GEOLOGIC HISTORY OF VALLES MARINERIS, MARS, REVISITED.

K. L. Tanaka[1], J.A.P. Rodriguez[2], C.M. Fortezzo[1], T. Platz[3], G. Michael[3], and S. Robbins[4]. [1]U.S. Geological Survey, Flagstaff, AZ (ktanaka@usgs.gov), [2]Planetary Science Institute, Tucson, AZ, [3]Freie U., Berlin, [4]U. Colorado, Boulder.

Introduction: The Valles Marineris (VM) on Mars (Fig. 1) constitute the most spectacular and yet one of the most puzzling canyon systems known in the Solar System [1-2]. Although VM have been the target of numerous studies, many fundamental aspects regarding the nature and timing of its development remain topics of controversy and continued study. Our geologic mapping and other analysis using post-Viking image and topographic data reveal some fundamental new insights regarding its geologic history.

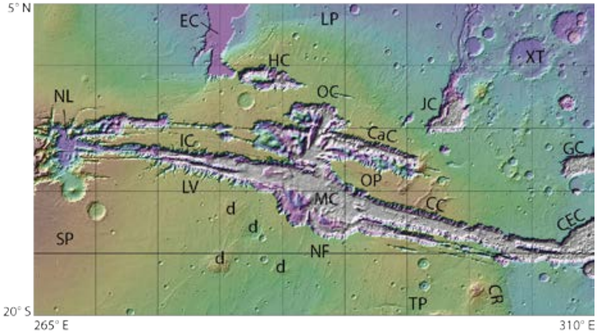

Figure 1. Color elevation shaded relief view of Valles Marineris, which cuts across a rise (green to brown region at center) that stands 3 to 5 km above terrains to the north and east. Locations include Echus Chasma (EP), Lunae Planum (LP), Xanthe Terra (XT), Noctis Labyrinthus (NL), Ophir Chasma (OC), Juventae Chasma (JC), Ius Chasma (IC), Candor Chasma (CaC), Ganges Chasma (GC), Louros Valles (LV), Melas Chasma (MC), Ophir Planum (OP), Candor Chasma (CC), Syria Planum (SP), Nia Fossae (NF), Thaumasia Planum (TP), Claritas rise (CR), and Capri and Eos Chasmata (CEC). Scene width is ~2650 km.

Proposed magmatic origins for the VM complex include rifting induced by dike emplacement [3] and mantle plume development associated with central uplift and associated flexure, volcanism, and outflow channel activity [2]. Also advocated is continental-scale salt tectonics for the origin of the Thaumasia plateau, in which VM represents a bordering zone of transtension and lateral shear; the sulfate-rich interior layered deposits (ILD) in this scenario are considered to be crustal rocks exhumed during VM formation[4]. However, the ILD locally drape over eroded ridges within VM, suggesting a depositional origin [1, 5]. Collapse has also been proposed as a way to initiate VM troughs prior to rifting by deep crustal fracturing and subsurface erosion by flowing water [6] or by catastrophic outbursts from pressurized aquifers, perhaps arising from melting of ice or clathrates [7].

The plateaus surrounding VM are covered largely by regional lava-flow sequences having Late Noachian and Early Hesperian crater ages. The plateaus have been extensively fractured and deformed by sets of narrow extensional grabens and contractional wrinkle ridges [2, 4, 5, 8]. In addition to these, the south margin of VM includes silica-bearing light-toned layered deposits (LTLD), dense drainage networks, possible debris flows, and tectonic rises [2, 5, 8, 9].

Previously, main development of Valles Marineris was suggested to be Late Noachian to Hesperian based on the dating of (1) surfaces cut by VM [5], (2) fault systems adjacent to and parallel with VM [8], and (3) oldest materials deposited within VM [5, 10]. The latter include ILD composed of sulfate and iron oxides of possible lacustrine, evaporite, aeolian, and/or volcanic origins and modified by diagenesis [5, 11].

In the following, we recap and revise the geologic history of VM, based on new global [12] and regional geologic mapping and crater counting [13].

Pre-Valles Marineris Activity: The Early Noachian crust exposed along the flanks of VM appears mostly layered. These layers likely consist of stacks of lavas [14], which may also characterize other layered sequences in the highlands of similar age. In addition, the highlands NE of Coprates include ridge systems of Early to Middle Noachian age, which could be radial to a giant Chryse-centered basin.

Initial Valles Marineris Development: During the Middle Noachian, volcanic edifices and rifts formed in the Thaumasia highlands, including along Coprates rise where WNW-trending rift structures occur south of and parallel to Coprates Chasma. This indicates that earliest VM rifting may also date to the Middle Noachian. However, earliest recognizable evidence of possible VM-associated widespread volcanism and/or fluvial resurfacing is Late Noachian, as indicated by lava and/or debris flows that extend southeast from Melas Chasma and by deposits making up smooth areas of Thaumasia plateau and lower areas east of VM and Thaumasia plateau.

LTLD occur along the south margin of Ius Chasma and have been interpreted as pyroclastic and/or lacustrine deposits [8]. The LTLD underlie a plateau unit that we have dated at 3.68 +0.04/-0.06 Ga, indicating that the LTLD and hence activity at Ius Chasma are Early Hesperian or older, and thus may have formed during initial chasma formation. These deposits may have been emplaced as volcanic or fluvial discharges in association with plateau rifting (similarly on Earth, lake formation and volcanism commonly occur in association in zones of continental rifting.)

Growth and Integration of VM: During the Early Hesperian, extensive fissure-fed basalt lavas were emplaced north of Ius and Coprates Chasmata, perhaps along with volcaniclastic deposits near the troughs. Volcanic flows and water discharges emanated from fissures and pits north and northeast of VM, resulting in flows and channels oriented downslope from their discharge sites. The VM rise then further elevated and deformed, including the warping and graben development of Nia Fossae south of Melas Chasma [2] and extensive graben development north of VM (including on Ophir Planum). VM troughs enlarged as plateau volcanism waned. Extant grabens and pit chains were cut into these plateau materials. The Syria Planum region erupted flood basalts, filling a basin south of Melas Chasma.

Louros Valles development. Our focused study of Louros Valles (LV) in Ius Chasma reveals some important timing and genetic relationships that help to elucidate trough development. LV progressively developed into a complex network of canyons that dissected large and deep proto-troughs of Ius Chasma. Lower reaches of LV became disconnected due to continued rifting in VM. The formation of LV may have resulted from flood discharges that also dissected shallower dendritic channels within the adjacent plateau surfaces. These channels commonly extend into the theater-headed upstream margins of LV, suggesting that a hard cap rock was undermined by removal of underlying, more friable and erodible rocks.

The deeply incised LV network appears to be unique within VM. We suggest that precipitation was localized in this region due to the development of microclimatic conditions associated with the release of water from fractured, eroded, oval dome and basin structures 70-150 km across and ~100-400 km south of Ius and Melas Chasmata (‘d’ features in Fig. 1). We interpret that these structures resulted from an emergent collection of salt diapirs that underwent dehydration upon its exhumation to the atmosphere. Whereas preliminary and in need of further testing, this hypothesis is attractive not only in that it can explain the regional tectonic setting south of Melas Chasma and the development of special microclimatic conditions, but also in that it provides a concentrated source of salts that can explain the LTLD and ILD as surface mineral precipitates. The putative diapirs themselves would originate from buried, Early to Middle Noachian salt deposits. Water discharges through LV could have been transported to deeper parts of VM and ponded to form deep lakes, thereby accounting for the construction of some of the larger bodies of ILD.

ILD do not appear faulted to any major degree, so trough faulting largely had ceased before ILD were emplaced. ILD also occur within some of the lower LV and so postdate or were contemporaneous with late-stage LV incision. ILD could represent pyroclastic rocks, spring deposits, and/or lacustrine fill.

Late-Stage VM Activity: During the Late Hesperian and Amazonian, VM trough-related faulting appears to have been negligible. However, major volcanism and tectonism appears to have migrated westward of VM in the Late Hesperian, resulting in eruption of a younger sequence of lava flows from Syria Planum and in formation of the Noctis Fossae and Labyrinthus rise and trough system, likely by extension of VM into the Noctis region [12]. Outflow channels and chaos formed north and east of VM, emanating from Echus, Juventae, and Coprates Chasmata. ILD within these and other VM canyons were dissected [5]. Surrounding Echus Chasma and within Melas Chasma, dendritic channel systems developed, indicative of possible Late Hesperian precipitation and runoff [15] and perhaps local pyroclastic activity [16].

Wrinkle ridges occur on the plateaus surrounding VM but appear largely absent within VM. It may be that compressional stresses resulting from Tharsis loading and global contraction became dominant as VM magmatism and tectonism waned. Wrinkle ridges within VM may have been obscured by later resurfacing.

Huge volumes of wall rock became unstable and collapsed into massive landslides [10], thereby enlarging the surface area of VM and reducing its depth. Dunes within VM and dark mantles along VM plateau margins indicate aeolian redistribution of surface fines. Thus, in spite of an overall absence of volcanic, tectonic, and fluvial activity during the Amazonian, the VM landscape and topography further evolved.

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