DISCRETE ELEMENT MODELING OF MARTIAN LANDSLIDES

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Introduction: High-resolution MOC, THEMIS, HiRISE, and HRSC image data and geomorphologic characterization [1] based on MOLA-derived topography are being used as input for discrete element modeling to simulate slope failure in the Valles Marineris. The main scarp and displaced material of a landslide provide insight into the mechanical nature of the surface and shallow subsurface of Mars. For purposes of this modeling, a landslide at the junction of Ganges and Capri Chasmata (41°30’W, 8°0’S) was selected to provide the basic geometry. This landslide has a 3-4 km high main scarp, a complex rupture surface with a displaced block, and a runout length of approximately 25 km. The landslide deposit is characterized by longitudinal ridges and furrows.

Methodology: We performed discrete element modeling of landslides using the code PFC2D [2]. PFC2D is based on the discrete element method that was developed initially for analyzing the mechanical interaction of granular materials [3]. With the addition of particle bonding, the method has been extended to a variety of problems, including folding, faulting, and dike injection [3–10]. The discrete element formulation requires selection of a set of micromechanical properties (e.g., friction, normal and shear bond stiffness and strength) that describe the interaction of the elastic particles with each other and the model boundaries (see [5], for details on the theoretical framework of PFC). The result is a set of micromechanical properties that provides the correct bulk (macroscale) material behavior, which includes both the elastic (recoverable) and inelastic (non-recoverable) components characteristic of natural deformation.

Our two-dimensional discrete element models are oriented parallel with the slide direction to examine the effects of mechanical layering upon the morphology of slip surfaces, scarps, and transported deposits that form as a result of slope failure on Mars. The initial geometry of the models is designed to approximate the height and length of the study site and to capture the observed and interpreted mechanical stratigraphy. Discrete element particle diameters range from approximately 30-60 m; a compromise between model fidelity and computation time. Bond properties (i.e., bond stiffness and strength), which control the macroscale behavior, are adjusted between layers to produce an initial mechanical stratigraphy that includes several strong layers. Models are conducted under Mars gravity (3.71 m/s^2) using a pre-slide free surface that dips 25°. Sliding in the base case model was driven solely by the gravitational load. Subsequent models include one or more normal faults that displace the stratigraphic layers to provide additional triggering of movement [11,12]. Models are considered complete once a stable particle configuration is achieved.

Results: Model results show that an initial slip surface forms some distance from the lateral free surface and subsequently migrates away from the free surface in discrete increments producing a well-developed main scarp (Figures 1, 2). The models also show rotated blocks of competent strata, localized zones of shear displacement and distributed flow of weaker materials. The mechanically variable stratigraphic intervals lead to a generally hummocky surface morphology for the displaced material. Interestingly, models that include faulting develop generally similar surface topography to those without faulting.

Discussion/Conclusions: Model geometries are similar to morphologic features observed in Martian landslides [1]. For example, the models show a well-developed scarp and an irregular deposit that includes several displaced and rotated blocks similar to observations of the landslide in Ganges/Capri Chasma. Our model results also suggest that direct evidence for faulting as a triggering mechanism for landslide initiation may be masked by the post-faulting mass movement of material.

Our results demonstrate that discrete element modeling can be a powerful tool for investigating landslide processes. For example, as new higher resolution topographic and image data becomes available, more detailed (accurate) mechanical stratigraphic configurations can be evaluated.

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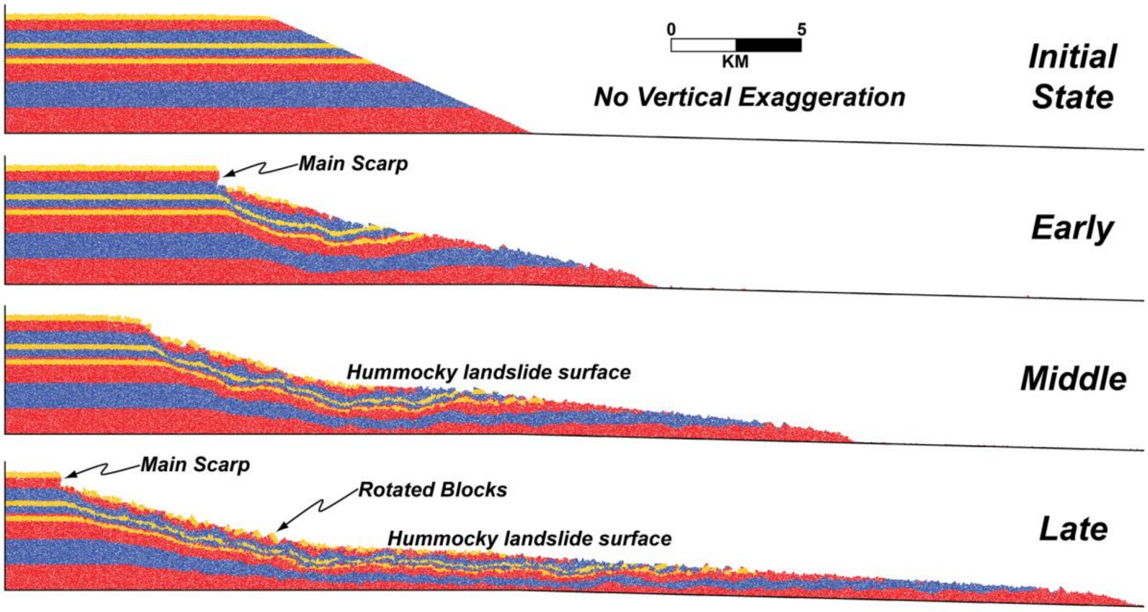

Figure 1. Base case results showing initial state and model evolution.

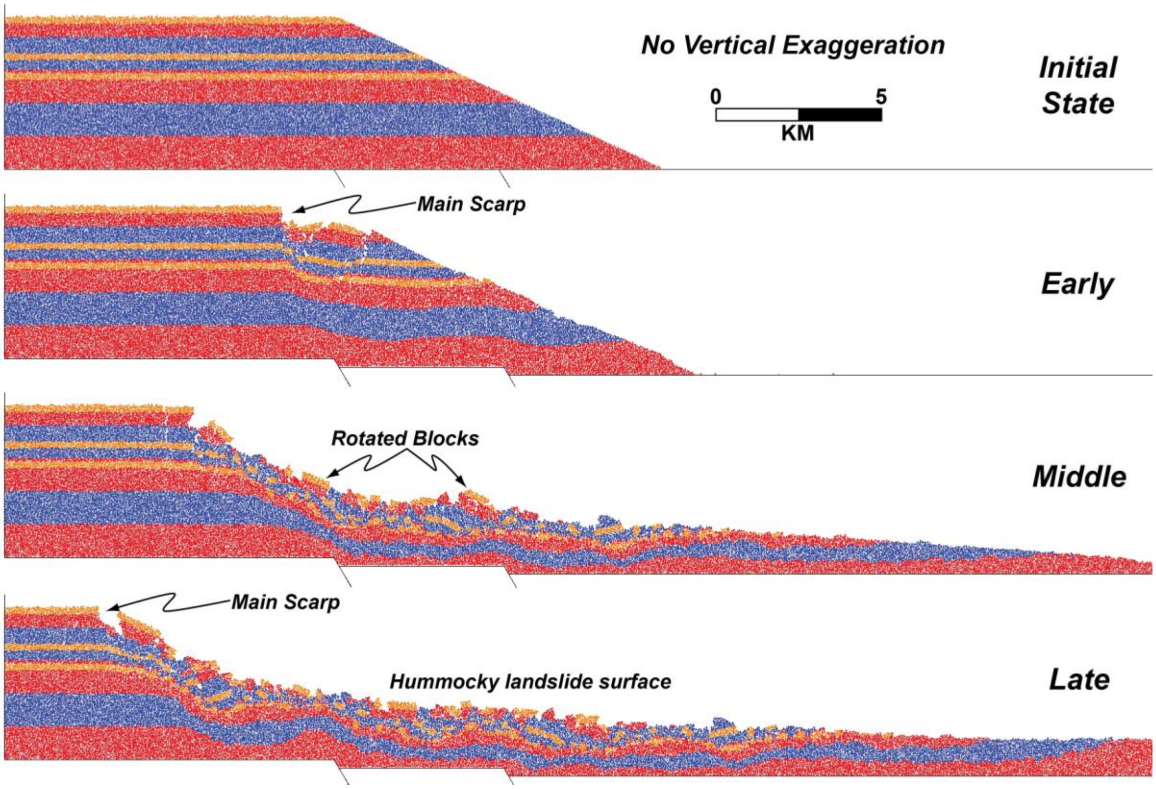

Figure 2. Results for model with two normal faults showing initial state and landslide evolution.