FORMATION OF LAKES IN THE ANCESTRAL VALLES MARINERIS IN THE EPOCH OF ALLEGHENY VALLIS, MARS. Neil M. Coleman, U.S. NRC, Washington, DC (nmcoleman@comcast.net)

Introduction: The discovery of outflow channels on a high Martian plateau reveals important details about hydrologic conditions during late Hesperian time. Allegheny Vallis and Walla Walla Vallis (IAU prov. name) discharged from pits associated with Ophir Catenae (IAU prov. name) [1,2]. The channel sources have elevations of >2500 m, too high to be explained by distant polar recharge and discharge from a globally connected aquifer system [3]. The Tharsis plateau stands much higher (>5000 m) than the channel source areas. Tharsis was a likely source region for Hesperian groundwater recharge [1] because of its high elevation, extensive volcanic activity, and because plausible recharge areas have not been identified near the channel source areas.

The floors of the deep Valles Marineris (VM) canyons (Fig. 1) would have been weak points because of their minimal overburden and low elevation with respect to the elevated potentiometric surface. At these locations hydraulic overpressures could have readily been relieved. If the ancestral VM canyons were deep enough, rising hydraulic pressures of the cryospherically-confined groundwater system coupled with tectonic stimuli would have created conditions favorable for groundwater breakouts and the growth of deep, ice-covered lakes.

Analysis: We cannot know the size and shape of the VM canyons when Allegheny and Walla Walla Valles formed. However, it is reasonable to conclude that the ancestral canyons would have been narrower, smaller in volume, and more isolated, analogous to present-day Hebes Chasma. The following analysis is based on four assumptions: (**a**) the 2500 m outflow elevation for Allegheny Vallis represented a regional potentiometric surface in Ophir Planum; (**b**) the deepest parts of the proto-canyons were as deep as the deepest parts of the modern canyons [starting point for calculations - results on p. 2 show this is not required]; (**c**) faults and fracture networks provided hydraulic continuity along canyon margins from the base of the cryosphere to the full depth of the ancestral canyons; and (**d**) the nominal cryosphere thickness at low latitudes was ~1 km, consistent with an estimate for the vicinity of Ravi Vallis [4]. We now estimate the buildup of hydraulic pressure beneath the canyon floors in response to the rising potentiometric level of the regional groundwater system.

Given initially static hydraulic conditions, groundwater would break through the canyon floor when the hydraulic pressure in the underlying confined aquifer exceeds the sum of the overburden pressure (10 MPa) and the cryosphere strength:

$$\rho_w g h_w > \rho_r g h_r + \sigma_r \qquad (1)$$

where ρ_w = groundwater density (1000 kg·m^{-3}), g = gravitational acceleration on Mars (3.7 m·s^{-2}), h_w = confined groundwater head expressed as a fluid column height (m), ρ_r = mean density of the ice-saturated, fractured basaltic cryosphere (2700 kg·m^{-3}), h_r = cryosphere thickness (1000 m), and σ_r = the strength (pascals) of a fractured basaltic rock mass. The height of the fluid column is the difference between the outflow elevation at Allegheny Vallis (2.5 km) and the lowest elevation of a canyon floor, plus 1 km to represent the cryosphere thickness beneath the canyon floor.

I rearrange Eq. 1 to solve for the maximum strength ($\sigma_{r\,Max}$) of the cryosphere that could be exceeded by hydraulic overpressure from beneath canyon floors (Eq. 2). Results are given in Table 1 for seven of the chasmata shown in Fig. 2.

$$\sigma_{rMax}(Pa) < \rho_w g h_w (Pa) - 10^7 (Pa) \qquad (2)$$

Table 1. Estimated maximum strength of a basaltic rock mass that must be exceeded to rupture the 1-km-thick cryosphere beneath the canyon floors.

Canyon	Min. elev. of modern canyon floor (km)	Hydraulic pressure beneath floor (MPa)	Maximum rock mass strength $\sigma_{r\,Max}$ (MPa)
Candor	−5.0	32	22
Coprates	−5.0	32	22
Ganges	−4.2	28	18
Hebes	−4.4	29	19
Juventae	−4.4	29	19
Melas	−5.0	32	22
Ophir	−4.8	31	21

Discussion: Intact basalt has great strength, with an unconfined compressive strength of 266 ± 98 MPa, cohesive strength of 66 MPa, and a tensile strength of −14 ± 3 MPa [5]. However, at large spatial scales the strength of a basaltic rock mass is not that of intact basalt; rather, it is a lesser value controlled by the strength of the network of faults, joints, and fractures within the basalt. Compared to the strengths of small-scale intact basalt, values of tensile and cohesive strength for a large-scale basaltic rock mass are 1–2 orders of magnitude lower [5].

Schultz [5,6] has estimated the cohesive strength (0.6 to 6 MPa) and tensile strength (−0.1 to −2.5 MPa) of a basaltic rock mass. I increased these strengths by 50% to include the effects of rock confining pressure and the presence of ice in fractures, and then compared them to the strength values calculated in Table 1. Hydraulic overpressures beneath canyon floors could have exceeded the strength of a basaltic rock mass by a factor ≥2. This simple analysis shows that groundwater breakouts would have been expected in the ancestral VM canyons if they were as deep as they are today, *or even if they were several km shallower.* The magnitude of the overpressures suggests that groundwater pressure alone could have initiated the fluid outbreaks. Nonetheless, tectonic activity associated with canyon growth would have helped to trigger groundwater outbreaks at lower fluid pressures.

West of Allegheny Vallis the potentiometric surface may have risen to elevations >2500 m in areas closer to hypothesized Tharsis recharge zones. Thus, even larger confined fluid pressures than are calculated here may have been possible. After deep, ice-covered lakes had formed in the canyons, confined hydraulic pressures would then have gradually increased in downgradient areas, leading to additional groundwater breakouts like those that formed Ravi and Shalbatana Valles [4].

Conclusions: The discharge points for elevated Martian channels, like Allegheny Vallis and Walla Walla Vallis, provide paleo-indicators of climax groundwater levels. The formation of lakes in the ancestral VM would have been likely, perhaps inevitable, as a consequence of the rising potentiometric levels of groundwater systems. Conditions were so favorable for groundwater breakouts that ice-covered lakes probably already existed in the canyons when these outflow channels formed. These channels lie in the heart of the VM, virtually surrounded by canyons. The high groundwater levels may simply have reflected quasi-equilibrium with lake surfaces in those canyons.

References: [1] Coleman, N., Dinwiddie, C., and Casteel, K. (2003), *6th Intl. Conf. on Mars*, Abstract #3071. [2] Dinwiddie, C., Coleman, N. and Necsoiu, M. (2004), *LPSC XXXV*, Abstract #1316. [3] Carr, M. (2002), *JGR* 107, 10.1029/2002JE001845. [4] Coleman, N. (2005), *JGR* 110, 10.1029/2005JE002419. [5] Schultz, R. (1995), *Rock Mech. and Rock Eng.*, 28, p. 1–15. [6] Schultz, R. (1993) *LPSC XXIV*, Abst. #1263.

[This article was prepared by an NRC employee on his own time apart from regular duties.]

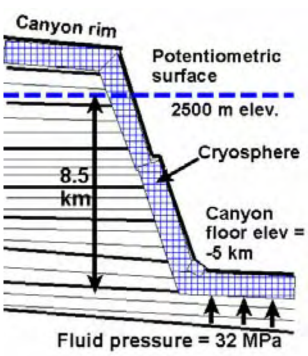

Figure 1. Schematic profile across Candor Chasma (no lake yet exists).

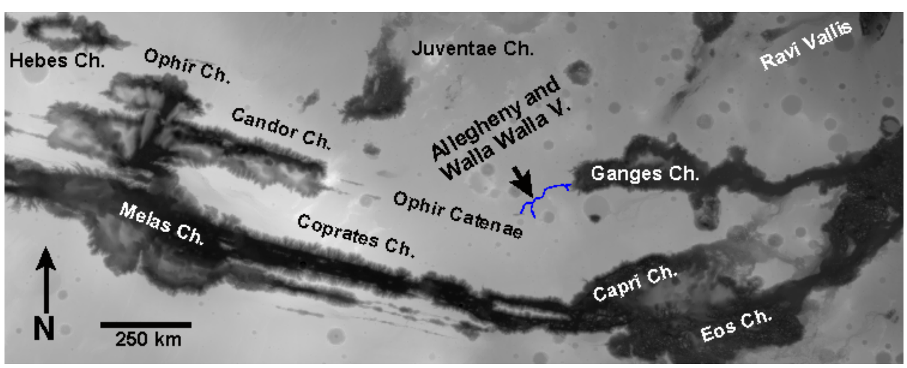

Figure 2. Regional map showing the Valles Marineris canyon system and the locations of Allegheny Vallis and Walla Walla Vallis.