WHAT IS THE SIGNIFICANCE OF LAYERING OBSERVED BY MOC IN MARTIAN HEAVILY CRATERED TERRAIN? K. L. Tanaka[1], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (ktanaka@flagmail.wr.usgs.gov).

Introduction: The geology of the martian heavily cratered terrains has been studied and mapped extensively with Viking images [1-3]. Impact, volcanic, fluvial, tectonic, periglacial, hydrothermal, and eolian processes have been suggested as contributing to the make up and modification of these terrains. Malin and Edgett [4], viewing the ancient landscapes of Mars with Mars Orbiter Camera (MOC) images, observe that the heavily cratered terrains are made up of layers expressed by contrasts in albedo or resistance to erosion. They interpret that the layered material predates "all of the landforms previously attributed to 'early Mars'" including valley networks and "all of the major volcanic and tectonic features of the Tharsis/Syria rise." Furthermore, they suggest that "some of the layers must be of sedimentary origin, and might have a regional extent that implies that processes occurred on ancient Mars that are completely unlikely processes that occur there today." They also claim that "the presence of a layered crust suggests that planet Mars was once unlike anything that anyone has ever described."

Although MOC images provide a spectacular advance in our ability to observe the martian surface, just how oblivious were previous workers to layering and its consequences in ancient martian rocks? Do the layers necessarily predate Tharsis volcanic and tectonic activity and early valley network formation? Does the layering require the erosion of large mountain ranges and the formation of vast seas? Or are the layers consistent with the same 'old' Mars expressed by the extant landscape?

Previous recognition of layering: Because Viking images typically range in resolution from tens to a few hundred meters, only the more prominent layers in highland terrains could be recognized directly. In other cases, the existence of layering has been inferred to explain the burial of preexisting topography or the control of erosional and tectonic features due to mechanical discontinuities.

Consistent erosional depths of 1 to 2 km measured in the outflow channels were interpreted by Soderblom and Wenner [5] as indicative of stratification due to fossil interfaces between pore water and ice in the martian crust. Later, more detailed study of Kasei Valles also revealed a sequence of thick units (Fig. 1) [6]. Regular stratification of about 8 layers was observed in northern Lunae Planum [6]. Also, 4 to 8 layers were recognized in places along the top of Valles Marineris in ridged plains material [7]. However, it is not possible to determine for sure whether or not the layering observed in ridged plains material extends back into the Noachian.

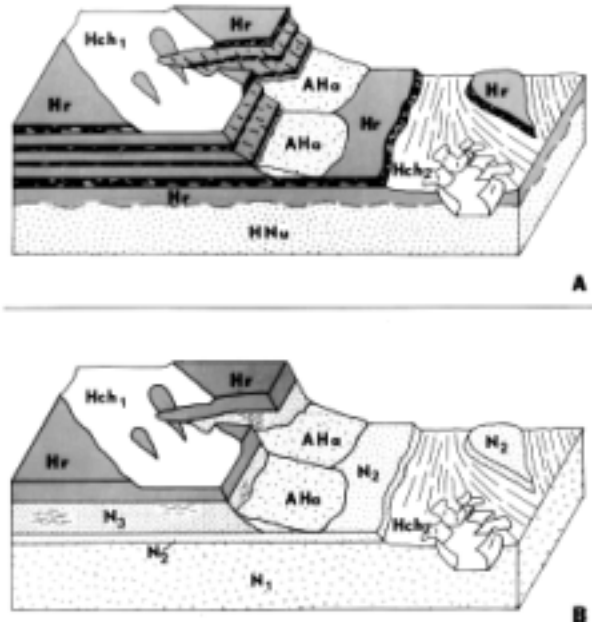

Fig. 1. Cross-sectional diagrams of northern Lunae Planum and Kasei Valles (looking west; north at right). Two proposed stratigraphies shown; both include layering in Hesperian and Noachian rocks (Fig. 4 from [6]).

Layering also has been observed in Viking images in the walls of channels that cut Noachian terrains. In northeastern Arabia Terra, Auqakuh Vallis, cuts through at least 4 layers can be discriminated in this deposit (~50 m/pixel resolution) [8]. Faint layering also was observed in Nirgal Vallis [9]. East of Isidis basin, deposition of layers was interpreted to explain the gradual burial of craters in intercrater plains material incised by valleys [10]. These examples of layering in ancient terrains observed in Viking images occur at much the same stratigraphic positions as those seen in MOC images.

Common widths of narrow grabens and depths of collapse features around the Tharsis region have been proposed to indicate mechanical discontinuities at consistent depths across broad regions [11-12]. Suggestions for the causes of these proposed discontinuities include stratigraphic contacts, the onset of ground water and ice, pristine vs. cemented basement rocks, and megaregolith vs. basement rocks.

Relative ages of geologic features: The heavily cratered materials on Mars formed during the Early and Middle Noachian Epochs, when impact rates were high [13]. The geologic record appears to indicate that the character of volcanism, tectonism, and valley erosion of ancient Mars was in many ways similar to that of later

Mars.

The Early Noachian includes the formation of the large impact basins of Hellas, Argyre, and Isidis and other large, prominent massifs whose relief is interpreted to result from tectonic processes. Most outcrops of this unit form along the southern periphery of the Tharsis rise and at Mareotis Fossae, east of Alba Patera [2]. Exposed faults of the Thaumasia region date back to the Middle Noachian [13]. The geologic record thus shows that Tharsis tectonism reached back into the Middle Noachian and probably the Early Noachian.

Early volcanism is difficult to recognize and date. Possible Noachian volcanoes include a couple dozen constructs in southern Tharsis [2, 14] and Tyrrhena Patera northeast of Hellas basin [15]. Postulated sills and dikes intrude the intercrater plains and may be Noachian or Hesperian in age [8, 10].

Valleys in some places clearly have been buried by tabular deposits, some of which are Noachian. For example, in northeastern Arabia Terra, inverted topography results where valleys have been filled by relatively resistant material followed by stripping away of valley wall material [8]. Layers seen in outcrops of Noachian rocks in MOC images locally appear to thicken, which may result from infill of previously dissected terrain (Fig. 2).

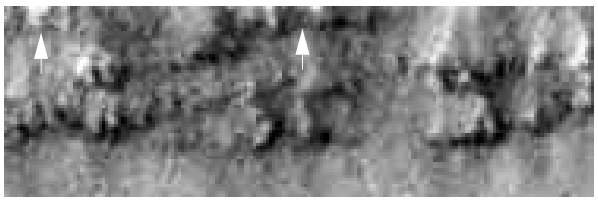

Fig. 2. Part of MOC image 46502 showing top of wall of a fretted channel in northern Arabia. Uppermost layer (white arrows) appears to be horizontal. The middle layers dip and perhaps thicken to the left. The bottom layer may be truncated at left.

Layering and early Mars: The layering observed in Mars' ancient crust in MOC images, while fascinating and worthy of detailed investigation, does not necessarily require a "new paradigm for Mars geology" [4]. Why not? One reason is that many layered rock sequences on Mars clearly postdate the ancient terrains. These include the polar layered terrains [16], the interior layered deposits of Valles Marineris [7], the ridged plains material of Lunae Planum (at least the uppermost section) [7], the mantling deposit of Arabia Terra [8], and the Medusae Fossae Formation [2]. Each of these deposits extends for thousands of kilometers. Another reason is that it remains to be established just how extensive layering has been preserved in the ancient crust.

Previous workers have noted or inferred a variety of instances of layering in the martian crust, and no doubt the new Mars Global Surveyor (MGS) datasets will lead to additional outcrops, insights, and hypotheses. For example, McEwen [17] has proposed that the thick sequences of layered rocks in the walls of Valles Marineris may consist of Noachian flood lavas that have been severely weakened by impacts and other processes.

Issues that can be addressed directly with MGS and Viking datasets include:

- How extensive in MOC images is layering in ancient cratered terrain? While Malin and Edgett [4] suggest that it is layered "everywhere that it is exposed in outcrop form," McEwen [17] observes that "there are many…areas where no layering is apparent."
- How are the layers expressed from place to place? Are they discerned by their slope expression or albedo? What do their slope characteristics indicate about competency and rheology? Are the layers of even and uneven thickness? Do they pinch out?
- Are layers structurally deformed by faulting or folding? Is some of the deformation buried?
- Could some layers be intrusive sills?
- Do some sequences of layers correlate with hydrologic basins or volcanic regions?
- How do ancient layered sequences compare with younger sequences? What are the implications for the geologic and climatic evolution of Mars?

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