RECONCILING CHANNEL FORMATION PROCESSES WITH THE NATURE OF ELEVATED HESPERIAN OUTFLOW SYSTEMS AT VALLES MARINERIS. D. W. Leverington, Dept. of Geosciences, Texas Tech University, 125 Science Building, Lubbock, TX, 79409-1053.

Introduction: Most outflow systems in the southern highlands of Mars head at elevations below the 1500 m level considered to be the uppermost level compatible with aquifer recharge beneath the south polar cap [1-3], and these lower systems are widely interpreted as the products of such recharge [e.g., 2]. However, some outflow systems head at greater elevations, and have been alternatively interpreted as the products of the melting of glacial or ground ice at high elevations [2,4]. Many elevated outflow channels on Mars are located on the flanks of volcanic rises [2], but notable channels in the southern highlands include three systems located at Ophir Planum [2,5,6]. The existence of these three outflow systems (Allegheny Vallis, Walla Walla Vallis, and Elaver Vallis) has been previously attributed to a sequence of events involving catastrophic melt of Tharsis glaciers, flooding of deep troughs of Valles Marineris, recharge of adjacent aquifers, and sudden outflow of groundwater to the surface [6]. However, the problematic nature of aspects of these hypothesized events, combined with the consistency between channel properties and those expected of volcanic systems, suggests that volcanic origins should be considered for these and other elevated outflow systems.

The Outflow Systems at Ophir Planum: Allegheny Vallis, Walla Walla Vallis, and Elaver Vallis are Hesperian outflow systems located at Ophir Planum [6]. Ophir Planum is a region dominated by Hesperian ridged plains that are contiguous with, and generally comparable in nature to, the units of Lunae Planum to the northwest. The three outflow systems of Ophir Planum head at elevations above the 1500 m limit for south-pole recharge [2,5,6]. The Allegheny and Walla Walla systems head at elevations ~1000 m above this threshold [6] and extend across uplands of Noachian to Hesperian age. The Allegheny Vallis system heads at an elongated depression (Ophir Cavus: ~37 km long, ~10 km wide, with a floor up to ~1700 m below its rim), has typical channel widths of ~3 to 5 km, and runs almost 200 km to the western rim of Ganges Chasma. The smaller Walla Walla Vallis system has typical widths of ~0.8 km and extends ~45 km from its head at a row of rimless pit craters northward across Wallula crater (~12 km diameter) to the Allegheny Vallis system, with channels terminating at and appearing to be truncated by the larger Allegheny channels [6]. The Elaver Vallis system has typical widths of ~4 to 35 km and extends ~150 km across Hesperian uplands to Ganges Chasma from its head at a 42 x 33 km depression within Morella crater (Ganges Cavus, >4.5 km deep). A high-flow mark of 1780 m is inferred for overflow prior to the breach of the rim of Morella crater [6].

The outflow systems at Ophir Planum consist of relatively simple channels that in places complexly anastamose about apparent erosional residuals. Complex reaches are most notable at Elaver Vallis, a system also characterized along parts of its floor by patches of chaotic terrain. The floors of the Ophir Planum channels are crossed in places by parallel sets of longitudinal ridges, an attribute typical of outflow systems on Mars [e.g., 7].

Difficulties Related to Hypothesized Aqueous Mechanisms of Channel Formation: Aquifer recharge at Ophir Planum has previously been inferred to have taken place through infiltration from lakes that once filled the canyons of Valles Marineris, with these lakes hypothesized to have formed as a result of the catastrophic melting of Hesperian-aged ice sheets at Tharsis [6]. These ice sheets are interpreted to have been larger versions of the glaciers inferred by some workers to have existed at the three main Tharsis volcanoes [e.g., 8,9], and are hypothesized to have been partly melted by subglacial eruption of flood basalts. Meltwaters are hypothesized to have flowed eastward from central Tharsis to the Noctis Labyrinthus region, or directly to Valles Marineris itself, ultimately recharging regional aquifers at Valles Marineris and forcing aquifer outbursts along pre-existing tectonic fractures extending eastward from Candor Chasma [6].

The above sequence of events is problematic on the basis of the following: ***(a)*** although there is abundant evidence for the past action of a range of volcanic processes across the Tharsis region, there is no geomorphic record supportive of the hypothesized catastrophic flow of Hesperian meltwaters from Tharsis to Noctis Labyrinthus or Valles Marineris; ***(b)*** the peripheries of Noctis Labyrinthus and Valles Marineris are marked by elevated plateaus that should have inhibited the funneling of glacial meltwaters from Tharsis into Valles Marineris; ***(c)*** the low elevations of the bounding uplands of eastern Valles Marineris should have prohibited accumulation of high-elevation lakes in the canyons to the west; ***(d)*** as noted in [6], hypothesized deep infiltration of glacial floodwaters at Tharsis and Valles Marineris is inconsistent with the existence of the ice-rich cryospheric seal of hemispheric or global extent presumed by many workers to have been necessary for formation of lower-elevation outflow systems on Mars; ***(e)*** the apparently pristine nature of olivine-rich basalt units at Ganges Chasma [e.g., 10,11] is potentially incompatible with significant aqueous weathering [10] and may be difficult to reconcile with the past existence of canyon-filling water bodies or long-lived near-surface aquifers at eastern Valles Marineris; ***(f)*** it is unclear that hypothesized Tharsis floodwaters would have had sufficient thermal energy to flow several thousand kilometers across the Martian surface, to pool at Valles Marineris, and to thaw through a thick cryospheric seal at both Valles Marineris and at the heads of the Ganges Chasma systems; ***(g)*** on the basis of thermal principles, thaw of kilometers-thick ice-rich cryospheric seals could not have taken place as catastrophic events; ***(h)*** continued investigation into proposed aqueous mechanisms of outflow-channel formation on Mars has served to highlight their many associated limitations, and the volumes and discharge rates of hypothesized aqueous floods remain inconsistent with expected regional-scale permeabilities [e.g., 12]; ***(i)*** hypotheses for formation of large outflow systems through catastrophic outbursts from the subsurface remain weakened by the absence of satisfactory analog processes.

Possible Analogs to the Ophir Planum Channels: The difficulties associated with hypothesized aqueous mechanisms for outflow-channel development at Ophir Planum suggest that promising alternative processes should be investigated. Aeolian, glacial, and CO_2-based processes have been previously evaluated and rejected for the Ophir Planum channels [6], but volcanism has not yet been considered as a central mechanism for formation of these systems. Significantly, a volcanic origin for the outflow systems at Ophir Planum is in accord with numerous basic considerations, including the volcanotectonic nature of the Valles Marineris region, the likely development of much of Ophir Planum itself through extrusive igneous processes, the consistency between the properties of local channel deposits and those expected of volcanic materials, and the striking correspondence between channel characteristics and those of apparent volcanic systems on the Moon and Venus.

The Allegheny and Elaver systems are of sufficient size to be well represented in available gridded topographic databases. If these systems formed volcanically, rudimentary assumptions [13] and channel-volume calculations imply erupted lava volumes of at least 6.4 x 10^3 km^3 for Allegheny Vallis and 6.2 x 10^4 km^3 for Elaver Vallis. The lesser of these lava volumes is of the same order of magnitude as that estimated for a small lunar channel at Marius Hills [14], and both values fall within the range believed to be typical of Martian flood lavas [15].

Potential Implications of a Volcanic Origin for the Ophir Planum Channels: Elevated Hesperian outflow systems on Mars are widely associated with regions possessing distinct volcanotectonic affinities [e.g., 2]. In past studies, these systems have been interpreted as having developed through the melting of glacial or ground ice, but, as at Ophir Planum, these systems have great potential to be more simply understood as the products of volcanic processes. A volcanic origin for elevated outflow systems on Mars would be consistent with a broader igneous hypothesis previously developed for all Hesperian outflow channels [13,16; see also 17].

The origin of outflow systems on Mars is of fundamental importance to our understanding of the nature and history of that planet. A non-aqueous igneous origin for Hesperian outflow channels would greatly undermine the basis for hypotheses involving the past existence of large water bodies on Mars [e.g., 18,19] and for the past occurrence of associated major shifts in climate. An intriguing implication of a shared igneous origin for the largest channels of the Moon, Venus, and Mars would be the possible existence of analogous igneous systems at the surface of the Earth during the Hadean or Early Archean.

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