnegan[2] and L. Glaze[3]. [1]Landslide Observatory, JCET, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD21250 (mbulmer@jcet.umbc.edu); [2]CRREL, Hanover, New Hampshire, 03755; [3]Proxemy Research Inc. Gallant Fox Lane, Suite 225, MD 20715.

**Introduction:** Three landslides sites located within the Valles Marineris (0º-20º S and 30º-90º W), studied using Viking data [1,2,3] have been reexamined using MOLA topography data and MOC images. Previously we have validated the extent to which the relative value and absolute variations of empirical parameters derived from Chezy-type models describe the behavior of the General's slide debris flow in Virginia [4]. We learnt that if we wish to improve our understanding of dynamics of martian debris aprons it is necessary to search for geomorphic signatures that can be used to estimate velocity, in addition to examining channel topography and flow thickness. In this study, MOC, THEMIS and MOLA data have been used to derive apron topography, thickness, and where possible travel speeds. These data have been combined with a Chezy modeling approach to examine their dynamics and to determine to first order their rheologies.

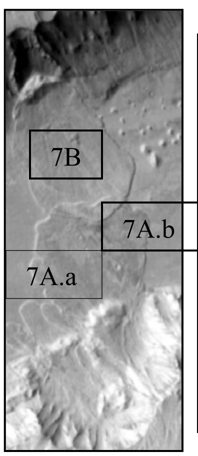


**Figure 1**. Site 7 on the eastern edge of Aurorea Planum. A landslide deposit on the northern wall, (Site 7B) has been studied in detail. The toe of ls 7B ran up-and-over the toe of ls 7A.a and ls 7A.b. The thickness *h* values at ls 7A.a and 7A.b are of 81 and 58 meters respectively.

**Image Interpretation:** Previous workers have often interpreted landslide aprons as the product of a single emplacement event [1,2,3]..Our observations of multiple discrete aprons, slump blocks and scarps may indicate numerous smaller failures that have occurred over time [5]. In this study we assume that the aprons at any one site may have been separated by some time interval but can be considered to be the product of a single emplacement event.

**Chezy Model:** We use the Chezy model since it has been used effectively to describe the bulk behavior of river and open channel flows, lahars, lava flows, turbidity flows and sediment-laden flows [5]. The assumptions that are part of the approach are (1) one dimensional flow at any point along a flow where the velocity in the flow is averaged to a single value $u$, and (2) there is no significant density variation in the fluid/medium. A typical version of the Chezy model used is:

$$q=uA=(gh \sin\theta/C)^n A$$

Where $A$ is cross-sectional area of the debris apron, $g$ is gravity, $\theta$ is underlying slope, $h$ is average thickness, $C$ is resistance to flow and $n$ is a constant. The martian debris aprons were examined with $n$=0.5 and 1 [4]. This therefore describes $q$ at any instant in time where $A$, $h$, $q$ and $C$ are available. Where the data allows, the Chezy model can be used to compute both variations in, and the absolute value of $C$ along debris aprons on Mars. The first approach assumes $q$ is constant and has the advantage of requiring only $h$ and $A$ but allows determination of debris' behavior in relative terms only and provides a poor constraint on the rheology.

If a constant volumetric flow is assumed, then the relative value of $C$ at any point can be given by,

$$C_n/C_o=(A_n/A_o)^2[(h_n \sin\theta_n)/(h_o \sin\theta_o)],$$

where $A_n$ and $A_o$ are the cross-sectional areas of the debris apron at $n$ and $o$, $h_n$ and $h_o$ are average thicknesses at $n$ and $o$, and $\theta_n$ *and* $\theta_o$ are the underlying slopes at $n$ and $o$.

In the second approach, observations that allow velocity to be calculated are used to estimate average speeds for a moving mass at several locations. The absolute values of $C$ are determined using:

$$C=(gh \sin\theta)/u^2,$$

**Estimating $\theta$, $A$, $h$ and $u$:** We obtained the dimensions of the debris aprons using MOLA gridded data IAU 2000 at 128 X 256 pixels/degree within the Gridview program as well as examination of the raw data. By correlating THEMIS and MOLA data many previously unknown features of debris aprons were observed. Both $A$ and $h$ were determined from cross apron profiles. In order to determine velocities at each of the respective cross-section locations we calculated acceleration:

$$a=g(\sin\beta - \mu \cos\beta)$$

where $g$ is gravitational acceleration and $\beta$ is slope, and the assumption that the initial and/or the final velocity of the displaced material must be equal to zero:

$$v_f = [v_i^2 + 2a(s_f - s_i)^{1/2}], \text{ OR } v_i = [v_f^2 - 2a(s_f - s_i)^{1/2}],$$

where $v$ is velocity, $a$ is acceleration and $s$ is distance.

The value u for Site 7B was calculated using the equation for a climbed obstacle v=√2gh, and then substituted into the equation for vf or vi for the corresponding cross-section, producing a known u value for each cross-section along the profile. The calculated velocities for Site 7B are 24.58 and 20.8 m/s, with an average maximum velocity calculation of 27.52m/s. The average maximum velocity for all of the sites, based on acceleration, assuming vi=0 range from 22.3-9.27 m/s, and vf=0 range from 16.05-10.4. The validity in this approach to finding u, has been tested with data from the Generals Slide debris flow [4].

**Model Results:** The relative value of *C* using a constant *q* for sites 7B, S1D, and S3 on Mars are 0.42 +/- 0.38, 0.52 +/- 0.78; and 0.19 +/- 0.19 respectively. The value the Generals slide is 0.43 +/- 0.18. These averages were derived from ten profiles for 7B and 1D, eleven from S3, and nine from the Generals Slide.

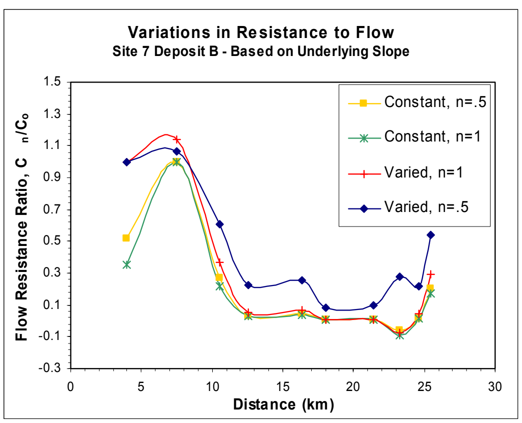


**Figure 2.** Variations in *C* for Site 7B

Variations in *C* at 7B are shown in Figure 2 for both modeling approaches, where *q* is either constant or varied. There is a general decrease in *C* with distance and similarity in the shapes of the curves for both approaches. The shape of the curves does not appear sensitive to the value *n*. The greatest decrease in *C* occurs from six to twelve kilometers out beyond which C drops below 0.3 and stay there. Table 1 shows the absolute values of C computed from estimated flow speeds for S7B and the Generals slide under varied conditions. For comparison between S7B and the Generals slide, C was calculated for S7B using a u value based on Earth's gravity. The average absolute *C* value for S7B, based on both overtopping events and calculations with Earths gravity, is 0.1565 for *n*=0.5 and 0.035 for *n*=1. For the Generals slide we favor values for *C* bound by *n*=0.5 since these are in agreement with eyewitness observations.

| Site | Av | Std Error |
|---|---|---|
| MS7B *n*=1 | 0.055 | 0.059 |
| MS7B *n*=0.5 | 0.186 | 0.110 |
| MS7B Eu *n*=1 | 0.038 | 0.040 |
| MS7B Eu *n*=0.5 | 0.167 | 0.087 |
| G *n*=1 Mu Eg | 0.086 | 0.021 |
| G *n*=0.5 E | 0.032 | 0.008 |
| G *n*=1 Mu Eg | 0.171 | 0.043 |
| G *n*=0.5 E | 0.065 | 0.016 |

**Table 1.** Values of flow resistance *C*. M is Mars, E is Earth and G is Generals slide.

**Comparing Rheology:** Broadly, increasing values of *C* correlate with increases in the flow resistance, which can be related to the effective flow viscosity and pore pressure. From Table 1 the average value of *C* for S7B, S1D and S3 when *q* is constant ranges from 0.18 to 0.5. This compares with 0.4 for the Generals slide. Calculations of *C* for S7B using varied *q* range from 0.009 to 0.2 indicating lower resistance to flow than for *q* constant. A comparison between the absolute values of *C* for S7B and for terrestrial flows can be made by calculating a flow speed at S7B under Earth conditions. The values of *C* range from 0.03 to 0.1 which can be used as a guide to rheology, These values are in the same range as those for a relatively dry terrestrial lahar [4]. Our next step will be to compile absolute *C* values for more martian debris aprons. These will then be compared to absolute values of *C* being calculated for additional 'flows' on Earth using high-resolution (~5cm) LiDAR topography data acquired using the NASA ATM-IV instrument.

**References:**

[1]Lucchitta, 1979, JGR 84, 8097-8113; 1987, Icarus, 72, 411-429 [2]McEwen, 1989, Geology, 17, 1111-1114 [3]Quantin et al., 2004. Planetary and Space Sciences 52, 1011-1022 [4] Bulmer et al. 2002. JGR 107, 10.1029 [5]Bulmer and Zimmerman, 2005, GRL 32, L06201.