

VOLCANIC INTERPRETATIONS OF THE MARTIAN OUTFLOW CHANNELS ARE CONSISTENT WITH SURFACE MINERALOGY. D. W. Leverington, Department of Geosciences, Texas Tech University, Lubbock, TX, 79409-1053.

Introduction: The origin of the Martian outflow channels is of central importance to our understanding of the geology and climate history of Mars. Partly on the basis of similarities between these channels and terrestrial diluvial systems, past investigations of the Martian channels have favored aqueous interpretations involving catastrophic floods from cryospherically-sealed aquifers [e.g., 1]. These aqueous interpretations have motivated hypotheses for the past existence of oceans and large lakes on Mars, as well as for the past occurrence of major changes or oscillations in global climate [e.g., 2,3]. Aqueous interpretations have also served as a basis for inferences of Martian volatile abundances [4].

Today, much Martian outflow-channel research is conducted under an assumption of aqueous channel origins. However, recent work has suggested that this assumption is unlikely to be valid [5-7]. Aqueous models suffer from numerous weaknesses, including inconsistency with modern climatic conditions, incompatibility with realistic estimates of crustal permeability, limited correspondence between Martian outflow landforms and those of terrestrial diluvial landscapes, and lack of analog processes for voluminous outflow from the subsurface. In contrast, the Martian outflow channels have distinct volcanotectonic affinities, and share many characteristics with large lunar and Venusian outflow systems interpreted by most workers as volcanic [5-7]. The fundamental origin of the Martian outflow channels, involving effusion of fluids from the subsurface, is far more consistent with volcanic mechanisms of development than with aqueous processes such as those that formed the floodways of terrestrial glacial lakes [6,7]. Indeed, large volcanic flows are known to have been erupted from the heads of the Martian outflow channels, most conspicuously at systems such as Mangala Valles [6] and Athabasca Valles [8]. Although alternative interpretations have been offered [e.g., 9], the primary surface materials exposed at all three outflow channel sites visited by landers (Viking 1, Pathfinder, Spirit) are volcanic flows subjected to extensive reworking by impact processes [5].

Orbital and Ground-Based Determinations of Mineralogy: Modern remote-sensing datasets offer a means by which the surface mineralogy of Mars can be mapped, providing an improved basis for the evaluation of hypotheses of outflow-channel development. Prominent among these datasets are thermal imagery generated by the Thermal Emission Spectrometer

(TES) on board the now inoperative Mars Global Surveyor spacecraft, and the Thermal Emission Imaging System (THEMIS) on board the Mars Odyssey spacecraft. Also of importance are hyperspectral imagery generated in the visible and infrared by the Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) instrument on board the Mars Express spacecraft, and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on board the Mars Reconnaissance Orbiter. Relevant datasets have independently been generated by recent ground-based investigations involving the Spirit rover at Gusev crater, the Opportunity rover at Meridiani Planum, and the Phoenix lander at Vastitas Borealis.

Surface Mineralogy and the Outflow Channels of Mars: Though notable exceptions exist [e.g., 10,11], hydrated minerals (including varieties of phyllosilicates and sulfates) are predominantly associated with materials altered during the Noachian or earlier parts of the Hesperian, suggesting that widespread aqueous conditions were mostly confined to the earliest stages of Mars history [12,13]. The persistence of olivine-rich units (~20-35% olivine) exposed during the Noachian, and the recognized susceptibility of olivine to aqueous alteration at timescales of no more than tens of thousands of years [14], confirms that even early hydrous conditions on Mars should have been of limited spatial and temporal extent [13,15-17]. Apparent preservation of exposed carbonate units of Noachian age [18] suggests that later acidic conditions of the early Hesperian were not globally pervasive [19], and the incomplete diagenesis of early sulfate-bearing units at Meridiani Planum [20,21] appears incompatible with the existence of wet conditions at this site beyond the time of original alteration [22,23]. The long-term dry conditions implied by Martian bedrock units are congruous with the high concentrations of olivine measured in ancient aeolian sediments, materials that should be especially susceptible to aqueous weathering [24-26]. The global mineralogical record suggests that the role of liquid water in Martian weathering processes has generally been profoundly limited over the past ~3.5 billion years [13,15].

Development of the Martian outflow channels mainly took place during the Hesperian and Amazonian [27,28], largely postdating the early period of widespread aqueous alteration on Mars. Beyond scattered associations with ancient altered materials [e.g., 29], there is no spatial correlation between Martian outflow channels and exposures of hydrated minerals

[13,30,31]. Importantly, the olivine-rich units that are distributed across the planet's southern hemisphere are prominently exposed at large outflow channels such as those of the circum-Chryse region [16,17]. The absence of a notable record of hydration at the Martian outflow channels, and the association of large channel systems with ancient bedrock exposures comprised of ~20-35% olivine, together appear incompatible with the long-term existence of massive Martian aquifers and water-saturated cryospheric seals.

Though not supportive of aqueous processes of outflow channel formation, the mineralogical record of Mars is consistent with previously hypothesized volcanic mechanisms of system development [5-7]. Volcanic processes are widely believed to have formed the outflow systems of the Moon and Venus [32-34], and although exotic magma compositions have previously been speculated as necessary for Venusian outflow channels and canali to have developed as volcanic systems [35-37], the lunar record strongly suggests that lavas of mafic composition can have the capacity for low-viscosity flow, substantive vertical and lateral erosion, and extreme lengths for both open and channelized flows [5-7,38,39]. The capacity of Martian volcanic processes for the past development of sinuous channels, anastomosing reaches, streamlined erosional residuals, and longitudinal channel features has recently been recognized at numerous smaller channel systems of Hesperian and Amazonian age [7,38-43], lending further support to the volcanic hypothesis.

Implications of Volcanic Origins: Recent determinations of surface mineralogy do not appear compatible with the large flood events, long-lived aquifers, and cryospheric seals required of aqueous hypotheses. This finding is consistent with suggestions that aqueous hypotheses are based upon implausible hydrological assumptions, merely superficial resemblances between outflow systems and terrestrial diluvial systems, and unsound characterizations of volcanic alternatives [5-7]. Compelling arguments in favor of aqueous models of outflow channel formation are elusive.

The implications of a volcanic origin for the outflow channels of Mars are profound. A volcanic origin does not require ancient swings in climatic conditions or atmospheric properties, and is therefore compatible with long-term dry planetary conditions. A volcanic origin implies a unification in major effusive volcanic processes and landforms across at least three bodies of the inner solar system, and potentially has significance with regard to the nature of early igneous processes on the Earth. Though a volcanic origin narrows the possible range of environments once favorable to Hesperian or Amazonian life, it may also highlight the greater astrobiological significance of any associated zones of localized hydrothermal activity that may have existed.

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