Pressurized groundwater systems in Lunae and Ophir Plana (Mars): insights from small-scale morphology and experiments

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INTRODUCTION

Outflow channels on Mars are related to the release of groundwater from pressurized aquifers. However, the hydrological and corresponding climate conditions remain a subject of debate and many more small features show important details.

METHODS

We investigate the detailed morphology of possible pressurized groundwater outflow systems in comparison to landscape evolution experiments.

- Experimental setup consists of a flume of 6 m long x 4 m wide and 1.20 m deep. See Marra et al., 2015.

Comparison of Martian morphology using imagery and elevation data.

EXPERIMENT RESULTS: SMALL-SCALE MORPHOLOGY

- Lobes indicate infiltration in early stage outflow
- Channelization: sustained outflow
- Holes / sand volcanoes: fissure outflow
- Cracks / bulging: high pressure outflow

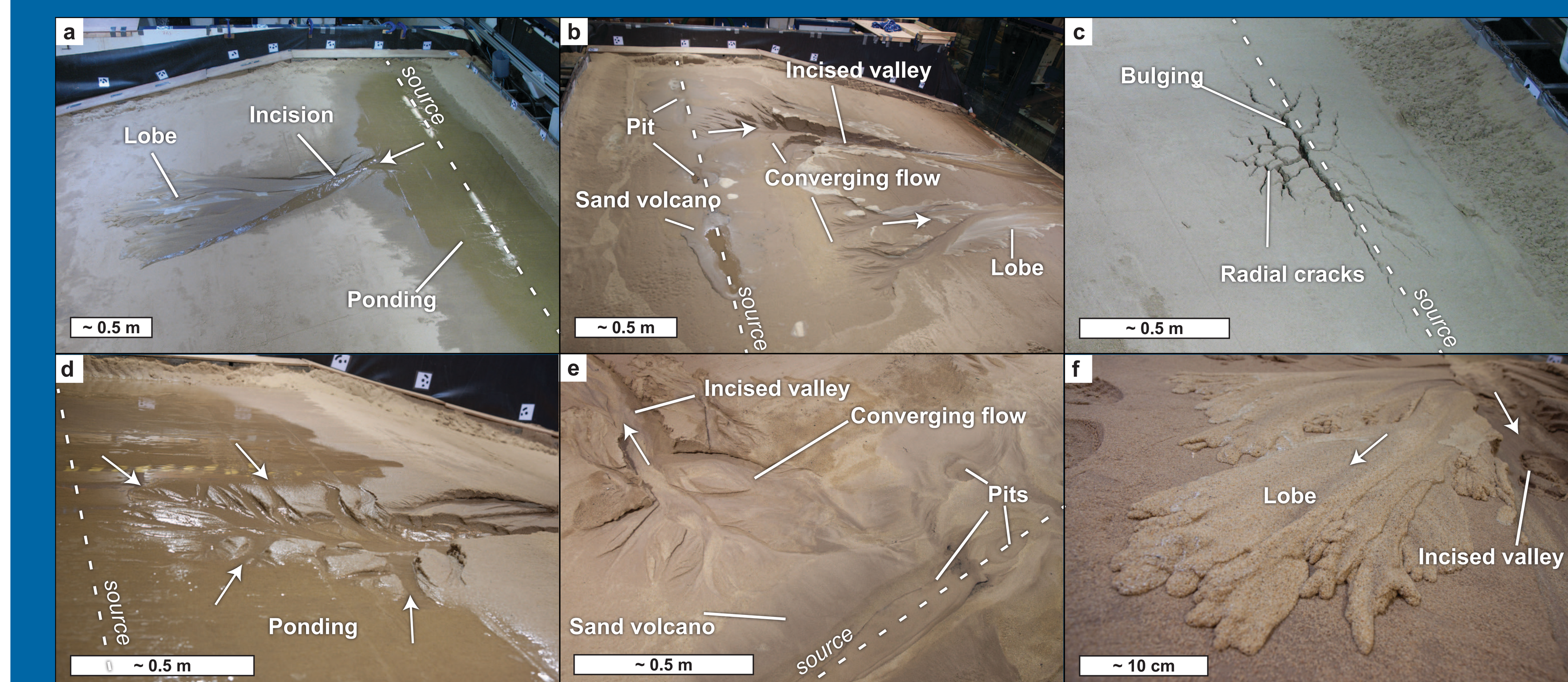

Figure 1: Groundwater outflow morphology, photographs of the scale experiments (Marra et al, 2015). (a) Outflow from seepage above the source area with downstream lobes and incising channel. (b) Outflow pits with standing water surrounded by sedimentary lobes, converging flow features and downstream valleys. (c) Radial cracks due to formation of subsurface reservoir moments before outflow. (d) Close-up of source area showing converging flow morphology and terraces in the background. (e) Close-up of outflow pit (lower right and upper right) with sedimentary lobe, incised valley and smaller lobes of initial outflow (upper middle). (f) Close-up of sieve lobe with later incised valley in the background.

GROUNDWATER OUTFLOW PROCESSES

- From a hydrostatic (unpressurized) aquifer, groundwater emerges at depressions at the surface (Figure 2a).
- Groundwater can become pressurized when confined, e.g. by the cryosphere (Figure 2b).
- Pressure could be driven by a elevation difference between infiltration source and outflow location.
- Groundwater could become pressurized by local processes like tectonism and volcanism (Figure 2c).
- Furthermore, subsurface obstructions may produce seepage at the surface (Figure 2d)

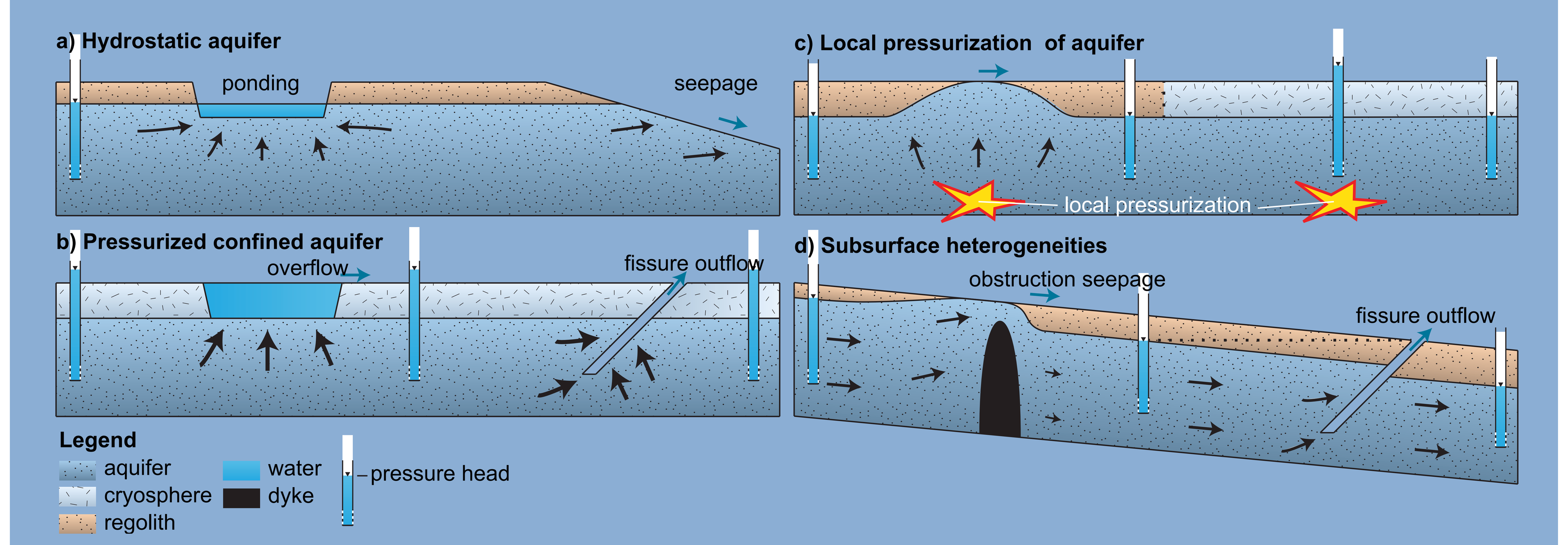

Figure 2: Hypothesized groundwater outflow mechanisms for Mars. (a) Groundwater outflow due to seepage from a hydrostatic aquifer, resulting in ponding in a depression and outflow at slopes. (b) In case of a pressurized aquifer, depressions can overflow and outflow locations are a function of subsurface properties. (c) Local pressurization and (d) subsurface heterogeneities may alter the outflow location.

MARS: OPHIR AND LUNAE PLANA - BETWEEN THE OUTFLOW CHANNELS

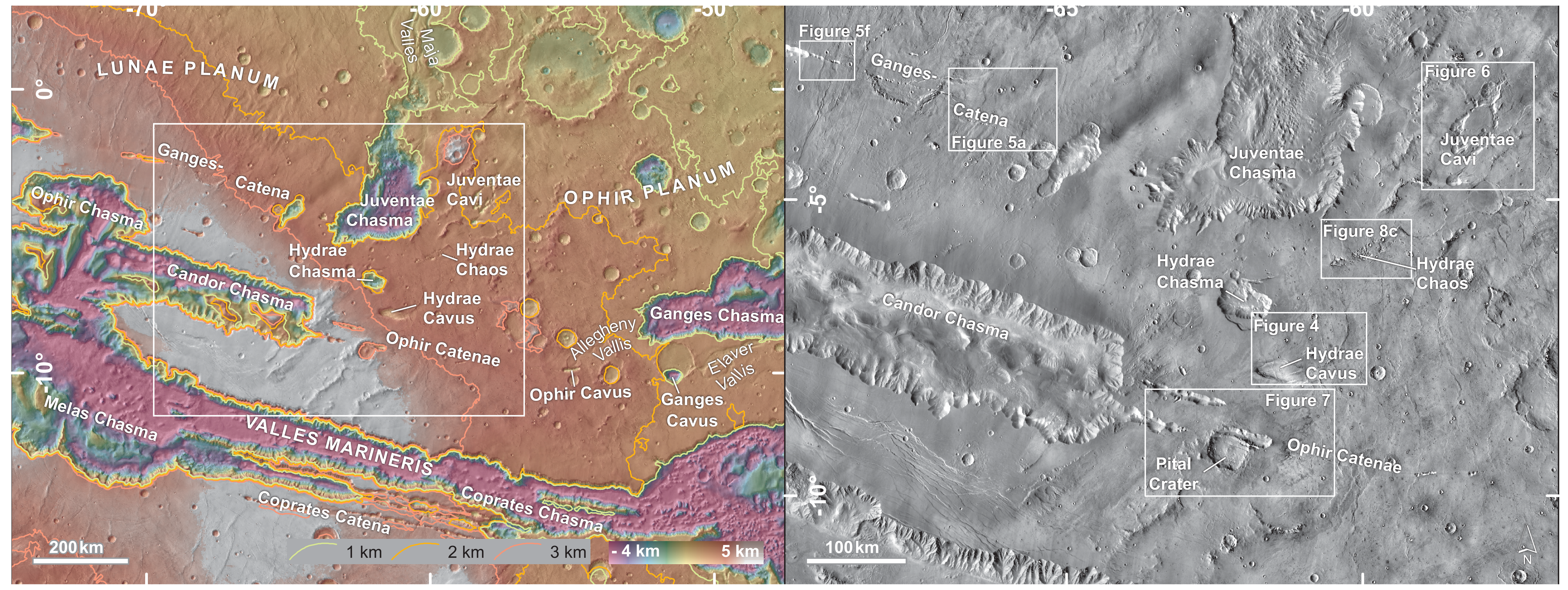

Figure 3: Overview map of study area. (a) Colored MOLA data overlain by daytime THEMIS IR mosaic with 1, 2, and 3 km MOLA-contours. (b) Daytime THEMIS IR mosaic showing extends of mapped area in Figures 4-7

HYDRAE CAVUS: LOBE FROM PIT

- Pit formed by collapse
- Lobe represent early stage outflow

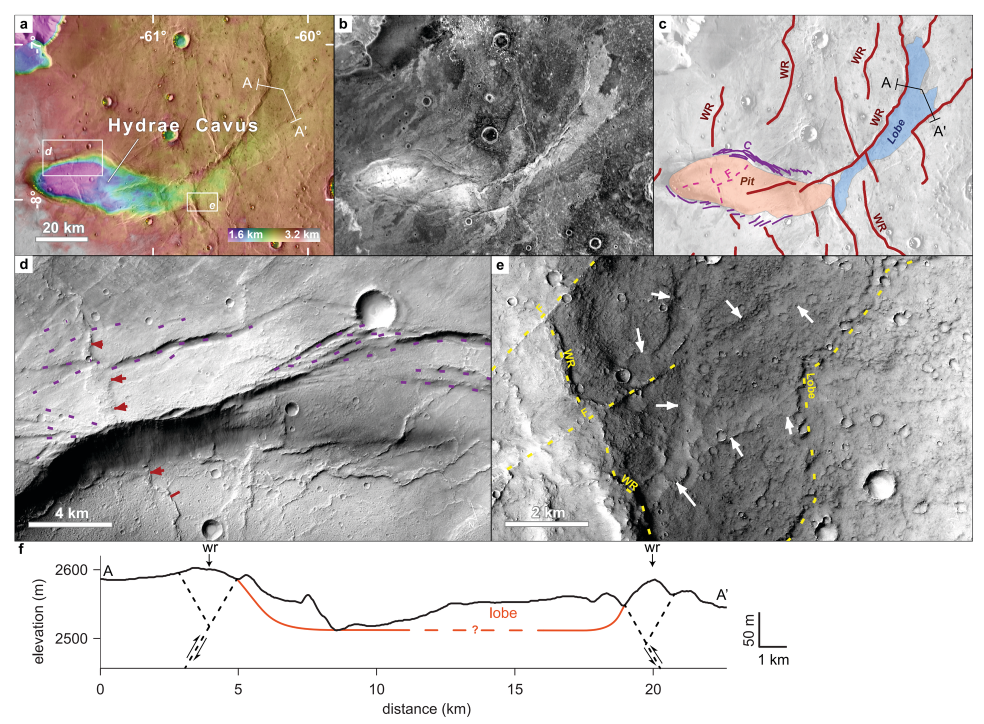

Figure 4: Morphology of Hydrae Cavus.

JUVENTAE CAVI: COLLAPSE AND OUTFLOW

- Field of pits: collapse related to Chasmata
- Chaos and outflow channel: high energy outflow

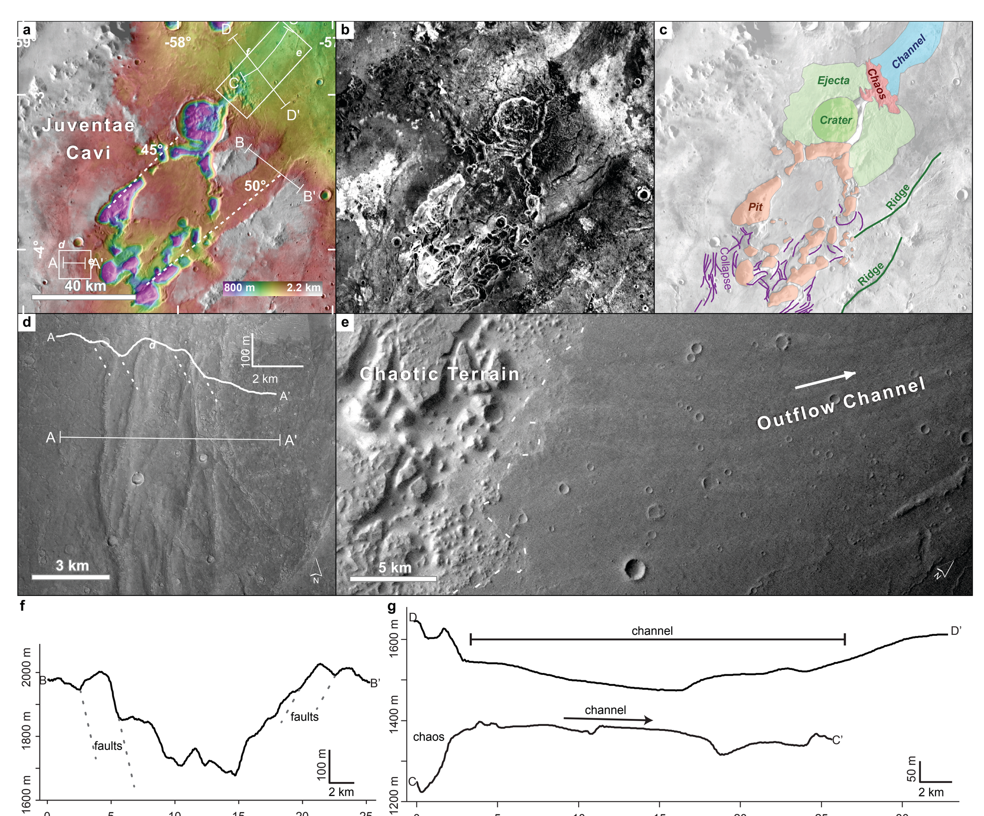

Figure 6: Juventae Cavi and associated outflow channel.

GANGES CATENA: CHANNELIZED LOBES

- Pit chain relates to tectonic structure
- Lobe represent early stage outflow
- Channalization due to sustained discharge

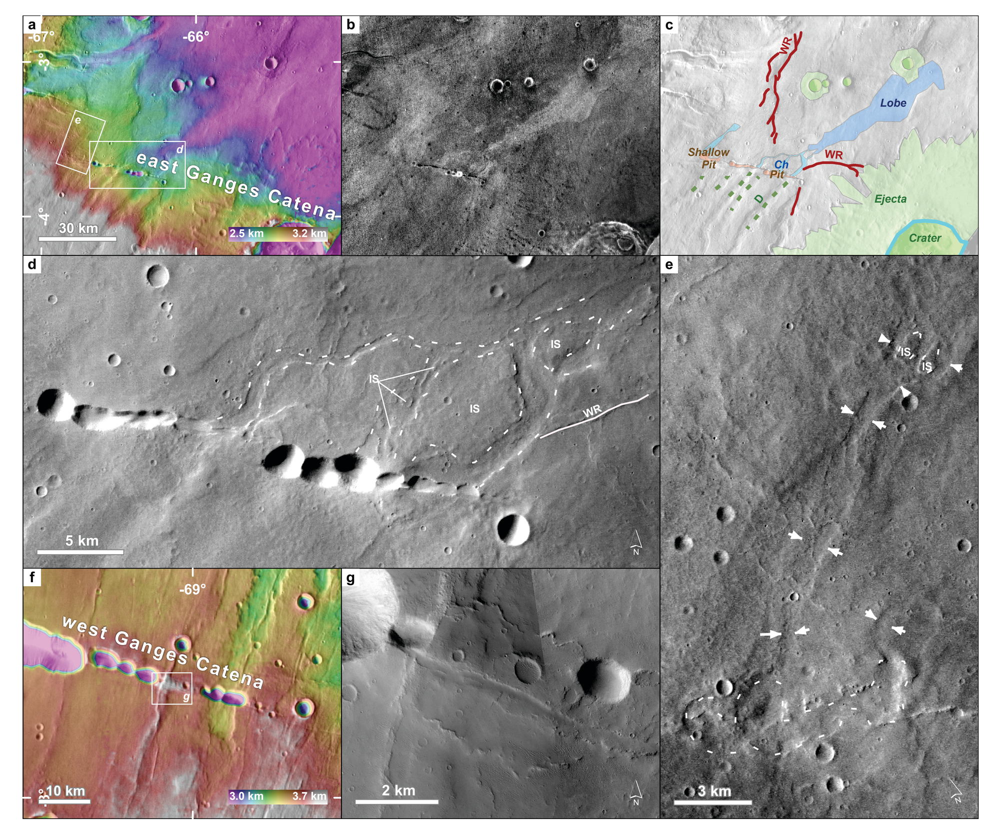

Figure 5: Outflow features from Ganges Catena.

OPHIR CATENE: LOBES FROM PIT CHAIN

- Pit chain relates to tectonic structure
- Lobe represent early stage outflow
- Lobe age: Amazonian, 1.23 Ga

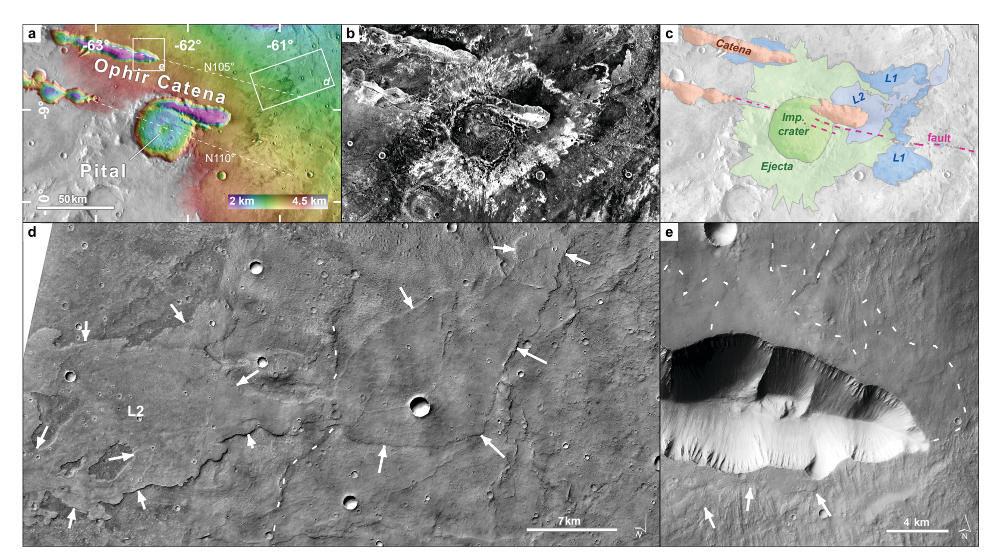

Figure 7: Lobes around Ophir Catena.

FRACTURES BY GROUNDWATER?

- Several fractures features on Mars
- Pattern similar to experiments
- Other processes (volcanic) are possible

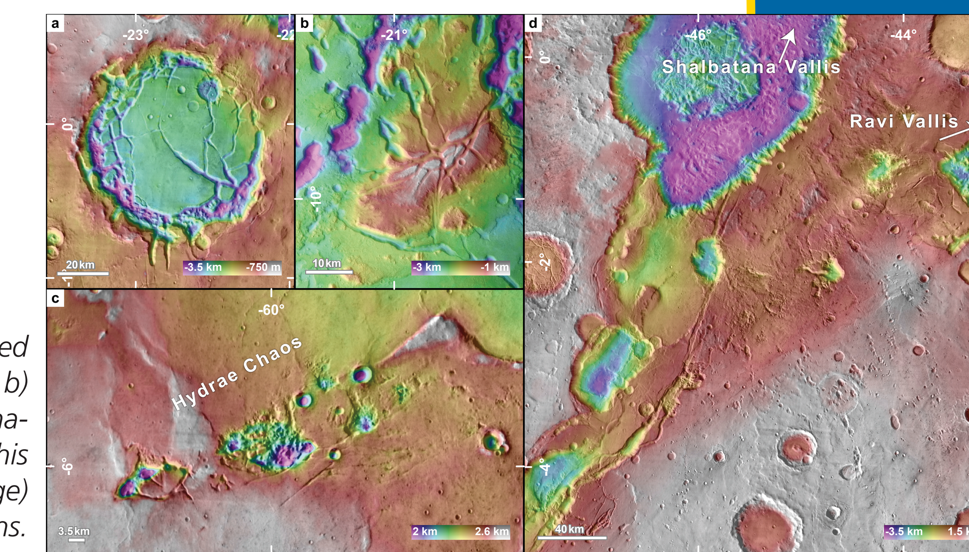

Figure 8: Several fractured features possibly related to pre-outflow processes. a) Floor-fractured crater, b) Fractured rise in Margaritifer Chaos, c) Hydrae Chaos, d) Area upstream of Ravi Vallis (Northeast of this image), and Shalbatana Vallis (North of this image) with fractures and depressions.

RECONSTRUCTION OF GROUNDWATER SYSTEM

- Strong relation between outflow locations and tectonic structure:
  - Outflow features described here and other outflow channels
  - Indicates single, closed aquifer - increasing pressure at surface with same base pressure
- Outflow activity throughout history:
  - Hesperian large outflow channels, perhaps still recharged by infiltration
  - Continued activity in Amazonian
  - Post-Valles Marineris activity: sustained pressure or re-pressurized by tectonism
- Climate: no warm conditions required for tectonic-triggered groundwater outflow

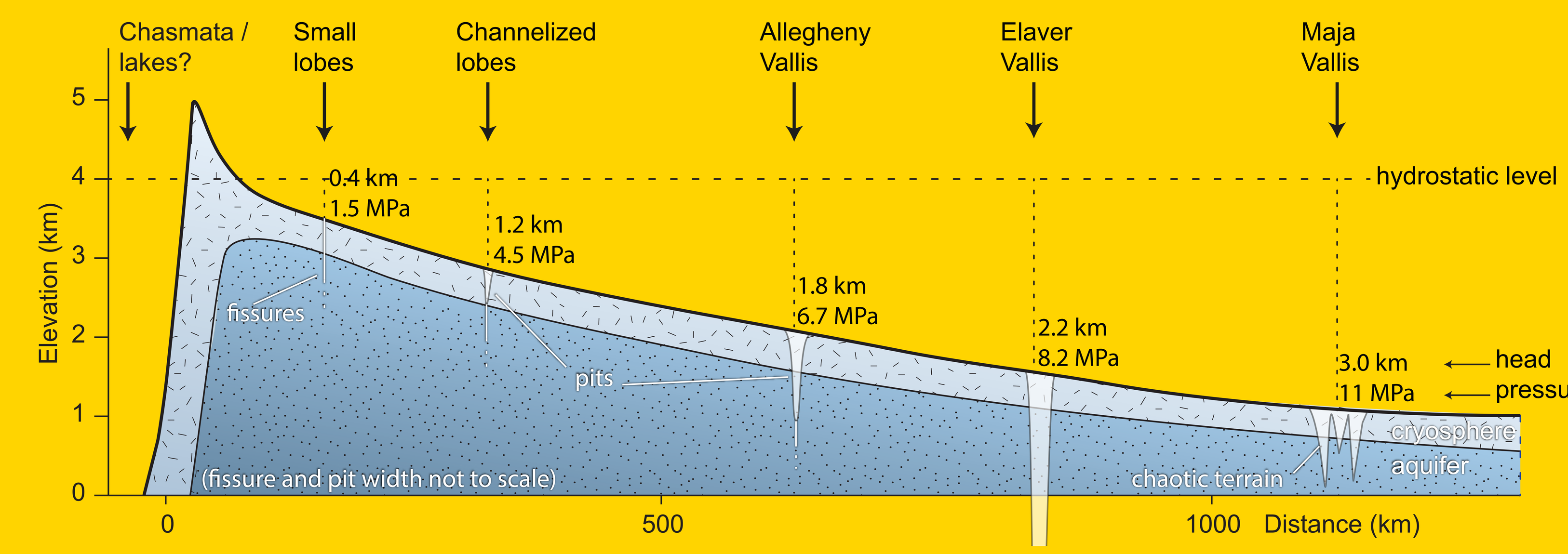

Figure 9: Schematic cross-section from Valles Marineris showing the location of different types of outflow features. Values correspond with groundwater head above surface and corresponding pressure in case of a confined aquifer with a pressure head at 4 km, which is equivalent to a source lake at that elevation.

CONCLUSIONS

- Groundwater outflow creates:
  - Lobes (early stage)
  - Incised valley (later stage)
  - Crack and pits (high pressure source)
- Small outflow features on Mars:
  - Lobes (Hydrae Cavus, Ophir Catena)
  - Channelized lobes (Ganges Catena)
  - Small outflow channel (Juventae Cavi)
  - Fractured features without outflow

IMPLICATIONS

- Trend in outflow magnitude in Ophir and Lunae Plana consistent with pressurized outflow from single aquifer.
- Outflow triggered by tectonics.
- Sustained presence of groundwater for large part of Martian history.
- Climate does not require an optimum.

Nomenclature used on this poster is approved by the IAU (Juventae Cavi, Hydrae Cavus, Pital Crater and Hydrae Chaos).

Used data Mola gridded elevation data (Zuber et al., 1992), THEMIS day and night IR mosaic (Christensen et al., 2004; Fergason et al., 2013), CTX imagery (Malin et al., 2007), MOC imagery (Malin et al., 1992), HiRISE imagery (McEwen et al., 2007) and HRSC imagery and DEMs (Jaumann et al., 2007; Scholten et al., 2005).

References **Christensen et al, 2004**, Space Sci. Rev. 110, 85, doi:10.1023/B:SPAC.0000021008.16305.94. **Fergason et al, 2013.** Lunar Planet. Sci. Conf. XLIV, abstract 1642. **Jaumann et al, 2007**, Planet. Space Sci. 55, 928, doi:10.1016/j.pss.2006.12.003. **Malin et al, 1992,** J. Geophys. Res. 97, 7699, doi:10.1029/92JE00340. **Malin et al, 2007**, J. Geophys. Res. 112, E05S04, doi:10.1029/2006JE002808. **Marra et al, 2015**, J. Geophys. Res. Planets 119, 2668, doi:10.1002/2014JE004701. **McEwen et al, 2007**, J. Geophys. Res. 112, E05S02, doi:10.1029/2005JE002605. **Scholten et al, 2005**, Photogramm. Eng. Remote Sens. 71, 1143, doi:10.14358/PERS.71.10.1143. **Zuber et al, 1992**, J. Geophys. Res. 97, 7781, doi:10.1029/92JE00341.