BROAD PERSPECTIVES ON PREFERRED TYPES OF MARS SCIENCE LABORATORY LANDING SITES: EXPERIENCE FROM CHARACTERISTICS OF PREVIOUS LANDING SITES AND DEVELOPING SEDIMENTOLOGIC FACIES MODELS.

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Introduction: Outside of the general engineering constraints imposed on Mars Science Laboratory (MSL) landing sites, the science objectives are to investigate habitable environments. Planetary protection requirements focus attention on ancient habitable environments that are preserved in rocks. In this abstract, we consider the general types and characteristics of sites best suited to such investigations from the experience gained from surface characteristics and landscape processes found at previous landing sites on Mars and the preservation potential of biomarkers from sedimentologic considerations.

Layered Sedimentary Rocks: Opportunity discovered sedimentary evaporites in Meridiani Planum that were likely deposited in salt-water playas or sabkhas [1,2] during the Late Noachian, based on mapped geological relationships [3,4] and the frequency of degraded craters >1 km in diameter [5]. These evaporitic rocks are preserved within the upper unit of a layered sequence of rocks several hundred meters thick that unconformably overlie heavily cratered terrain that experienced extensive denudation [6], approximately coeval with a wide variety of geomorphic indicators (valley networks, degraded craters, highly eroded terrain and layered sedimentary rocks) that indicate a possible early warmer and wetter environment [7,8]. The Meridiani rocks are part of a global set of Noachian sedimentary rocks [9], many of which are also sulfate rich [10,11] that also likely formed in aqueous environments. As a result, Opportunity results coupled with imaging and multispectral data argue that widespread layered materials on Mars likely record, at least in part, aqueous environments that are well suited to addressing the MSL science objective to investigate habitable environments.

Landscape Evolution and Gradation State: Of the five landing sites on Mars, four are on Hesperian cratered surfaces as revealed by orbital images. Viking 1 and 2, Mars Pathfinder and Spirit landing sites are characterized by rocky (and generally dusty) and soil rich surfaces that obscure or cover completely any outcrop [12,13,14]. Most of the rocks at the Viking and Spirit landing sites appear to be ejecta from the impact craters and flat-lying outcrop is found only at the Viking Lander 1 site, peeking beneath the soil and rocks and in the older Columbia Hills in Gusev. Except for this outcrop, all rocks at these sites are float, and a variable thickness impact-generated regolith has been produced at the Gusev cratered plains [14]. These observations suggest that Hesperian cratered surfaces may not preserve intact stratigraphy that is important for understanding aqueous environments, or construction of a locally more highly-resolved geological sequence important for understanding the context of the deposits.

The Meridiani Planum landing site is distinct in that the surface age of the sand sheet is Late Amazonian [5] that contrasts with the age of the sulfate-rich bedrock, which is Late Noachian [15]. As a result, the Meridiani Planum landing site has been exhumed by several tens of meters so that the entire Hesperian cratering record has been removed. Because the sulfate rocks are so weak, deflation by saltation abrasion is very efficient and leaves little residue, except for the hematite spherules [16]. Many of the layered sedimentary deposits described by Malin and Edgett [9] also have very lightly cratered surfaces, suggesting they are also easily erodable by the wind and maintain relatively undisturbed stratigraphy for investigation by a rover.

The Meridiani site is also the first landing site in a characteristically low albedo (dark) site on Mars [17]. To first order, the albedo correlates with the dust on the surface, with bright, high-albedo sites having much more surface dust than dark, low-albedo sites [18]. Observations from the surface show that dust at the other 4 landing sites coats the rocks and soils making initial identification of different surface units difficult using remote sensing instruments. Low-albedo sites do not have this problem with surface dust, so surface remote sensing instruments can identify distinct soils and rocks for efficiently directing subsequent in situ investigations.

Sedimentary Facies: Our preference for MSL landing sites is thus for layered sedimentary rocks with young surface ages and low albedo. Further preference is for sites where a substantial stratigraphic section is exposed and trafficable for study by the rover. In this regard, the Meridiani Planum site has so far only allowed study of about 10 m of section. We would prefer a site that has substantially more section available for documenting the longer-term variability in facies and past environments.

We also prefer low energy sedimentary environments that maximize the accumulation of organic matter and preservation of potential biomarkers. At Meridiani Planum, most of the Burns formation section explored by Opportunity are the relatively high-energy eolian sand sheet and sand dune environments that are not optimal for either accumulating or preserving biomarkers. Alternatively, two optimal facies would be clay-rich mudstones deposited in distal fluvio-deltaic and/or lacustrine settings, and bottom-growth evaporites precipitating within desiccating brine pools. The first would be a silicate-dominant target, and the second a sulfate-dominant target. In the ideal case, a landing site

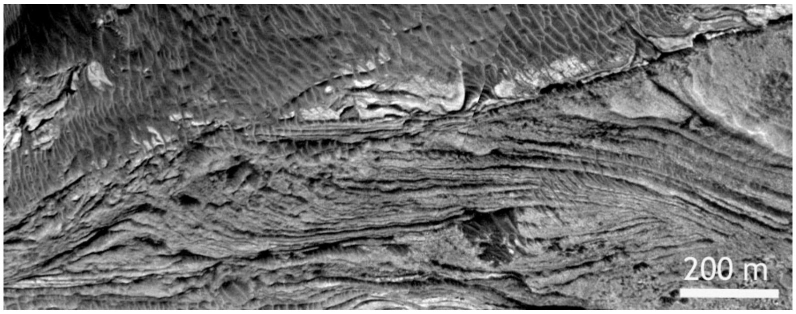

Figure 1: MOC image show prograding clinoforms in southwest Melas Chasma. The convergence of clinoforms in the down dip direction provides direct evidence for section condensation, which in turn suggests a corresponding decrease in grain size, and the possible accumulation of clay minerals, on which organic compounds may preferentially adsorb.

could be selected that would allow both types of sedimentary rocks to be examined.

On Earth, organic matter is preferentially sequestered by clay minerals due to the sheltering and preservative effects that phyllosilicate surfaces provide to organic matter in both soils and marine sediments [19,20]. In addition, laboratory experiments show that preservation of labile organic compounds is significantly enhanced through associations with clay minerals [21]. Spectroscopic remote sensing, coupled with image analysis of stratal geometries can provide a predictive basis to identify potentially distal environments where clay minerals, and therefore organic compounds, may preferentially accumulate (Figure 1).

Chemical sedimentary environments also provide significant potential to preserve organic compounds. In some cases, organic abundances are so high that terrestrial evaporites are regarded as potential hydrocarbon source rocks [22]. This is due to the possibility of prolific growth of benthic microbial mats, but also because stratification of oxygen may occur in the water body, which limits remineralization. Furthermore, preservation of organics in evaporite sediments is enhanced due to their very low permeabilities.

At Meridiani, bottom-growth sulfate evaporites might be developed in playa, sabkah, or even deeper-water, more long-lived settings. OMEGA results from Juventae Chasma suggest a transition in mineral composition within a very thick (>2km) succession of rocks [23] (Figure 2). Such a site might be a location where significant subaqueous evaporite deposition occurred. The transition from kieserite to gypsum is apparently concordant with the layering expressed in outcrop, and therefore may represent a stratigraphic transition between minerals with different solubilities. Such transitions are typical of terrestrial evaporite successions and there is no *a priori* reason to expect that this should not also be the case for Mars.

Diagenesis is an uncertain variable in predicting organic preservation potential. Where recrystallization occurs in chemical sediments, and rock-water interactions are significant, the effects can be inimical. This is especially true where pore fluids are strongly acidic [24]. On the other hand, for chemical sediments that have undergone limited exchange, diagenesis can enhance preservation through restricting later exchange with pore fluids. In contrast, siliciclastic sediments may suffer too little diagnesis, and if left uncemented, organic compounds may be easily oxidized by exchange with the atmosphere.

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Figure 2: High Resolution Stereo Camera color image of interior layered deposits in Juventae Chasma with possible landing ellipse (~20 km diameter) located on the adjacent sand sheet. OMEGA shows the upper layers contain gypsum, whereas the lower material contains kieserite [23]. The layered deposits are over 2 km thick and the MSL rover could sample at least the lower half of the section by driving northward along its western side. Each layer could be studied because the soil-bedrock contact gains elevation to the north and allows access to successively higher layers.