MODELLING UPWELLING MARTIAN FLUIDS AND RESURFACING IN UTOPIA PLANITIA. Mackenzie Mills[1], Alfred McEwen[1], and Amanda Hughes[1], [1]University of Arizona, Tucson, AZ 85721, email: macken-ziemills@email.arizona.edu.

Introduction: Utopia Planitia (UP), a 3300-km-diameter basin in the northern plains on Mars, has been proposed to have experienced widespread resurfacing[1-10]. Wide, relatively featureless swaths of the surface appear to have been reworked relatively recently in geologic time. The source for this reworking is currently ambiguous.

There are also multiple morphologies that may have been created or modified by resurfacing flows and fluids in UP[1,3,5,7,8]. One such studied UP morphology is the pitted cone. An example of pitted cones is shown in Figure 1. These cones appear as elliptical mounds that display a single, central crater which likely forms as the cone forms. Also, the cone populations show various grouping characteristics. Cones can occur individually, in clustered populations, or in connected chains of overprinting cones.
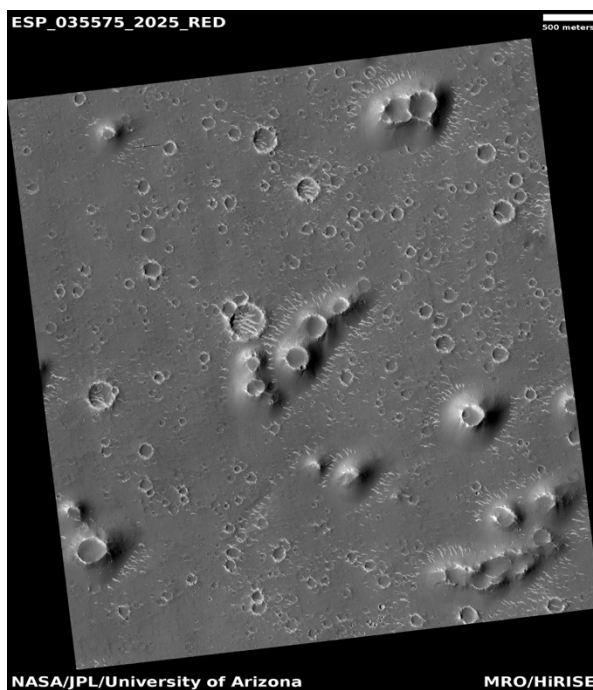

Figure 1: Observed pitted cone features in Utopia Planitia. The central craters, mound-like characteristic, and "clustering" nature of the cones can be seen. Some cones overprint each other while several cones occur singly.

These features resemble constructional cones on Earth[8] and have been proposed to form through classic volcanism or sedimentary volcanism flows. In a classical volcanic model, there would be a central pipe to a magma source, and the cone would be built up over time through numerous lava flows, similar to terrestrial cinder cones. In a sedimentary volcanic model, the cones would have formed like terrestrial mud volcanoes. Cones would form over time by layered mud eruptions. The mud would erupt from the subsurface due to the pressurization of a buried fluid and sediment reservoir. We choose to investigate the mud volcanism scenario because of the implications that buried Martian fluids have. These include the geomorphological evolution of UP, including past resurfacing, along with the astrobiological implications of large amounts of water having once existed in UP.

Numerical Model: We apply a terrestrial mud volcano model (updated for Mars) to UP to explore the feasibility of mud volcanoes and ascending subsurface fluids to cause the observed amount of resurfacing. Our numerical model in Python estimates the volumes of fluids and/or sediments that could have erupted based on a size range of subsurface reservoirs. In this abstract, we discuss only one reservoir size, but our results consider a range of reservoir sizes, up to thousands of cubic kilometers. This size range allows us to fully catalog the reservoir sizes which could have produced feasible widespread flows. Other model parameters include the salinity of the reservoir, the amount of silt and/or sediments suspended in the fluid, the surrounding crustal temperature and the geothermal gradient, gravity, the reservoir burial depth, and the presence of ground ice, clay or other impermeable layers.

In our model, we consider a certain volume reservoir of liquid water, contaminated by some amount of salts and silt, buried at a certain depth in the Martian crust. The fluid in this reservoir is therefore experiencing three types of pressure. Firstly, it is experiencing gravitational pressure from the overlying sediments and strata.

Secondly, terrestrial mud volcanoes often occur along depositional margins where sediments are buried so quickly that the resulting layers are undercompacted, leading to a density anomaly and buoyancy at depth[11]. Our model considers undercompacted sediments that originate from high past sedimentation rates, perhaps driven by the voluminous outflow channels.

Thirdly, we assume that the reservoir is experiencing pressurization due to freezing. We assume that the top of the reservoir has reached the freezing point of water and that a freezing front is propagating down from the top of the reservoir. This freezing front originated

from the Martian surface through the burial depth down to the reservoir. The freezing front must reach the top of the reservoir before the reservoir begins to freeze and experience pressurization. In our model, this top-down freezing front is represented by the Stefan problem. Initially, the freezing front propagates rapidly for the first ~100 years. Then, the propagation slows down until it flattens out around 300 years.

Freezing pressurization occurs because of the volume expansion of liquid water as it turns into a crystalline solid. As portions of the reservoir freeze, the remaining fluid component, already trapped in the subsurface, experiences a degree of pressurization proportional to the amount of the original reservoir that has been frozen. This freezing and pressurization is the primary way to overpressure the remaining fluid and force it to the surface to create resurfacing eruptions.

Our model will explore a range of burial depths. Shallow reservoirs may have contributed to resurfacing, but deeply buried reservoirs may be more effective for explaining widespread resurfacing[12]. Considering observations of pitted cones in UP, the cone fields are mainly found in low-laying areas and basins, suggesting that deep basin fill is necessary to create cone fields. Also, the fields are widely distributed which suggests a widespread, and not an anomalous local, source for the fields. Finally, cone fields do not show obvious places of collapse from the removal of subsurface material. This suggests the volume was removed from a deep depth, causing broad deformation and low surface strain. Providing support either for shallow reservoirs or deep reservoirs to have created these cone fields is a primary motivating factor for our model development.

Initial Results: Table 1 shows initial results from our numerical model for a $4.5 \cdot 10^8$ m^3 reservoir volume. With increasing depth, we find that significant percentages of the reservoir can be erupted using an adapted terrestrial mud volcano approach.

Depth (m)	Erupted Volume (m3)	% Reservoir Erupted
100	2.62139e+07	6
250	6.10021e+07	14
500	1.18982e+08	26
700	1.65367e+08	37
1000	2.34943e+08	52
1500	3.50904e+08	78
2000	4.5e+08	100

Table 1: Eruption estimates of a $4.5 \cdot 10^8$ m^3 volume reservoir erupting from various burial depths (left column). Each depth has a erupted volume based on freezing and hydrostatic pressure. The top right column displays these volumes in cubic meters. The bottom right column shows the estimates as a percentage of the original reservoir size. Deeper reservoirs appear to have the potential to have larger eruption volumes.

The volume estimates suggest that, assuming there were once numerous subsurface reservoirs under UP due to outflow channels and ground porosity, mud volcanism may be an effective way to resurface UP and create the swaths of relatively featureless terrain observed[13].

Expected Results: Our initial model has been expanded to include considerations involving buoyancy of undercompacted sediments, along with accounting for the interaction of fluids with "sealing" layers such as ground ice and clays. Such layers often occur in terrestrial mud volcanoes. We expect that including these layers will make our model more realistic and our volume estimations more accurate.

Our initial model also uses the Stefan problem, which we note is utilized for a freezing boundary layer. Thus, the Stefan problem will be modified to apply to fluid layers buried under kilometers of material. This will include considering the thicknesses of the reservoirs, the geothermal gradient, the surface temperature, and the conductivity of the burial crustal material[12].

With the final model, we estimate resurfacing potential and categorize the parameter space for a range of environmental variables. These include: reservoir initial and final salinity, reservoir silt/mud content, density of the reservoir fluid, density of the overlying sediments, the area of the conduit through which the eruption occurs, and the geothermal gradient. Exploring the effects of the different model parameters on the potential erupted volumes, and then comparing this work to future mapping in UP of the resurfaced terrains, will help answer the feasibility of mud volcanoes and erupting fluids to have reworked large swaths of the Martian northern plains.

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