METEORITES AT MERIDIANI PLANUM INDICATE EXTENSIVE SURFACE WATER ON EARLY MARS.

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Overview: Four Fe-Ni meteorites have been discovered in the Meridiani Planum region of Mars by the Mars Exploration Rover (MER) Opportunity. The discovery and characteristics of the meteorites can be explained as the result of their impact into a soft and wet surface sometime during the Noachian or the Hesperian, subsequently to be exposed at the Martian surface through differential erosion. Therefore, the Fe-Ni meteorites represent physical evidence that Mars once had a denser atmosphere and considerable amounts of water at and near the surface.

The meteorites: The four large Fe-Ni meteorites have been discovered by the MER Opportunity in its nearly 25-km-long traverse through Meridiani Planum (e.g., [1]). The meteorites have been informally named "Heat Shield Rock" (given the approved official name "Meridiani Planum" after the location of its find--see Connolly et al., 2006, referred to hereafter as HSR to avoid confusion with the site), "Block Island" (BI), "Shelter Island" (SI), and "Mackinac Island" (MI). The MER Opportunity Alpha Particle X-Ray Spectrometer (APXS) shows that the elemental compositions of HSR, BI and SI are nearly identical, all being type IAB complex iron meteorites based on their Ni, Ge, and Ga contents [2,3]. Compositional information, however, was not obtained for MI [3,4]. The four Fe-Ni meteorites likely fell on Mars more than 3 Gy ago [4]. This is consistent with calculations that meteorite decay due to chemical weathering in the equatorial regions of Mars should have occurred on a multibillion-year timescale, even considering the continuous availability of water close to the meteorite in a "wet" early Mars scenario [5].

Geological history of Meridiani: Meridiani Planum is a distinct stack of light-toned, layered rock sequences ~600 m thick that lie disconformably on an older, slightly tilted Noachian cratered terrain, near the top of which there is an exposure of hematite-rich plains covering an area of ~9×104 km^2 [6,7]. Bedding is observed within the stratum, maintaining uniformity and horizontality for hundreds of kilometers. The sediments are interpreted to consist of coarse sand with varying competency among the layers reflecting various degrees of induration and therefore erosional expressions [7]. During the Noachian, acid and saline water interacted with the sediments in Meridiani [8-11], during a time in which regional erosion rates were similar to slow denudation rates of environments on Earth that are dominated by liquid water [10]. Meridiani has been interpreted to have recorded a watery past, including a shallow sea, a mud ocean, a playa, a hydrothermal environment, fluvial channels, an environment of fluctuating ground water, and/or an icy landscape [11-14].

Impact into a soft and wet surface: We envision that the four Fe-Ni meteorites found in Meridiani fell sometime during the Noachian or the Hesperian on a soft and wet surface characterized by the expressed evidence for the presence of significant amounts of surface and near-surface water. Meteorites were encased underground upon impact and/or by subsequent burial by water-enriched materials for a long time. During the Amazonian, the almost complete disappearance of surface water and the desiccation of the landscape followed by the induration of the sediments and the subsequent differential erosion, which includes 10-80 m of wind-driven deflation of Meridiani Planum sediments in the last 3-3.5 Gy [10], have exposed the buried meteorites at the Martian surface. These levels of denudation may very well account for the uncovering and concentrating pre-Amazonian buried meteorites at the surface today. Our hypothesis is summarized in Figure 1.

Aqueous weathering: The chemistry and appearance of the meteorites support our interpretation of their impact into soft and wet materials, which includes intermittent interaction with groundwater. The four meteorites have portions of their surfaces that are smooth, and they show ubiquitous hollows and pits that appear similar to regmaglypts likely deformed during the descent through the atmosphere [1,15], by subsequent aqueous interaction once on the surface [3,4,16] or while encased underground, and/or by aeolian abrasion once exposed at the surface. Cavernous features indicate differential acidic corrosion removing less resistant material, suggesting chemical weathering produced by aqueous alteration removing softer inclusions (common to iron meteorites), such as troilite. Chemical corrosion and very little mechanical weathering is also indicated by the shape and angularity of the cavernous features [4], suggesting a prolonged interaction with acidic surface water and/or groundwater. As water has been mostly absent from the surface and the upper subsurface of equatorial Mars such as in Meridiani Planum during the Amazonian, significant chemical alteration is likely to have occurred shortly following impact during wet conditions. In this sense, the aqueous chemical alteration shown by the meteorites and the extreme arid conditions of the Amazonian Period point to a "martian age" of the meteorites (the time the meteorites have been on Mars) of > 3 Gy.

Terrestrial analogs: Similar sequences of events are common on Earth: abundant accumulations of meteorites are found in areas where wind deflation has removed ancient sand covers, such deflation basins or blowouts that have been excavated upon a mantle of eolian coversands [17]. In the same way, meteorite stranding areas in Antarctica show high meteorite concentrations, as they are ice ablation surfaces where old ice is outcropping and ice is being removed, leaving behind thousands of meteorites [18,19].

References:

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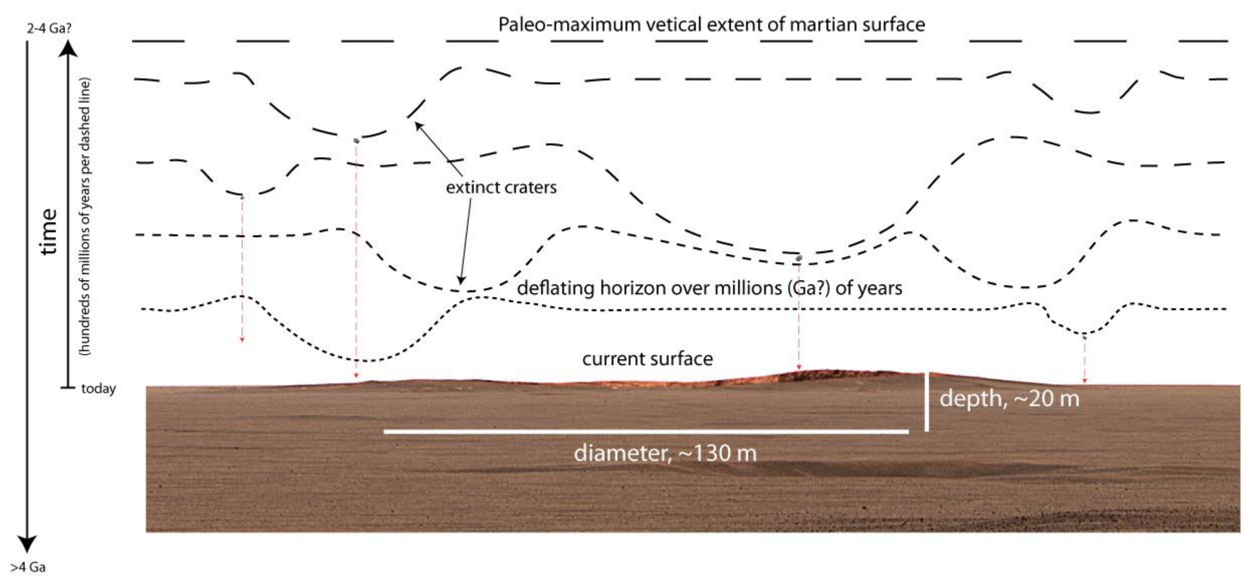

Figure 1: The Meridiani surface has been undergoing deflation for the last ~3 Ga, leaving behind the current eroded expression of the sulfate-rich sediments. The maximum extent of the layered sediments probably peaked more than 3 Gy. ago, just after the Heavy Bombardment period, possibly as much as 80 m above the current surface horizon. As weathering processes acted on the sedimentary sequences, the meteorites were exposed. Due to the nature of the meteorites being highly dense relative to the sulfate-rich outcrop, they remain exposed on the surface for extended periods of time, producing the population expressed on the surface.