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Martian groundwater outflow processes and morphology; reconstruction of paleohydrology using landscape evolution experiments

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Groundwater played an important role in the aqueous history of Mars but how, how long, and with what intensity remains unclear. Two types of fluvial landforms related to groundwater emergence are the giant outflow channels and the disputed sapping valleys. Understanding of the relation between subsurface and surface processes is slim, which limits inferences of climate implications from the observable morphology. We aim to increase this understanding and to apply this knowledge to Martian cases to reconstruct former hydrological conditions.

Using a series of sandbox experiments, we investigated formative processes of valleys formed by groundwater. These experiments showed the morphology and processes of groundwater sapping and pressurized groundwater outflow (see Marra et al, 2014, Icarus doi:10.1016/j.icarus.2013.12.026) and further focused on landscape characteristics of groundwater sapping sourced locally or distally, and identified various processes linked to pressurized groundwater outbursts including the formation and eruption of subsurface reservoirs that can explain the high reconstructed discharges of large outflow valleys (see Marra et al, 2014, JGR doi:10.1002/2014JE004701). Based on the experiments, we identified novel morphological indicators for groundwater outflow in the outflow channel region of Lunae and Ophir Plana. These, in combination with the classic outflow features, show a clear trend of increasing outflow magnitude with decreasing elevation to the northeast, indicating a head from a common aquifer.

The putative aquifer we identified was likely recharged by infiltration over the Tharsis region. Outflow channel activity peaked in the Hesperian, but continued in the Amazonian at a lower magnitude. Our results agree well with groundwater recharge in the Noachian and Early Hesperian, corresponding to a climate that sustained an active hydrological cycle. Furthermore, the large outflow events require a confining layer to build up enough pressure, which is consistent with the formation and thickening of the cryosphere that started in the Hesperian. The location of outflow features aligns with tectonic features, which suggest outflow through the cryosphere was triggered by tectonism related to the formation of Valles Marineris in this region.

The decreasing discharges of later outflow events suggest that recharge ceased during the Hesperian. The small late-Hesperian and Amazonian outflow events could have been sourced from the residual groundwater in the aquifer, again triggered or even re-pressurized by tectonic activity. Clearly, no active surface hydrological cycle is necessary for this period, nor atmospheric conditions that could sustain liquid water. Furthermore, since tectonism is the most likely outflow trigger, an episodic warm and wet climate is not a necessary condition for the outflow channels.