DIAGNOSTIC MORPHOLOGY FOR MARTIAN GROUNDWATER OUTFLOWS FROM FLUME EXPERIMENTS.

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Introduction: Channels on Mars have been found in many locations and across all possible scales, indicating presence of flowing water in the past. Several hypotheses for the formation of these channels have been proposed, including a role for groundwater. In this study we explored the morphology formed by three types of groundwater systems, all three previously hypothesized as possible Martian scenarios: 1) seepage from a regional groundwater system [1], 2) seepage from local precipitation [2] and 3) groundwater release from a pressurized aquifer (varying from sub- to super-lithostatic pressure) [3]. Here we present the results of analogue scale models which were focused on characteristic morphological elements, which we compare to Martian cases.

Experimental setup: We performed a series of scale experiments to study the morphological development of different scenarios. Several experiments were conducted in a setup of 1x3x0.25 m (width x length x depth, at Utrecht University) and in a large setup of 4x6x1 m (in the Total Environmental Simulator at University of Hull). Lightweight plastic sediment was used in the small setup and sand in the large setup, both poorly sorted. To simulate the three hydrological conditions mentioned in the introduction, 1) a constant sub-surface hydraulic head was applied using a header tank connected to the sediment, 2) a series of rainfall simulator nozzles were used (UoH setup only) and 3) a super-surface hydraulic pressure was applied to a perforated pipe beneath the sediment. The two scales of experiments allow us to assess the scalability to real-world conditions. We collected detailed DEMs and time-lapse imagery of the morphological development of the sediment surface.

Results: In the regional groundwater experiments (Fig. 1a), elongated valleys with circular, steep-walled, heads developed with depths down to the groundwater table. Valley heads and sides developed as result from mass wasting processes; within the valley material was transported by fluvial processes. Multiple parallel valleys formed initially, but one or two eventually capture most of the outflow and became much larger compared to the pirated valleys. In the precipitation-fed seepage experiments (Fig. 1b), groundwater flowed from all directions into valleys rather than just from upslope. Again, multiple parallel valleys with semi-circular heads formed but the valleys were shallower and wider compared to the regional groundwater system experiment. For the pressurised groundwater release (Fig. 1c), channel formation was significantly faster and initially formed sieve deposits flanking a small channel, as the sediment downstream of the source was not yet saturated. With increasing pressure, pits developed in the source area as sediment was

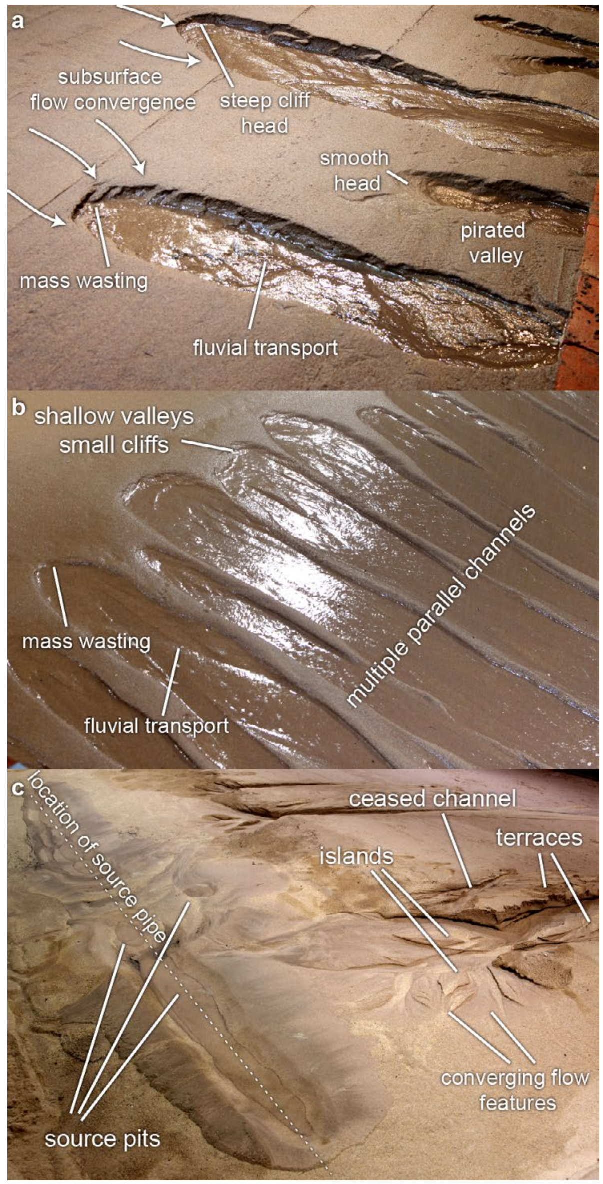

Fig. 1 Examples from the three types of experiments: a) regional groundwater source, in action; b) precipitation-fed seepage, in action; and c) pressurized groundwater (super-lithostatic), final dried morphology, subsurface source indicated. In all cases flow is from left to right.

washed out and distinct features of converging flow were observed in the source area towards the resulting channel.

Martian cases: Both short and long channels with semi-circular heads have been identified on Mars which are attributed to seeping groundwater. Mega-outflow channels on Mars have been attributed to pressurized groundwater, but smaller features such as sand volcanoes and pitted dome-features also require a super-surface water pressure to form.

Ophir Cavus has been identified as the source area for the connected Allegheny Vallis [4] (Fig. 2a). Ophir Cavus is a large pit in a chain of many similar pits. These pits have been attributed to subsidence as material sinks into a void caused by a dilating fault [4], however our experiments show that similar pits develop when sediment is removed due to super-lithostatic pressure. The relatively low elevation of this area near the higher Tharsis region makes this area a potential candidate for a pressurized aquifer. A fault could promote the break of a pressurized aquifer and at the same time act as a preferential flow path with both mechanisms focussing the outflow at the fault location. The key similarities between this area and our experiment (Fig. 1c) are the elongated pit, an area of flow convergence toward the channel and incisional terraces.

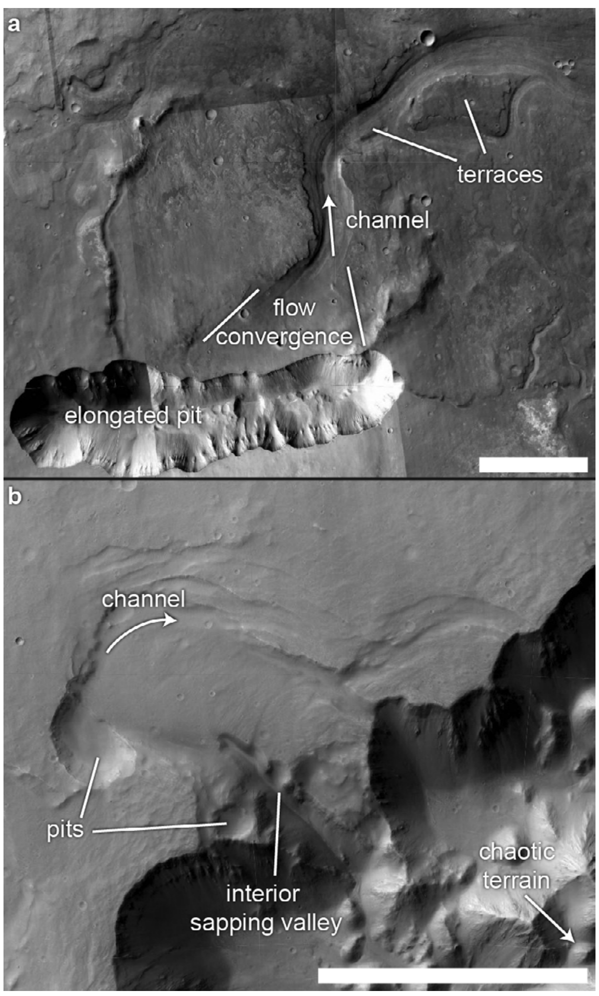

Fig. 2 Possible pressurized groundwater induced landforms on Mars. a) Ophir Cavus (large elongated pit) and Allegheny Vallis (~W55°, S9.8°). This structre is part of a regional chain of similar features. b) pits and channels NW of Aromatum Chaos (~W43.5°, S0.9°). Similar and larger pits exist in this area. The interior channel resembles the morphology observed in the sapping experiments. Scale bars are 10 km.

In several places, pitted features are observed in the vicinity of a chaotic terrain, for example North-West of Aromatum Chaos (Fig. 2b). Multiple pits and connected channels observed in this area are truncated by the chaos, and probably pre-dates chaotization. A valley with a semi-circular head and no source pit resembles the morphology observed during our sapping experiments (Fig. 1a) and likely post-dates chaotization and earlier channels.

Discussion and conclusion: The observed pitted morphologies that result from super-lithostatic pressure are likely to be observed at areas with other systems attributed to pressurized water, for example mega-outflow channels and chaotic terrains. Also, a combination of pressurized groundwater and sapping induced morphologies in the same area can be the result of a single event. As local super-surface groundwater pressure will result in sub-surface groundwater pressure at a distance and during a later stage of the event as the water pressure decreases.

Generally, we show that channels require very diverse timescales to form by the different sources of groundwater (ranging over several orders of magnitude). Correct identification of the process and water source is therefore key when assessing the formative timescales of Martian channels. Discriminative properties, that are unique for different sources of groundwater, are evident in the final valley morphology (break in slope, valley shape), regional characteristics (drainage density) and several non-channel morphologies (features in source area, preserved initial-stage deposits).

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