THREE-DIMENSIONAL STABILITY BACK-ANALYSIS OF SMALL MARTIAN AVALANCHE CHUTES. R. Sullivan, Department of Geology, Arizona State University, Tempe, AZ 85287.

Steep slopes are interesting areas for examining the characteristics of martian surface and near-subsurface materials and the activity of gradational processes because (1) slopes steeper than the angle of repose are likely to be less obscured by a fine-particle mantle, (2) scarp recession may periodically yield relatively fresh exposures, and (3) gradient-dependent gradational processes may occur in such settings at revealingly high rates. This work explores what small martian avalanche chutes reveal about the strength properties of near-subsurface martian materials, and the gradational processes that affect them.

The morphometry of an evacuated avalanche chute reflects the strength (at time of failure) of the material that once filled it. For instance, larger, deeper, steeper avalanche chutes must have had stronger material along their slip surfaces at time of failure than smaller, shallower, less steep avalanche chutes. By analyzing the topography of an evacuated avalanche chute it is possible to calculate the strength along the slip surface just required (that is, at time of failure) to support a filling material. Furthermore, broad classes of geological materials can be distinguished on the basis of their strengths. In this study material strengths are calculated from the morphometry of martian avalanche chutes, resulting in determination of the mechanical character of the martian surface and near-subsurface materials that once resided along these slip surfaces. Calculations are carried out using a three-dimensional stability back-analysis technique developed specifically for this purpose.

The gradients, depths, and widths of martian avalanche chutes can be inferred from combining two sets of data: (1) three high resolution 1:500,000 scale topographic maps covering portions of the Valles Marineris; and (2) high resolution Viking Orbiter images that overlap with the topographic maps. The three-dimensional technique presented here shares many of the same assumptions of successful two-dimensional techniques: the strength of geological materials is assumed to be adequately described by the Coulomb equation; failure is assumed to be brittle (and for the martian case, dry); and the factor of safety is assumed $= 1$ at failure. The technique uses a local infinite slope analysis description of the shear and normal forces applied to any patch of the slip surface. The approach is similar to the ordinary method of slices (OMS), but the third (transverse) dimension is included, so the vertical slices of the two-dimensional OMS become vertical quadrilateral rods in the three-dimensional technique developed here. As the slip surface cross-sectional profile extends outward from the chute centerline, rising gradually toward the surface, less and less mass above the local area of slip surface requires a steeper slope to maintain $FS=1$. The cross-sectional chute profile can be constructed such that at all places the slip surface is locally tilted toward the centerline (with a constant downhill component) sufficiently to maintain $FS = 1$ at all points.

Across the martian surface there are several thousand chutes visible on Viking and Mariner images. Chute depths are typically several tens of meters; chute widths are typically several hundreds of meters. However, various difficulties combine to severely restrict the number of features that are suitable for analysis. The great majority of features are simply too small or are too confusingly illuminated on available imagery to be measured accurately enough. Most critically, only three 1:500,000 topographic maps are available for overlap with suitably high resolution images, and two of these maps are preliminary.

General results: (1) The contrast between material angle of internal friction and the average slope angle determines the width:depth ratio of the chute. If the contrast is large, the width:depth ratio is smaller. (2) The material cohesion directly influences the cross-sectional size of an avalanche chute, independently of its transverse shape. If the cohesion is high, the resulting chute will be larger in cross-sectional area. (3) If the cohesion and angle of internal
friction are held constant as the average slope angle is increased, both the depth and the width:depth ratio will decrease.

Martian results: (1) Calculated values of cohesion and friction angle reveal the martian materials to be similar to moderately cohesive debris -- not bedrock. Glacial till is a good mechanical (not genetic) terrestrial analog for much of the analyzed material (Figure 1). (2) Most chutes have width:depth ratios between 11:1 and 4:1, and this range is narrow enough so that values of friction angle can be estimated from average surface slopes. Approximately, friction angle = slope angle - 4. If the width:depth ratio is smaller than average, subtract a little more; if width:depth is larger, subtract a little less. (3) Some chutes (not included in the twenty-two reported) with small width:depth ratios were not analyzable with this method. This probably is a reflection of the limitations of the assumptions of the algorithm, especially the simplified geometric model and uniform distribution with depth of density, cohesion, and friction angle. Another possibility is that the problematic features have a different or multi-genetic origin besides simple catastrophic mass-wasting.

Failure for the martian chutes occurred at depths of tens of meters beneath the surface slopes. Through these depths, slope material strength was reduced to values similar to glacial till and other terrestrial debris materials when failure occurred. It may be that this weakening -- presumably through weathering process(es) (sublimation of volatile ice cement?) -- has been characteristic of near-subsurface materials elsewhere on Mars; this process is revealed best on steep slopes only because slope failure results. If this is the case, the weathering depth range indicated in this work for steep slopes is probably an underestimate for elsewhere, because the actual range should be greater beneath more level surfaces that do not suffer periodic renewal through downslope failure of their debris/soil layers.

Cohesion and Friction Angle of Martian Chute Materials

![Figure 1. Comparison of chute analysis results with terrestrial hard rocks, glacial till, and Viking Lander results.](image)

References


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