THE TODILTO FORMATION AND SCIENCE GOALS AT NORTH MERIDIANI. D. T. Vaniman, Group EES-14, MS D462, Los Alamos National Laboratory, Los Alamos, NM 87545 (vaniman@lanl.gov)

Introduction: Sites in North Meridiani were proposed early in site selection discussions for Mars Science Laboratory (MSL) [1] and remain of interest for Mars 2018 [2]. Although all terrestrial analog sites have limitations, and are at best partial analogs, there are certain features of the Todilto Formation in the Southwestern United States (Figure 1) that may be relevant to a North Meridiani mission. The Todilto Formation is a zoned carbonate (calcite with minor late dolomite) to sulfate (gypsum in outcrop, anhydrite where deeply buried) evaporite deposit that developed in a short period (10^4-10^5 yr) after rapid flooding of the vast dune field of the Entrada Formation in the Jurassic. Despite the very different hydrogeologic environments of Mars and Earth, the Todilto setting of short-lived brine incursion into a largely eolian environment, with terminal formation of a salt hydrate common to both planets (gypsum), provides a useful field area for petrogenetic studies of evaporite evolution and of lacustrine interaction with a porous, sandy substrate. Although much is known about a small portion of Meridiani through data collected by the MER rover Opportunity, that knowledge is focused on higher hematite-rich portions of a laterally extensive and very thick stratigraphy. The data from Opportunity show eolian dune forms overlain by eolian sand sheets and interdune/playa sediments [3]. Although the indications from Opportunity are that groundwater brines have predominated and surface discharge is minimal, the situation may be considerably different at North Meridiani where extensive and continuous sedimentary units mark a sedimentary section >1 km thick [1], with greater chance of including both eolian and lacustrine deposits. These deposits are sulfate rich and although the evidence from Opportunity indicates a complex mixture of Mg, Ca, Fe sulfates the chemical data also are best fit by including Ca-sulfate [4], likely as gypsum. A significant aspect of the Todilto Formation is its association with bituminous materials that are extensive enough to yield a small commercial petroleum field where buried beneath the Colorado Plateau. Biochemical occurrences in the Todilto have likely microbial precursors, in a brine-microorganism association that may represent a potential setting for primitive life as might be found on Mars.

Figure 1: Location map of the Todilto Formation.
Mission Description: The mission envisaged here (Figure 2) is an example from the MEPAG 2-Rover International Science Analysis Group [2]. However, the vast extent of the Meridiani deposits provides other possibilities. Edgett and Malin [1] provide a view of the site in Figure 2 with regional context. One of the hypotheses that could be tested with this mission is whether the deeper section at Meridiani, beneath the hematite plains, includes lacustrine deposits. Large inverted channels shown in [1] indicate that the deeper sulfate-rich sections of Meridiani have had a much wetter history than the spot examined by Opportunity. Mission elements that include a rover with significant range with imaging, spectral, chemical, and mineralogical analysis capability would be suitable, as well as ability to detect biomarker molecules.

Figure 2: Example North Meridiani locality from [2]. The site is at ~1.5°N, 357.2°E at an elevation of about -1.6 km. Science targets include sulfate-rich sediments north of the hematite-rich plains (north of the yellow landing ellipse). The orange circle marks a possible landing spot; blue circles are example MAX-C sampling sites, pink circles are example EXM sampling sites, and the blue box represents a cache for sample return.

Science Merit Related to Mission Objectives: The Todilto Formation provides a variety of sedimentological, mineralogical, and biogeochemical features relevant to interactions between brines and eolian sediments (see especially [5]). Discussion of the Todilto Formation as a Mars analog with references to the scant literature on biogeochemistry of the Todilto is published in [6-8]. Although the Todilto evaporite deposits are relatively thin (a few tens of meters) they cover a vast area and contain some significant geochemical as well as physical sedimentary boundaries [7].
**Most Important Question Answered by the Todilto Site:** The most important science question that could be answered at North Meridiani would be whether the observed fluvial features are related to lacustrine systems that were sufficient to provide habitable environments. Studies of the Todilto Formation related to this question include (1) a closer analysis of features in the Todilto evaporites and underlying Entrada sands that demarcate surface water versus groundwater components of site hydrogeology and (2) application of modern biogeochemical methods to defining the microbiology of the Todilto evaporite, with particular emphasis on microbiological differences between the sulfate and carbonate zones.

**Logistic and Environmental Constraints:** Access to and field conditions for the Todilto Formation are generally excellent; a summary is provided in Table 1 and more extensive descriptions are provided in [8].

### Table 1: Todilto Formation as an analog site for North Meridiani.

<table>
<thead>
<tr>
<th>Center Coordinates</th>
<th>Most outcrops are located between 35° and 37.5° N latitude and 105.5° and 109° E longitude.</th>
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<tr>
<td>Elevation</td>
<td>1.5 to 2.4 km</td>
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<tr>
<td>Areal Extent</td>
<td>&gt;150,000 km² (much is subsurface)</td>
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</table>
| Prime Science Questions | 1) What mineralogical and sedimentological features are characteristic of brine discharge over eolian dunefields?  
2) What subhabitats for microbiota and what genera are hosted in evolving, gypsum-precipitating brines? |
| Distance of Science Targets from nearest road or airstrip | Many localities are readily accessible at a few tens of meters to <1 km from paved or dirt access roads. The Albuquerque International Airport is within 50 km of several Todilto exposures. |
| Environmental characteristics | Max temp: +43 °C  
Min temp: -30 °C  
Precipitation: 20 to 60 cm per year  
Vegetation coverage: sparse, from scrub to piñon or ponderosa forest. Most outcrops are in cliff or scarp exposures. |
| Previous studies at analogue site | See references [5,6,7,8] |
| Primary Landing Site Target | North Meridiani near or within sulfate-rich sediments beyond the hematite plains |

**References:**