SLOPE STABILITY ANALYSIS OF VENUSIAN SCARP, ARTEMIS CHASMA. **William H. Roadarmel** and **Richard A. Schultz**, Geomechanics–Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno, NV 89557-0138 (whr@mines.unr.edu).

Summary.

As the first phase of a larger project investigating the rock mechanical properties of the brittle upper Venus crust, a slope stability analysis was performed for a Venusian scarp of remarkable dimensions to determine admissible cohesive and frictional parameters. Two-dimensional analyses of the scarp and vicinity, performed using the Janbu method and program XSTABL, provide limiting values of rock-mass cohesion and friction angle for stability of this 700 m high, 60° dipping scarp. The results of these calculations are consistent with the stable, unfailed morphology of this slope and rock-mass strength parameters previously suggested for near-surface rocks on Venus.

Introduction and Background.

Identification of an interesting scarp [1] on the inner annulus of Artemis Chasma [2], located near 36°S, 143°, presents a unique opportunity to examine the stability of a high, steep slope. This landform has a slope of ~60° and is almost 700 m high [1]. The elevation of the base is ~0.3 km above mean planetary radius (MPR) and the top is ~1 km above MPR. Analysis of this remarkable slope provides the first direct look at the strength properties of the rock mass that underlies the slope. Given its position within the Artemis annulus, the slope may represent a normal-fault scarp that apparently has experienced negligible mass wasting or other types of slope degradation found in other areas on Venus [3]. Because the slope is developed in only the upper km of the Venus crust, an analysis of the brittle rock-mass strength (disregarding lower crustal strength) can be accomplished.

Methods.

Slope stability analysis of the Venusian scarp has been conducted by using the XSTABL computer program. This program is routinely used in the analysis and design of terrestrial slopes to determine the factor of safety (FS) when the slope dimensions and material properties are known for a particular slope. For the present study, the usual method was reversed to solve for admissible combinations of cohesion and friction angle, corresponding to a unit factor of safety, for the Venus slope. Given the slope dimensions, pairs associated with a factor of safety of one were computed and used to define a line separating areas of failure (FS < 1) and stability (FS > 1) on a plot of friction angle vs. cohesion.

Four scenarios were evaluated with XSTABL: no atmospheric pressure, a uniform atmospheric pressure acting on the slope face and surroundings, a graded atmospheric pressure gradient which varies with altitude [4], and a graded atmospheric pressure combined with the associated pore pressure within the rock mass. The latter three analyses were done to address the effect of Venus' substantial atmospheric pressure on the rock properties necessary to maintain stability of the slope.

We use the Rock Mass Rating System (RMR) [5] to independently estimate the strength properties for the slope-forming materials, following [6]. For Venus, the plausible range for near-surface rock mass strength is given by 45 < RMR < 75 [6], from which instantaneous values of friction angle and cohesion can be obtained [7]. We note that the friction angles associated with a slope-stability analysis are those for a rock mass that lacks a preferred anisotropy or set of well-developed failure planes. The resulting values of cohesion and friction angle usually differ from those typical of faults (e.g., zero cohesion and friction angles of 25–35°) because the preferred failure surface breaks through intact rock bridges in addition to utilizing appropriately oriented sliding surfaces.

Results and Discussion.

The calculations clearly define regions of stable and unstable behavior on the friction vs. cohesion plots (Fig. 1). For the zero atmosphere case (Fig. 1), the results are qualitatively similar to those reported for large Martian slopes [8] that also lack a substantial atmospheric component. Here we compare the XSTABL predictions explicitly to rock-mass behavior using RMR, demonstrating that the strength parameters for the slope-forming material are consistent with stable behavior (Fig. 1) and morphology. The calculations also show that stable behavior is predicted for the atmospheric cases; as evident in Fig. 2, the constant atmospheric pressure case is not substantially different in its stability predictions than the graded atmosphere case. However, addition of pore pressure in the slope-forming materials shifts the stability limit to the right, toward higher values of friction angle. This result may be anticipated by recalling the concept of effective stress as implemented on a Mohr diagram. In all three cases involving the thick Venusian atmosphere, the slope is unequivocally predicted to be stable, even when the pressure-dependent values of instantaneous cohesion and friction angle, calculated for 9 MPa atmospheric pressure, are considered (Fig. 2, triangles).

Conclusions.

Slope stability calculations for a steep, high fault scarp on Venus reveal that the predicted values of rock-mass strength for Venus rocks are consistent with observations of a stable slope. Rock-mass strengths are large enough relative to the stability limits for this slope that the details of atmospheric interaction with slope performance cannot presently be assessed. Similar analyses of failed slopes elsewhere on Venus [3] may provide better clues to this effect. Examination of likely triggering mechanisms for slope failure, such as seismic activity, in those areas may also be required.

Because the values of RMR are not defined uniquely for a given rock type, but depend instead on characteristics of the fracture population, inversions of slope stability for strength parameters are unable to descriminate between different lithologies for these large-scale slopes. Further, conventional slope-stability analyses require constant strength properties regardless of depth. We plan to refine these calculations using depth-dependent rock-mass strength parameters in the program to augment our understanding of rock properties on Venus.

References. [1] Connors, *JGR* **100**, 14,361, 1995. [2] Brown and Grimm, *Icarus* **117**, 219, 1995. [3] Malin, *JGR* **97**, 16,337, 1992. [4] Luhmann *et al.*, *AGU Geophys. Monog*. **66**, 1992. [5] Bieniawski, *Engineering Rock Mass Classifications*, Wiley, 1989. [6] Schultz, *JGR* **98**, 10,883, 1993. [7] Schultz, *Rock Mech. Rock Eng*. **28**, 1, 1995. [8] Lucchitta *et al.*, in *Mars*, 453, 1992.

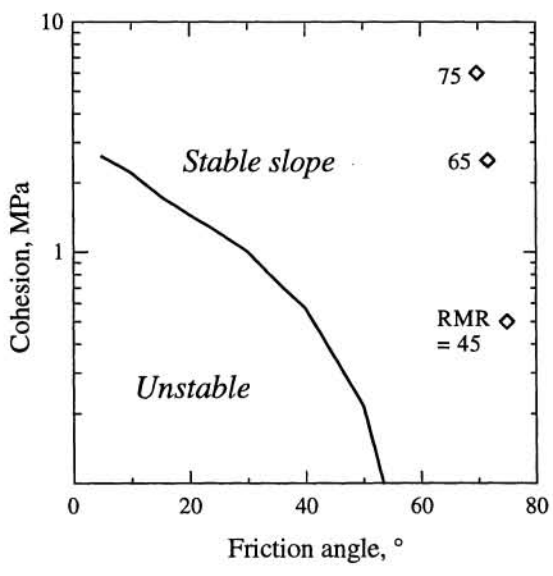

Figure 1. Stability plot for the Venus scarp assuming no atmospheric pressure. Note that the strength parameters for likely ranges of rock masses plot in the stable regime.

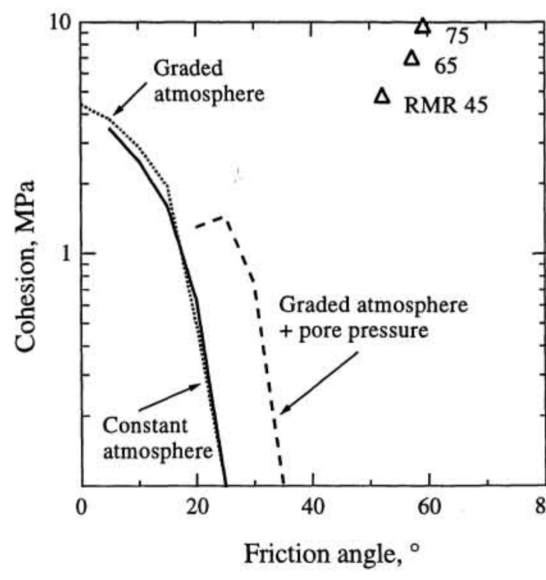

Figure 2. Stability plot showing the influence of the thick Venusian atmosphere on the delineation of stable pairs of strength properties. The pressure-dependent rock-mass values plot in the stable regime.