Paterae On Io: Compositional Constraints From Slope Stability Analysis

T. Slezak1,2,*, L.P. Keszthelyi1, C. Okubo3, D.A. Williams2

1Astrogeology Science Center, U. S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001; 2School of Earth & Space Exploration, Arizona State University, Tempe, AZ 85287; 3Astrogeology Science Center, U. S. Geological Survey, 1541 E. University Blvd., Tucson, AZ 85721; *tjslezak@asu.edu

Synopsis

Io is the most volcanically active planetary body in the solar system. Persisting from initial debates prompted by observations from the Voyager mission, the relative roles of sulfurous and silicate materials in Io's surface and upper-crust have yet to be resolved. This project utilizes numerical slope stability analysis to perform a compositional back-analysis of candidates amenable to fit the structural constraints observational data provides. Compositional constraints are examined in both static and dynamic environments for a range of representative materials ranging from ash to mafic rock. We find that a scarp composition of α-sulfur lies on the threshold of stability for highly dense materials, mafic rock far exceeds thresholds, and snow falls below all threshold lines. The results of this study seek to provide data to qualitatively test the Jaeger and Davies [2006] model for Io's crust.

Background

Subsequent to the observations from the Voyager fly-bys when Io’s surface geology was first resolved, extensive debate subsequently erupted over the comparative roles of sulfur and silicate materials in the surface and crust.

Clow and Carr (1980) provide powerful basin models for further investigation of Io and the pro-continuity that applied methods of slope stability analyses allow. This study continues upon previous work however seeks advantage in technological development and substantial gains in the Io dataset.

The withstandings of observed scarp formations on Io, such as the 3km tall scarp at Chaac Patera (image provided above) with observed slopes of 70° to 90° (Radebaugh et al., 2001) holds clues to Io’s interior. Provided known values for physical and mechanical properties of rock and soil material compositions supported by evidenced from observation, structural characteristics observations allow viable compositions to be constrained. This study varies values for physical properties density (p), slope angle (θ), as well as mechanical properties, cohesion (c) and angle of internal friction (ϕ). While these factors each have their own interdependency, comprehensive end-members may be placed where no constraints currently stand.

Methodology

The Slide (5.0) software ( Rocscience Inc.) allows a multivariable platform for running the in the architecture of each numerical simulation runs is required to allocate viable data sets. Corrections for Io’s gravitational acceleration are implemented into model parameters by a conversion factor of 0.001796 (Io gravity ~1.796 km/s/m) when translating a given material’s terrestrial density (kg/m³) into its respective Ionian Unit Weight (kn/m³).

The Bishop Simplified analysis method to determine the factor of safety is chosen for this study as it is the most universal (and planetary) methodology for highly reliable, general slope stability analysis (Spencer, 1967). The two values of prime importance in the study’s examination of material that permits near-vertical slope retention include internal friction (ϕ) and cohesion (c), given by the Coulomb Failure Criterion:

\[ F = \tan(\phi) + c \]

Utilizing the Slide Software (rocscience.com) and datasets acquired since Clow and Carr (1980), additional constraints can be applied, Mohr-Coulomb Failure Criterion: tan(ϕ) = c + µ r

Maximum values for ϕ and c are determined (per ϕ, per r). Represented material tested range from ash to mafic rock to establish end-member constraints. Dynamic modeling implies a seismic element that is appropriate a priori in consideration of the gravitational interaction and tidal flexing Jupiter incurs on Io. Dynamic modeling incorporates a seismic coefficient of 0.5, a midpoint of the coefficient range, as no empirical evidence suggests Io’s tectonism is silent or violent, just that it very likely exists. In classifications of earthquakes rather than Ioquakes, S=0.5 is representative of “catastrophic” earthquakes.

Acknowledgements

The authors thank and hold in gracious regards the NASA Physics and Astronomy REU program, the United States Geological Survey Astrogeology Science Center, and the Ronald Greeley Center for Planetary Studies (the NASA Regional Planetary Information Facility (RPF) at ASU). This research was funded by National Science Foundation Grant AST-1004107.