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Hydrodynamics of Groundwater Flow on Mars: Parametric Study of THV in Ius Chasma

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Abstract

Geomorphological observations and heat-flow models suggest Mars to have an active groundwater system that could still be generating artesian discharge, resulting in transitional flow features such as the Recurring Slope Lineae [1] or potential collapse features such as the Theater Headed Valleys (THV) in Ius Chasma [2]. Thermophysical models suggest groundwater to be a few kilometers deep [3] beyond the reach of existing radar probing experiments [1], hence the occurrence of aquifers and talik can only be inferred and characterized from surface geomorphological features and their terrestrial counterparts [4]. Herein we propose to constrain ambiguities associated with the hydrodynamical parameters of potential Martian aquifers beneath Ius Chasma by examining the fluid dynamics that could be responsible for the formation of THV using a parametric simulation of subsurface hydraulic erosion and associated ground collapse. Our preliminary results suggest that water salinity, in addition to the hydraulic forces associated with groundwater seepage, can substantially alter the basaltic ground compressive strength and hardness, causing collapse and subsequently forming THV.

1. Introduction

The formation of THV by groundwater sapping is challenged by the capability of physically demonstrating how artesian springs can cut canyons into massive rocks, causing collapse of the rocky material and retreat of the side walls along the plateau edges. On Earth however, widespread THV cutting through the carbonate plateaus in the Sahara are confirmed to be formed by long-lasting groundwater processes based on recent isotopic, geochemical and hydrogeological evidence [4]. Herein, we provide a parametric physical study constraining the hydraulic parameters of fluid erosion in fractured basalts needed to deteriorate its mechanical properties, allowing ground collapse to occur and hence to generate the THV. In particular, we explore how groundwater movement, velocity, salinity, reservoir pressure and soil structure affect erosion and collapsing processes. On Earth, simulating such collapse has been performed through Finite Element Modelling (FEM) by coupling the time rate of change in strain from the solid mechanics equations in Darcy's Law, and adds the fluid pressure gradient as a stress contribution. This multiphysical coupling describes the linked interaction between fluids and deformation in porous and fractured media and have been validated against real fieldwork in several cases including land surfaces in Fresno, CA, which dropped 9 m in 20 years and subsidence in California Central Valley due to over-pumping of water, where such cases were benchmarked [5]. In this study we adapt the FEM multiphysical model to constrain the ambiguities associated with the hydrodynamic of groundwater on Mars in Ius Chasma.

2. Methods

Fluid flow with deformation is modelled by mimicking the fluid pressure or equal hydraulic head in a reservoir, which absorbs stress. If water movement significantly reduces pore fluid pressures, the ground could shift due to the increased load. Because the reduction in the pore space brings more fluid movement, the reservoir could compact further. It follows that lateral stretching must compensate for the vertical compaction. Herein, we study different flow salinities ranging from fresh flows (<500 ppm) up to highly saline ones (35,000 ppm), while the groundwater acidity (mainly sulphates) pH ranges from 2 up to 7 and the ground water velocity ranges from 0.15 up to 15 meters per day. The model domain is 6 km width and 1 km in ground-depth, where the aquifer is located beneath two layers of fractured basaltic rocks (Fig. 1). The simulation time domain of the artesian flow erosion going upward through the fractures is four billion years. Fractures in our preliminary simulations have an arbitrary orientation and are not always connected in the two layers.

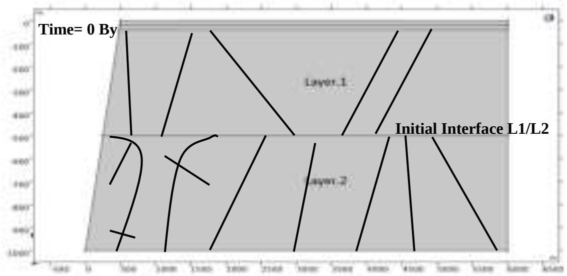

Figure 1: FEM geometry for the simulation of rock hardness degradation by fluid erosion in layers 1 & 2 associated with artesian flow through fractures from the aquifer below layer 2 (dimensions in m).

3. Results

Preliminary results suggest that substantial ground collapse on the order of 125 m (top Fig. 2) start to be observed after 1 billion years of simulation.

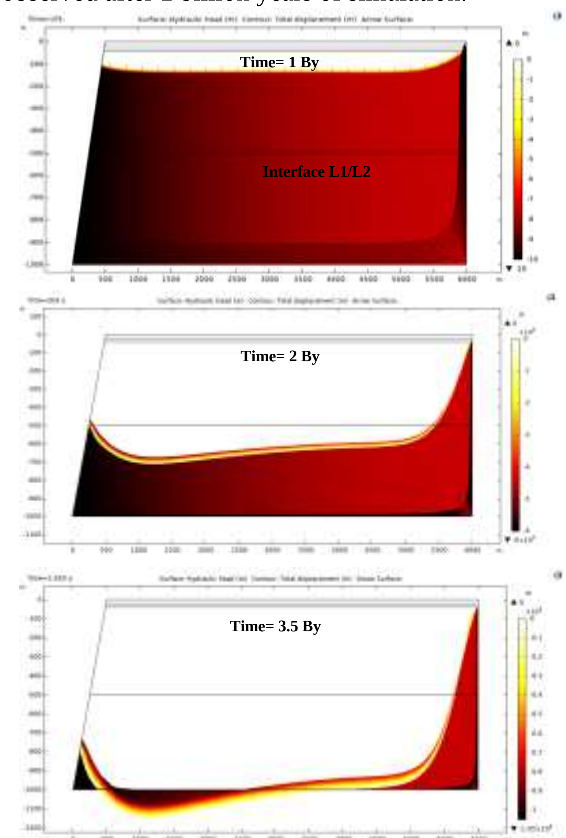

Figure 2: Ground collapses arising from artesian flow through the fractured basalt in layers 1 & 2 after respectively from top to mid to bottom, 1, 2 and 3.5 billion years.

The upward fluid erosion starts first with layer 2 in the bottom causing collapses and structural degradation causing the surface of layer 1 to increasingly deform as layer 2 gets more and more erosion. We note that the observed surface collapse arising from the degradation of the ground mechanical properties by fluid erosion through the basalt's fractures occurs unevenly toward the edges in the first 1 billion years. After 2 billion years, layer 2 completely collapsed and disintegrated (mid Fig. 2) and fluid erosion from the aquifer continues upward to erode layer 1 on a slow time scale as aquifer pressure declines with time at a hypothetical rate of ~30 bar/By. After 3.5 billion years, the canyon's inner edges from layer 1 totally collapse forming geomorphological features similar to those of THV (bottom Fig. 2). These simulations assume a linear initial (i.e. at time zero during Post-Noachian) aquifer vertical pressures of 100 bars from the bottom of layer 2 reaching surface pressure at the surface. In our simulation, the pressure profile decays exponentially with time. Groundwater salinity and acidity have been held constant in Figure 2 at the respectively 10,000 ppm and 4 pH.

4. Preliminary Conclusions

Our preliminary results suggest that water salinity and movement are the main two parameters governing the fluid erosion in basalts and the associated ground collapse. In the conference, we will present more parametric simulations for other variables such as water velocity, ground hardness, fracture distribution, salinity and acidity to constrain the boundary values needed to form the THVs. The implications of these results for understanding the groundwater origin and dynamic for forming THVs on Mars will be presented at the conference.

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