FORMATION OF ARES VALLIS BY EFFUSIONS OF LOW-VISCOSITY LAVA AT IANI, ARAM, MARGARITIFER, AND HYDASPIS CHAOS. D.W. Leverington[1], [1]Department of Geosciences, Texas Tech University, Lubbock, TX 79409.

Introduction: Ares Vallis is one of the largest outflow systems on Mars, extending northward more than 1500 km from the highlands of Margaritifer Terra to the Chryse and Acidalia basins [1]. This system mainly developed as a result of voluminous effusions from the subsurface that took place during the Hesperian and Amazonian at sites associated with Iani Chaos, Aram Chaos, Margaritifer Chaos, and Hydaspis Chaos [2-4]. Additional possible sources have previously been inferred for the Ares Vallis system as far south as the Argyre impact basin [5].

Though Ares Vallis is widely interpreted as a product of catastrophic outbursts of water from cryosphere-confined aquifers [2,4-15], its attributes do not support aqueous origins of any kind. Instead, as is the case at hundreds of ancient channels of the inner solar system, the basic nature of Ares Vallis is fully aligned with dry volcanic origins.

Past Aqueous Interpretations of Ares Vallis: The channels of Ares Vallis are variously characterized by the presence of streamlined erosional residuals, longitudinal grooves, inner channels, hanging valleys, and cataracts [2,4,6,8,13,16,17]. Such features are typical of terrestrial floodways carved by catastrophic floods, and the Ares Vallis system has correspondingly been interpreted as a product of enormous aqueous outbursts from the subsurface [2,4-15]. The terminal basins are widely assumed to have hosted lakes or oceans [5,18].

Previous estimates of maximum discharge rates at Ares Vallis range between ~10^6 m^3/s and 5 x 10^9 m^3/s, involving water depths of ~20 to 100 m [2,6,19-21]. Modeling results have suggested the occurrence of at least ~160 to 660 separate aqueous flood events here [12]. More generally, individual outflow systems on Mars are believed to have required up to thousands of flood events for their development [11,12].

A Volcanic Interpretation of Ares Vallis: The basic attributes of Ares Vallis are not consistent with development by aqueous processes. Though fluvial, glacial, lacustrine, and oceanic sedimentary deposits continue to be proposed for component channels and basins [2,4,8,22-24], clear examples of such features have not been identified at this or any other Martian outflow system [25-32]. As is the case at all other outflow channels, there is no evidence for extensive aqueous alteration of Ares Vallis, and the system is instead widely characterized by relatively pristine mineralogy [33-37]. The preservation at Ares Vallis of large volumes of olivine-rich materials, including those of the Noachian units that form the inner walls of component channels [36,38-42], is clearly inconsistent with the purported occurrence of dozens to thousands of aqueous outburst floods, and with the long-term existence of highly porous and permeable aquifers later exposed by channel incision [32].

Though alternative interpretations exist [23], evidence is missing for: 1) the pervasive hydrous alteration of geological materials exposed within the Chryse impact basin and other northern basins hypothesized to have held large Martian water bodies; and 2) the thick sequences of evaporite minerals expected of the former sites of terminal lakes and oceans [33,43,44]. Consistent with this orbital view, the mineralogy of the Pathfinder landing site, located at the mouth of Ares Vallis, is known to have been little altered by water [20,45-47].

Beyond major inconsistencies between the expected and actual mineralogy of the Ares Vallis system, the catastrophic release of groundwater pressurized by the downward propagation of a freezing front [5,9,15] is yet to be validated as a realistic mechanism for development of the Martian outflow channels [48]. Indeed, though alternative perspectives exist [11,49], recent work suggests that expected megaregolith porosities are insufficient for the formation of outflow channels without the associated generation of extraordinarily large water chambers in the subsurface [50]. In contrast, volcanic processes can readily account for the formation and basic attributes of the Ares Vallis outflow system. Volcanic processes resulted in the development of hundreds of ancient volcanic channels on rocky bodies including the Moon, Venus, Mercury, and Earth [51-57], and certainly represent the most realistic mechanisms by which the Martian outflow channels could have formed [29,30,32,58]. The channels and basins of Ares Vallis are extensively associated with volcanic features [39-42],

Constraints on the Volcanic Effusions that Incised Ares Vallis: Quantitative models are available for constraining the most basic flow parameters of lavas. This study utilized flow and incision relations [59-63] explored in depth in numerous earlier studies [64-67]. Flows were assumed to have had initial viscosities of 1 Pa s and temperatures of 1350°C.

For a channel width of 25 km, which is typical of much of the main Ares Vallis system north of Iani Chaos, discharge rates are estimated for 50-m-deep and 100-m-deep flows to respectively be ~31 x 10^6 m^3/s to 97 x 10^6 m^3/s on slopes of only 0.2°. Corresponding rates of mechanical incision are estimated to be ~4 m/day and 12 m/day, respectively. Thermal incision for 50-m-deep and 100-m-deep flows on slopes of 0.2° is estimated to be more modest at ~1.9 m/day and 2.3 m/day, respectively.

Total effused lava volumes can be crudely estimated for large volcanic channel systems on the basis of parameters such as channel widths, incision depths, estimated discharge rates, and estimated incision rates [32,62,63]. A total effused lava volume of ~1.35 x 10^6 km^3 is predicted for lavas with depths of either 50 m or 100 m on the basis of: 1) predicted discharge rates; 2) assumed incision depths below adjacent uplands of 1000 m; and 3) conservative overall incision rates of 2 m/day and 6 m/day (roughly half those predicted for mechanical incision alone). The Ares Vallis system is known to have formed over an extended period of geological time, and thus its development must have involved multiple individual eruptive episodes separated by long periods of little to no volcanic activity.

Based on thermal principals that conservatively ignore the independent action of mechanical processes, the minimum volume of erupted lava required for removal of a particular volume of substrate can be crudely estimated [62,63,68-70]. For formation of the main Ares Vallis channel and the four related regions of chaos, a total minimum erupted lava volume of ~1.6 x 10^6 km^3 to 5.8 x 10^6 km^3 is estimated. A still greater minimum lava volume would be required if the southern reaches between Margaritifer Chaos and the Argyre impact basin were also considered.

References: [1] Carr M.H. (1996) *Water on Mars*. [2] Komatsu G. and Baker V.R. (1997) *JGR*, 102, 4151-4160. [3] Rotto S. and Tanaka K.L. (1995) USGS Map I-2441. [4] Warner N. et al. (2009) *EPSL*, 288, 58-69. [5] Clifford S.M. and Parker T.J. (2001) *Icarus*, 154, 40-79. [6] Masursky H. et al. (1977) *JGR*, 82, 4016-4038. [7] Golombek M.P. et al. (1999) *JGR*, 104, 8523-8553. [8] Pacifici A. et al. (2009) *Icarus*, 202, 60-77. [9] Carr M.H. (1979) *JGR*, 84, 2995-3007. [10] Glotch T.D. and Christensen P.R. (2005) *JGR*, 110, E09006. [11] Andrews-Hanna J.C. and Phillips R.J. (2007) *JGR*, 112, E08001. [12] Harrison K.P. and Grimm R.E. (2008) *JGR*, 113, E02002. [13] Warner N.H. et al. (2010) *Geology*, 38, 791-794. [14] Warner N.H. et al. (2011) *JGR*, 116, E06003. [15] Head J. et al. (2018) *49th LPSC*, #2194. [16] Baker V.R. and Kochel R.C. (1978) *9th LPSC*, 3181-3192. [17] Mars Channel Working Group (1983) *GSAB*, 94, 1035-1054. [18] Parker T.J. et al. (1993) *JGR*, 98, 11,061-11,078. [19] Carr, M.H. (1979) *JGR*, 84, 2995-3007. [20] Smith, P.H. et al. (1997) *Science*, 278, 1758-1764. [21] Smith, D.E. et al. (1998) *Science*, 279, 1686-1692. [22] Rodriguez J.A. et al. (2014) *Icarus*, 242, 202-210. [23] Salvatore M.R. and Christensen P.R. (2014) *Geology*, 42, 423-426. [24] Salvatore M.R. and Christensen P.R. (2014) *JGR*, 119, 2437-2456. [25] Greeley R. et al. (1977) *JGR*, 82, 4093-4109. [26] Ghatan G.J. and Zimbelman J.R. (2006) *Icarus*, 185, 171-196. [27] Carling P.A. et al. (2009) in *Megaflooding on Earth and Mars*, 33-49. [28] Hobbs et al. (2011) *Icarus*, 214, 258-264. [29] Leone G. (2014) *JVGR*, 277, 1-8. [30] Leone G. (2017) *JVGR*, 337, 62-80. [31] Rice J.W. and Baker V.R. (2015) *46th LPSC*, #2979. [32] Leverington D.W. (2011) *Geomorphology*, 132, 51-75. [33] Bibring J.-P. et al. (2006) *Science*, 312, 400-404. [34] Mangold N. et al. (2008) *PSS*, 56, 1030-1042. [35] Carter J. et al. (2013) *JGR*, 118, 831-858. [36] Wilson J.H. and Mustard J.F. (2013) *JGR*, 118, 916-929. [37] Ehlmann B.L. (2014) *8th Int. Conf. on Mars*, #1245. [38] Rogers A.D. et al. (2005) *JGR*, 110, E05010. [39] Salvatore M.R. et al. (2010) *JGR*, 115, E07005. [40] Salvatore M.R. et al. (2016) *JGR*, 121, 273-295. [41] Ody A. et al. (2011) *42nd LPSC*, #2459. [42] Ody A. et al. (2012) *43rd LPSC*, #2430. [43] Christensen P.R. et al. (2008) in *The Martian Surface*, 195-220. [44] Pan L. et al. (2017) *JGR*, 122, 1824-1854. [45] Golombek M.P. and Bridges N.T. (2000) *JGR*, 105, 1841-1853. [46] Foley C.N. et al. (2003) *JGR*, 108, E12, 8096. [47] Farrand W.H. et al. (2008) in *The Martian Surface*, 265-280. [48] Hanna J.C. and Phillips R.J. (2005) *JGR*, 110, E01004. [49] Manga M. (2004) *GRL*, 31, L027002. [50] Marra W.A. et al. (2014) *JGR*, 119, 2668-2693. [51] Wilhelms D. (1987) *Geologic History of the Moon*, USGS Prof. Paper 1348. [52] Baker V.R. et al. (1992) *JGR*, 97, 13,421-13,444. [53] Komatsu G. et al. (1993) *Icarus*, 102, 1-25. [54] Byrne P.K. et al. (2013) *JGR*, 118, 1303-1322. [55] Hurwitz D.M. et al. (2013) *PSS*, 79-80, 1-38. [56] Williams D.A. et al. (2001) *JVGR*, 110, 27-55. [57] Williams D.A. et al. (2011) *Miner. Dep.*, 8, 943-958. [58] Baumgartner R.J. et al. (2017) *Icarus*, 296, 257-274. [59] Hurwitz D.M. et al. (2010) *Icarus*, 210, 626-634. [60] Hurwitz D.M. et al. (2012) *JGR*, 117, E00H14. [61] Leverington D.W. (2014) *Precamb. Res.*, 246, 226-239. [62] Hopper J.P. and Leverington D.W. (2014) *Geomorphology*, 207, 96-113. [63] Leverington D.W. (2018) *Icarus*, 301, 37-57. [64] Hulme G. (1973) *Mod. Geol.*, 4, 107-117. [65] Williams D.A. et al. (1998) *JGR*, 103, 27,533-27,549. [66] Williams D.A. et al. (2000) *JGR*, 105, 20,189-20,205. [67] Keszthelyi L. and Self S. (1998) *JGR*, 103, 27,447-27,464. [68] Cataldo V. et al. (2015) *JGR*, 120, 1800-1819. [69] Dundas C.M. and Keszthelyi L.P. (2014) *JVGR*, 282, 92-102. [70] Leverington D.W. (2019) *PSS*, doi:10.1016/j.pss.2019.01.002.