VERNAL CRATER, SW ARABIA TERRA: MSL CANDIDATE WITH EXTENSIVELY LAYERED SEDIMENTS, POSSIBLE LAKE DEPOSITS, AND A LONG HISTORY OF SUBSURFACE ICE.

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Summary: Vernal Crater is a Mars Science Laboratory (MSL) landing site candidate providing relatively easy access to extensively layered sediments as well as potential lake deposits. Sediments of Vernal Crater are 400-1200 m below those being investigated by Opportunity in Meridiani Planum, and as such would allow study of significantly older geologic units, if Vernal Crater were selected for MSL.

The location of Vernal Crater in SW Arabia Terra provides exceptional scientific interest, as rampart craters and gamma-ray spectrometer (GRS) data from the region suggest a long history of ice/ fluids in the subsurface. The potential value of this MSL candidate is further enhanced by reports of atmospheric methane over Arabia, as any insight into the source of that methane would significantly increase our understanding of Mars. Finally, should MSL survive beyond its prime mission, the gentle slope within Vernal Crater would provide a route out of the crater for study of the once ice/fluid-rich plains.

Regional Setting: Arabia Terra is a one of the few equatorial regions on Mars characterized by relatively high abundances of near-surface hydrogen as measured by GRS (1); this has been taken to suggest the presence of shallow ice or hydrated minerals [1,2]. Vernal Crater [3] lies in SW Arabia Terra, halfway between a proposed ancient Arabia basin [4-6] to the east and the massive circum-Chryse outflows to the west (Fig. 1). SW Arabia Terra adjoins northern Meridiani Planum and both include extensive layered units that have been interpreted as sedimentary rocks [8,9]. Rampart craters are common in SW Arabia Terra (Fig. 2); they range in diameter from 1 to 25 km, impact three different geological units (L, S and R of Edgett [9]), and have ejecta blankets with both rounded and angular morphologies. This latter observation suggests that the ramparts have experienced varying amounts of erosion and thus are of varying ages [6,7]. This, in turn, implies that ice or fluids have been in the subsurface for extended periods [6,7]. The fact that numerous small (1 to 5 km-diameter) ramparts are present might additionally suggest the presence of near-surface ice in the last several million years, when obliquity was higher and ice was stable closer to the equator.

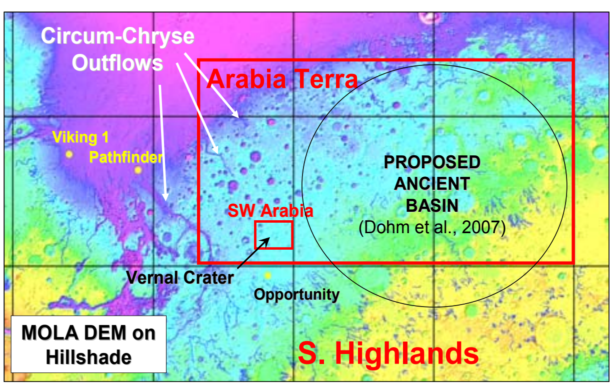

Fig. 1. Regional setting, proposed ancient Arabia Basin, and circum-Chryse outflows.

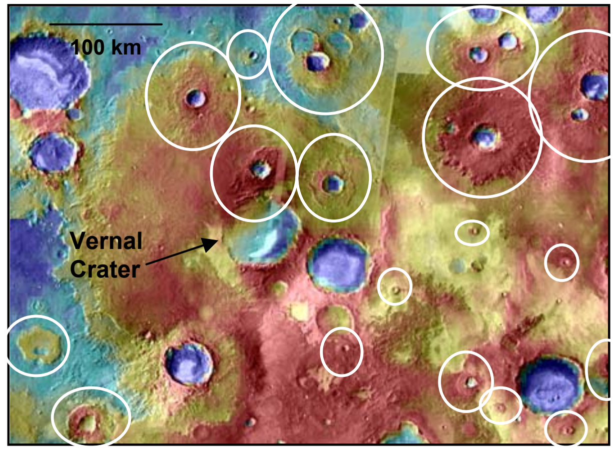

Fig. 2. Rampart craters (white ovals) in the region of Vernal Crater. Daytime IR on MOLA topography. Color scale: reds = highs (-1300m); dark blue = lows (-2000m).

Atmospheric methane has been detected over Arabia in concentrations suggesting recent release to the atmosphere [10-12]. Various sources, both biogenic and abiogenic, have been postulated for this gas [13], and any insight into the production and release of methane to the Martian atmosphere would be a major advance in our understanding of Mars.

Vernal Crater: Vernal Crater (Fig. 3) is a 55 km-

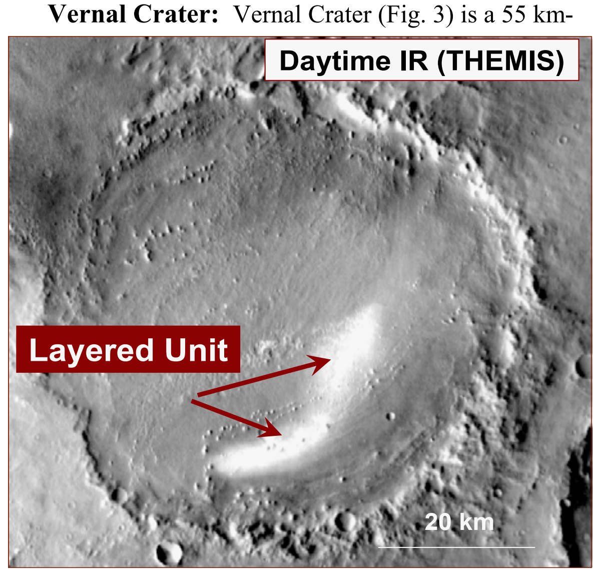

Fig. 3. Vernal Crater. Daytime IR.

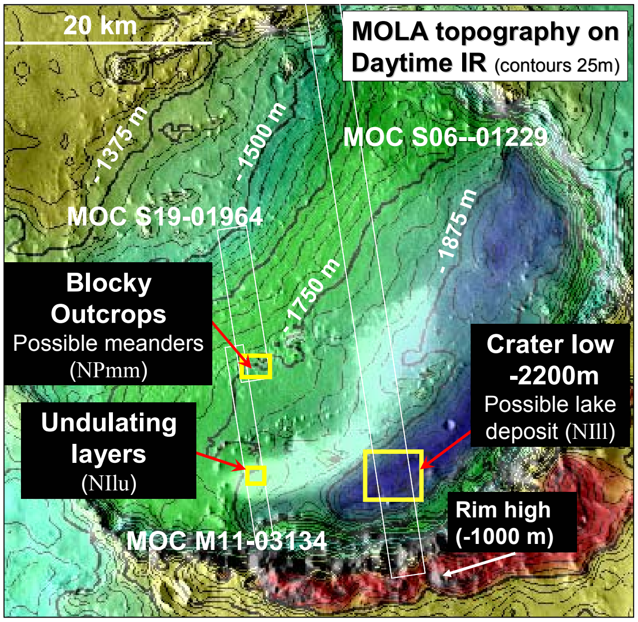

Fig. 4. Vernal Crater. MOLA topography on Daytime IR. Color indicates topography: red = highest elevation; dark blue = lowest. Yellow rectangles show areas of detail for Figs. 7-9.

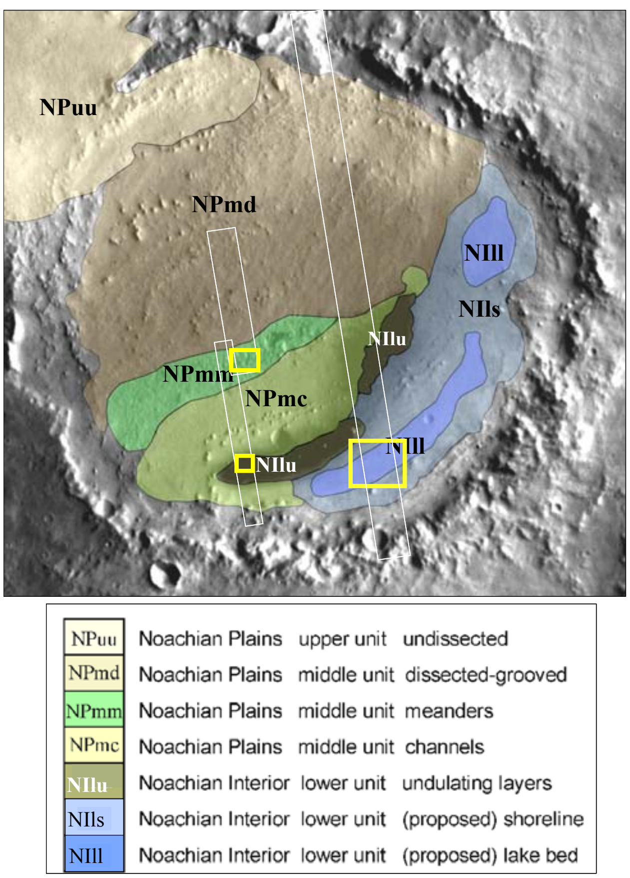

Fig. 5. Geomorphic units in Vernal Crater on Inverted Daytime IR. MOC footprints and rectangles as in Fig. 4.

diameter structure, centered at 6° N, 355.5° E. It is characterized by a well defined IR-bright feature which corresponds to a layered unit, a gentle slope of ~1.5 degrees (from about -1350 m in the north to -2200 m in the south), and a strongly asymmetric rim (Fig. 4).

Seven geomorphic units in this crater have been mapped (Fig. 5) using detailed comparisons of THEMIS VIS/IR, MOLA, and MOC images that were spatially rectified in ArcGIS [14]. The northern half of the crater contains Noachian Plains units (NPuu and NPmd) dominated by features typical of aeolian processes (dunes and yardangs). The southern half may expose Noachian fluvio-lacustrine sediments; it contains few dunes or obvious yardangs but has possible meandering and braided stream units (NPmc and NPmm), layered deposits (NIlu) corresponding to the IR-bright feature, and a potential lake deposit (NIll) with associated shoreline-like bedding (NIls) (Fig. 5). These more southerly deposits are likely to be the units of greatest applicability to MSL science goals related to present and past habitability.

Stratigraphically, the youngest units (in the northern half of Vernal Crater) appear to lie a minimum of four hundred meters below those investigated by Opportunity in Meridiani [9]; the older and deeper units to the south (the layered unit and possible lake/ shoreline deposits) would be 900 to 1200m (respectively) below the sediments being investigated by Opportunity.

Landing Ellipse and MRO Footprints: The recommended landing ellipse and footprints for HiRISE, CRISM, and CTX from Mars Reconnaissance Orbiter (MRO) are shown in Fig. 6 [15]. The gentle slope in Vernal Crater should provide relatively easy access to all the geomorphic units and the 750 m of exposed section. All MSL engineering constraints, including that for maximum dust coverage, are met in this site [15].

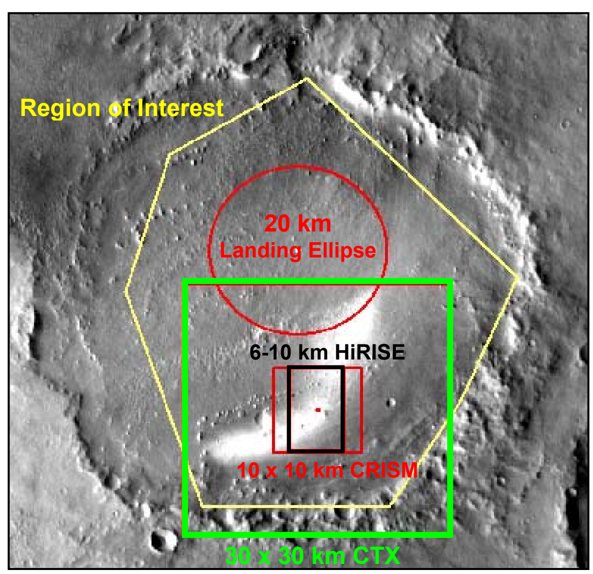

Fig. 6. Vernal Crater (SW Arabia Terra) - MSL Landing Ellipse and MRO footprints on Daytime IR.

Discussion: The area characterized by bright IR response in daytime images (Fig. 3) corresponds to a slight ridge in the topography and is comprised of several packages of layered sediments. Each package consists of approximately ten to a few tens of light-toned layers (Fig. 7, and Figs. 4-5 for location). The correspondence of the layered sediments to a ridge suggests that they are indurated and somewhat resistant to erosion. Their wavy fabric might suggest fluid-rich deposition and/or soft sediment deformation. This undulating fabric is not likely to be attributable to lava, since few volcanic features or fissures are known from which lava could emanate [9]. Thus, the layers seem likely to be of aqueous origin and their induration and resistance to erosion might be attributable to cementation by either interaction with hydrothermal fluids or by evaporation.

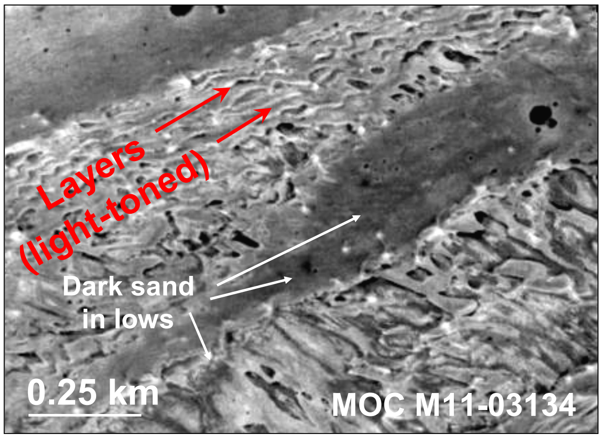

Fig. 7. Vernal Crater. Undulating layers (NIlu).

This layered unit has similarly bright (though not identical) responses in both daytime and nighttime IR. Detailed comparison of spatially rectified MOC, THEMIS VIS, and THEMIS IR imagery suggests that the nighttime IR response is due to the packages of light-toned layers while the daytime response originates from dark sand resting in lows within the layered unit

North of the layered unit and about midway within the crater is a distinctive, east-west trend of blocky outcrops that resembles incised meanders (Fig. 8 and Figs. 4-5, for location). These outcrops have flat tops and somewhat curved edges, and are individually separated by rounded, incised regions. The flat tops and curved edges seem more likely to have been produced by aqueous erosion than by wind erosion. The belt of outcrops is separated from features to the south by a relatively wide, curving path that is smooth except for the presence of dunes; this may represent the remnant of a meander path. Finally, patches of inverted channels resembling braided stream deposits occur in association with these blocky outcrops. Taken together, these features are suggestive of fluvial processes in the southern half of Vernal Crater.

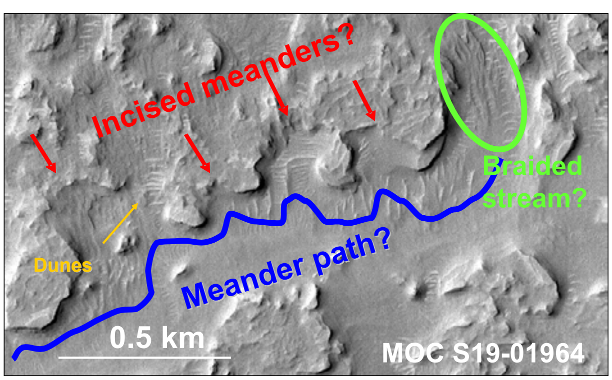

Fig. 8. Blocky outcrops resembling meanders (NPmm).

At the southernmost end of Vernal Crater, remnants of crater lake deposits could be located in the area of the major topographic low (Fig. 9, and Figs. 4-5, for location).

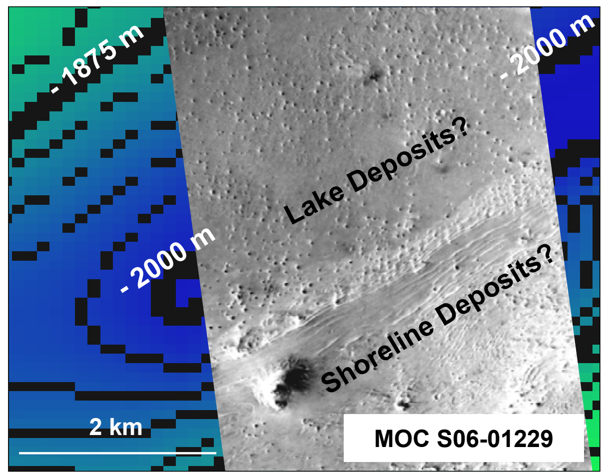

Fig. 9. MOC image with possible lake (NIll) and shoreline deposits (NIls) on MOLA topography.

The fact that the lowest elevation in the crater is just north of the highest part of the rim (Fig. 4) may not be coincidental. While the asymmetric rim may have focused wind currents such that the area of the topographic low would have been preferentially eroded and exhumed, the asymmetric rim additionally would have shadowed the region immediately to the north during periods of high obliquity; and this shadowing could have preserved any ice present in that portion of an ancient crater lake. Thus, Vernal Crater's asymmetric rim, with its highest part in the south, may have set the stage for preservation of a lake with relatively long-lived ice in this particular crater. Such a long-lived lake may be the type of setting in which organic remains of either a prebiotic chemistry or possible early Martian microbes (if life ever developed on Mars) might be preserved.

It is difficult to distinguish among different scenarios for the history of Vernal Crater based on available data: Was the crater completely filled with layered deposits, then simply exhumed by wind to give us the topography we see today? Or is it possible that some ancient features, such as a long-lived lake, are reflected in the current topography? Is all of the erosion that we see due to wind or are we seeing a combination of erosion due to wind and fluvial processes?

New data from MRO and Mars Express will provide fresh insight into these questions. Since Vernal Crater is a MSL candidate, HiRISE, CTX, and CRISM data will be acquired from MRO for this site. The footprints requested for HiRISE, CTX, and CRISM were chosen to provide detailed information about the layered deposits and possible remnants of lake and shoreline sediments. We anticipate using these new data to better assess the crater-filling deposits and their regional significance.

Conclusions: A variety of data suggests that SW Arabia Terra has had a long history with ice or fluids in the subsurface. The abundance and varying morphologies of the rampart craters (Fig. 2) suggest differing degrees of erosion and hence differing ages of impacts into ice/fluid-rich targets in this region [6,7]. The fact that numerous, relatively small craters (less than 5 km diameter) are associated with apparently fluidized ejecta might additionally suggest that ice has been relatively shallow in the region of Vernal Crater in the last several million years. This conclusion is consistent with GRS results suggesting present-day occurrence of ice or hydrated minerals in the near-surface of Arabia Terra.

It may be that the regional setting of SW Arabia Terra predisposed this area to receive abundant surface and sub-surface waters (surface waters from southern highlands runoff and extensions of circum-Chryse outflows; sub-surface waters from updip migration out of the proposed giant Arabia Basin). If such processes did occur, they may have been the reasons for abundant ice /fluids in the subsurface. Subsequent uplift and erosion of the proposed ancient Arabia Basin (recently suggested as a consequence of loading at Tharsis [6]) may have been a source for much of the material making up the vast sedimentary deposits in the region.

While Vernal Crater /SW Arabia Terra share some features with the MER B site being investigated by the Opportunity Rover in Meridiani Planum, the two regions are nevertheless quite different both geologically and chemically. Vernal Crater provides a stratigraphic section for study that ranges from about 400 to 1200 meters below that being investigated by Opportunity. Rampart craters are abundant in the vicinity of Vernal Crater but seem less common in the vicinity of the Opportunity Rover in Meridiani Planum. Because of this, selection of Vernal Crater as the MSL landing site would allow for testing of stata deposited in an earlier period of Mars' history, perhaps in a region with a longer history of substantial subsurface ice or fluids. The proposed existence of a long-lived lake in Vernal Crater adds to the uniqueness of this site and provides a location in which potentially biogenic organic remnants might be preserved below the surface. Finally, SW Arabia is not associated with the hematite signature characteristic of Meridiani Planum, and Arabia Terra is more closely associated with the possible current release of methane to the Martian atmosphere.

Certainly a significant aspect of the geological history of Mars is reflected in the extensive and massively layered deposits in Arabia Terra and parts of Meridiani Planum. The occurrence of examples of those sediments in Vernal Crater - in a region associated with long-lived subsurface ice and possibly current release of methane - provides strong impetus to consider Vernal Crater for the MSL landing site. Moreover, Vernal Crater allows ready access to those layered deposits and additionally may provide a window into an ancient cold trap preserving sediments and perhaps organic materials associated with a long-lived lake. Finally, should MSL survive to explore beyond the originally planned mission of one Mars year, the gently sloped ramp of sediments into Vernal Crater also would provide a route out of the crater to study the ejecta of nearby rampart craters that have sampled ice-rich sediments of three different geological units and attest to a long history of subsurface ice in the region.

References: [1] Boynton W.V. *et a*l. (2002) *Science*, *297*, 81-85. [2] Feldman W.C*. et al*. (2002) *Science*, *297*, 75-78. [3] The name, Vernal, has recently been approved for this crater by the IAU WGPSN. This site was previously called SW Arabia Terra in the listing of MSL candidates. [4] Dohm, J.M. *et al.* (2004) *LPS XXXV*, Abs. # 1209. [5] Barlow, N.G. & Dohm, J.M. (2004) *LPS XXXV,* Abs. # 1122. [6] Dohm, J.M. *et al.* (in press). *Icarus*. [7] Barlow, N.G. & Bradley, T.L. (1990) *Icarus, 87*, 156-179. [8] Malin, M.C. & Edgett, K.S. (2000) *Science, 290*, 1927-1937. [9] Edgett, K.S. (2005) *Mars. Intl. J. Mars Science & Expl. 1*, 5-58. [10] Krasnopolsky, A. *et al*. (2004) *Icarus*, *172*, 537-547. [11] Mumma, M.J. *et al.* (2004*) 36th DPS*, Abs. # 26.02. [12] Formisano, V. *et al*. (2004) *Science*, *306*, 1758-1761. [13] Allen, M. *et al.* (2006) *Eos, 87* (41), 433-448. [14] Oehler, D.Z., et al. (2007) *LPS XXXVIII*, Abs. # 1057. [15] Paris, K.N. *et al.* (2007) *LPS XXXVIII,* Abs. # 1316.

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