THE GEOLOGIC RECORD OF EARLY MARS: A LAYERED, CRATERED, AND "VALLEY-ED" VOLUME. K. S. Edgett and M. C. Malin, Malin Space Science Systems, Inc., P.O. Box 910148, San Diego, CA 92191-0148 USA.

Introduction: Analysis of images from the Mars Global Surveyor (MGS), Mars Odyssey, Phobos 2, Viking, and Mariner 9 orbiters shows that the upper crust of Mars is a layered, cratered, and "valley-ed" volume. Buried craters do not indicate a singular, "pre-Noachian surface." Instead, filled and buried craters—and valley networks—are found at many scales and at multiple stratigraphic levels within the upper 10 or more kilometers of the martian crust. These layers record the depositional environments of early Mars. The craters have diameters up to 100s of kilometers. The rocks that comprise these layers, more often than not, appear to be sedimentary rather than volcanic. The rock units are both vertically and laterally heterogeneous. The martian heavily cratered terrain familiar since Mariners 4–9 is the end-product of a long period of erosion and deposition, burial and exhumation. Some very large craters (> 100 km diameter) at the surface of Mars today were once buried, yet retain little evidence of their burial; some valley networks begin or end, fully-born, in the middle of nowhere, with their end points either still buried or long since removed. The attributes of the martian geologic record suggest that early Mars was a very dynamic place.

Several regions exhibit exposures of layered bedrock that provide insights to the nature of the martian geologic record. This paper describes key examples in Gale Crater, Sinus Meridiani, Arabia Terra, the chaotic terrain east of the Valles Marineris, and the troughs and uplands surrounding the Valles Marineris.

Gale Crater: Gale Crater captures many elements of the rich and complex martian geologic record. The ~5 km-high stack of layered sedimentary rock in Gale is vertically heterogeneous; contains erosional unconformities; buried, filled, and exhumed channels; and is just a remnant of material that once completely filled the crater. But that is not all—the top of the layered sequence lies above the rim of Gale Crater. Gale was not only filled, it was buried. The sequence in Gale is more than twice the thickness of the rocks that lie above the Great Unconformity in the Grand Canyon on Earth. While thickness does not equal time, the processes that deposited and formed the rocks above the Great Unconformity, and the uplift and erosion that created the Grand Canyon, all took place in a period of ~0.5 billion years, so the layers and erosional unconformities in Gale must, at least, represent a considerable period. Finally, the sequence in Gale is profound for another reason: at the Grand Canyon, we know from field studies that these rocks record the comings and goings of seas, deserts, and mountain ranges. What do the rocks in Gale, more than twice the thickness of those in the Grand Canyon above the Great Unconformity, tell us? With its buried impact craters and valleys, the mound in Gale, all by itself, is a layered, cratered, and valley-ed volume. But it is merely a remnant of a much larger story.

Sinus Meridiani: Features in images and topographic maps of northern Sinus Meridiani and adjacent areas of western Arabia Terra, like the mound in Gale Crater, show that the upper crust of Mars is a layered and cratered volume. Northern Meridiani presents a vast outcrop of light-toned, layered sedimentary rock that is larger in areal extent than the Colorado Plateau of North America. Craters of diameters up to and > 60 km are interbedded with the layered bedrock of this region. The low-albedo material associated with hematite in Meridiani Planum unconformably overlies a previously-eroded suite of the light-toned sedimentary rocks. In addition to showing that fairly large craters are interbedded with layered rock in the upper martian crust, northern Sinus Meridiani and adjacent portions of western Arabia also show that layered rocks in the filled and interbedded craters can be completely different from the rocks exposed in the adjacent intercrater terrain. For example, the sedimentary rocks in a 65 km-diameter crater at 8°N, 7°W, have 100s of repeated beds that form yardangs and erode into a stair-stepped pattern, while the rocks outside the crater, which include materials stratigraphically and topographically higher than the crater's rim, are more massively bedded, do not form yardangs, and do not show the repetition of bedding and physical properties. The depositional environment within a crater such as that at 8°N, 7°W, was different from that of the intercrater terrain, meaning that the materials are not simply an airfall deposit of ancient (or more recent) tephra, as some investigators have suggested. The observation also demonstrates that, because of the differences between rocks within and outside of filled and buried craters, rock units in the upper crust of Mars are laterally heterogeneous.

Arabia Terra: Light-toned, sedimentary rocks in northern Sinus Meridiani are also present in western Arabia Terra, but they are mantled by dust. Exhumed and inverted channels (valley networks) are also present in the region, but not as common as in central and, especially, eastern Arabia Terra. Eastern Arabia exhibits considerable erosion of layered bedrock material. The erosional properties and patterns of these materials show that they are different from the rocks in Sinus Meridiani and western Arabia Terra, but the pattern of interbedded impact craters and valleys is a common element. The headward areas of valleys such as Auqakuh and Huo Hsing are lost to erosion because the strata that were cut by them have been removed. Other valleys have been filled and in numerous cases inverted as erosion removed less-resistant materials from around the ancient valleys.

Chaotic Terrain east of the Valles Marineris: Prior to the MGS mission, the Mars science community generally recognized the presence of light-toned, layered and massive rock units, known as "Interior Layered Deposits," within the Valles Marineris. These materials were considered by most investigators to be sediments deposited in the Valles Marineris after the troughs opened up—for example, these might be the products of lacustrine sedimentation or volcanism that occurred within the Valles Marineris chasms. These ideas were formulated prior to MGS, when the fact that similar rock outcrops occur in the chaotic terrains east of the Valles Marineris was not known. The outcrops in the chaotic terrain were exposed by the chaos-forming processes; that is, they were buried beneath the surface of Mars and only became exposed when the chaotic terrain formed. The light-toned, layered outcrops of regions including Iani and Aureum Chaos are in some cases indistinguishable from similar materials in the Valles Marineris. The materials of the chaotic terrain, like those in western Arabia and northern Sinus Meridiani, also demonstrate the lateral heterogeneity of the upper martian crust—many of the light-toned sedimentary rock outcrops are lenses of material surrounded by otherwise less-distinctive, dark-toned rock. These lenses may, and in some cases clearly do, represent the locations of filled and buried impact craters that were re-exposed to the surface by the chaotic terrain-forming events. The largest crater of this region is Aram Chaos; this basin is filled, in part, by light-toned sedimentary rock. Aram Chaos also demonstrates that craters > 100 km in diameter can be filled, or nearly filled, with these kinds of materials.

Valles Marineris and environs: In the Valles Marineris, more light-toned, sedimentary rock outcrops have been seen in MGS Mars Orbiter Camera (MOC) images than were previously recognized in Viking and Mariner 9 pictures. These materials are exposed at places within all of the troughs of the Valles Marineris, including the Labyrinthus Noctis. In addition, the central peak of Oudemans Crater, which impacted plains immediately adjacent to the Labyrinthus Noctis, is composed of light-toned, layered rock that existed beneath the plains and were brought to the surface by uplift during the impact event. Light-toned sedimentary rock exposures occur on the upland south of Ius Chasma, southwest of Juventae Chasma, north of Coprates Chasma, and elsewhere. In southwestern Juventae Chasma, the light-toned sedimentary rocks are cut by the chasm walls, and in these walls they are completely indistinguishable in terms of erosional expression from other materials in these and most other Valles Marineris walls. In Coprates Chasma, lenses of light-toned, sedimentary rock have been exposed in the chasm walls, in the ridges running down the long axis of the troughs, and in the pit chains that parallel the chasm to the south; these lenses, like those of the chaotic terrains, may be the filling materials within buried impact craters. In southwest Candor Chasma, outcrops of 100s of layers of sedimentary rock with highly repetitious beds and nearly identical properties occur; similar beds are found in the upper walls of southwest Candor and western Ius Chasma. The layers in southwest Candor appear to be the down-dropped remnants of strata that occur just beneath the plains into which the chasm is cut. The most critical thing to understand about the Valles Marineris is that the layered, cratered, and valley-ed volume is laterally, as well as vertically, heterogeneous. Arguments that the Valles Marineris wall rock and the interior layered "deposits" are different and therefore that the interior layered materials represent something deposited in the chasms after they opened up miss this point—of course there are differences between some wall rock and some interior layered units; the upper crust, demonstrated elsewhere and nearby, is laterally heterogeneous. MOC images have shown no unequivocal evidence for volcanism (lava flows, vents, shields, cones, etc.) nor evidence for deposition of major, light-toned, layered rock in the chasms after they formed. Instead, the Valles Marineris reveal what lies beneath the plains into which they are cut. If one could see what is beneath the Lunae, Syria, and Sinai plains, one would see a laterally and vertically heterogeneous suite of rock layers that include filled and buried valleys and impact craters of sizes up to 10s and perhaps 100s of kilometers in diameter.

Concluding Statement: The upper crust of Mars is a layered, cratered, and valley-ed volume. This volume is laterally as well as vertically heterogeneous and contains much sedimentary rock. These materials are the record of early Mars. Discussion of what early Mars was like—and the emphasis of future missions such as the 2009 Mars Science Laboratory—need to shift focus toward the opening and reading this record.