HABITABILITY ASSESSMENT AT GALE CRATER: IMPLICATIONS FROM INITIAL RESULTS. P. G. Conrad[1], D. Archer[2], S. Atreya[3], D. Blake[4] , P. Coll[5] , M. de la Torre[6] , K. Edgett[7] , J. Eigenbrode[1], M. Fisk[8], Freissenet, C.[1], H. Franz[1], D.P. Glavin[1], F. Gómez[9] , R. Haberle[4] , V. Hamilton[10] , J. Jones[2] , L. Kah[11], L. Leshin[17], P. M. Mahaffy[1], A. McAdam[1] , C. McKay[4] , R. Navarro-Gonzalez[12], A. Steele[13] , J. Stern[1], D. Sumner[14], A. Treiman[2] M.H. Wong[3], J. Wray[15], R.A. Yingst[16] and the MSL Science Team [1]NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771 Pamela.G.Conrad@nasa.gov, [2] NASA Johnson Space Center, Houston, TX, [3]The University of Michigan, Ann Arbor, MI, [4]NASA Ames Research Center, Moffett Field, CA, [5]LISA, Univ. Paris-Est Créteil, Univ. Denis Diderot & CNRS, Créteil, France, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [7]Malin Space Science Systems, San Diego, CA, [8]Oregon State University, Corvallis, OR, [9]Centro de Astrobiologia (INTA-CSIC), Madrid, Spain, [10]Southwest Research Institute, Boulder CO, [11]University of Tennessee, Knoxville, TN [12]Universidad Nacional Autónoma de México, México, [13]Geophysical Laboratory, Carnegie Institution of Science, Washington, [14]Univ. of California, Davis, CA, [15]Georgia Institute of technology, Atlanta, GA, [16] Planetary Science Institute, Tucson, AZ, [17]Renssalaer Polytechnic Institute, Troy, NY.

Introduction: Mars Science Laboratory has made measurements that contribute to our assessment of habitability potential at Gale Crater. Campaign organization into a consistent set of measurable parameters allows us to rank the *relative* habitability potential of sites we study, ultimately laying a foundation for a global context inclusive of past and future Mars mission observations.

Chemical, physical, geological and geographic attributes shape environments. Isolated measurements of these factors may be insufficient to deem an environment habitable, but the sum of measurements can help predict locations with greater or lesser habitability potential. Metrics for habitability assessment based on field work at sites sharing features analogous to Mars have previously been suggested [1] (Table 1).

Table 1

CHEMICAL
Elemental abundance, ratios and phase state
Inorganic molecular inventory
Organic inventory
Hydration state and phase of water
PHYSICAL
Temperature (absolute, frequency & magnitude of diurnal and seasonal variation, including air, surface and interface gradients)
Thermal inertia of the surface
Wind speed, direction & variability
Pressure (atmospheric, lithostatic, etc.)
Light (solar bandwidth, wavelength-specific intensity)
Other ionizing radiation, e.g., cosmic, SEP, radiogenic elements in the environment
Slope
Electrostatic charge
GEOLOGICAL
Mineral abundances
Rock type and texture
Frequency & type of volcanic and seismic events
GEOGRAPHIC
Latitude, elevation or depth below surface
Areal extent of environment

Grouping these metrics helps us to develop an index for their application to habitability assessment. The index is comprised of the weighted values for four groups of parameters, the habitability threshold for each is to be determined.

Approach: Atmospheric and surface data acquired by Curiosity through sol 100 addresses many of these metrics. These have been binned according to the categories listed in Table 1 and are then considered from a temporal perspective, as some measurements must be acquired frequently to infer diurnal or seasonal fluctuations.

Factors considered more important for particular environments must be weighted. For example, in a subaqueous environment, nutrients or depth of light penetration may be the primary limitation. On the surface of Mars, it could be rock-cover density that provides protection from ionizing radiation. As the data set grows, weighting values should become more apparent from cluster analysis or other multivariate methods.

Results:

Chemical measurements: The atmospheric volume mixing ratios of CO_2, Ar, N_2, O_2, and CO have been measured by SAM [2, 3] and provide updates to earlier measurements from Viking and meteorites. Preliminary stable isotope ratios for C and O in CO_2, H in H_2O, $^{40}Ar/^{36}Ar$, and $^{15}N/^{14}N$ have also been measured [4, 5]. Data acquired during Curiosity's first 100 sols uphold previous results concerning the present oxidized state of the martian atmosphere; and the measured isotopic compositions support models suggesting that atmospheric loss processes have produced enrichment in the heavy isotopes of these elements. SAM has not definitively detected martian organic materials in the first solid sample analyzed and nor has it definitevely detected martian CH_4 in the atmosphere, but results suggest an upper limit for methane concentration of 3.5 parts-per-billion (ppb) [4]. Astronomical observations have suggested that CH_4 values vary seasonally, so periodic measurements will continue.

In addition, the DAN investigation has detected water to a depth of 1 m. Chemical composition of the Rocknest drift was measured by SAM and CheMin.

Physical measurements:

REMS has observed near-surface air temperature trends within 190 K to ~280 K. Seasonal warming since landing has been observed as expected. In addition, increases in temperature starting on Sol 96 were associated with a dust storm.

REMS atmospheric pressure cycles have been measured [6] and correlated with fluctuations in ionizing radiation detected by RAD [7].

G*eological* assessment has proceeded at every level of payload investigation (remote sensing, contact and analytical lab analysis). Thermal inertia of the exposed materials at Gale Crater is under evaluation, and this has implications for the thermal stability of materials that could be deemed habitable.

Geographic Setting. Gale is a 154 km diameter impact crater just south of the martian equator. As Curiosity climbs Mt. Sharp, we will note changes associated with elevation, but for this report we focus on the MSL measurements in hand from Rocknest, because it is the only place where we have coordinated remote sensing, contact and analytical measurements.

Rocknest wind drift: The crystalline mineralogy is like that of basalt, based on X-ray diffraction data [8]. Chemically, the composition appears to be similar to measurements of MER regolith fines. A bimodal grain size distribution was observed at Rocknest, where the finer fraction appears to be more hydrated [9,10]. Further, MAHLI showed armouring of surface grains and horizons at depth (Fig.1) suggesting the drift is inactive [11].

Figure 1. Sol 66 MAHLI image of horizons or banding in the wall of the first scoop trough at Rocknest.

Major molecular species produced during SAM evolved gas analysis (EGA) of Rocknest fines include H_2O, CO_2, O_2, and SO_2 [12]. There are many potential sources of these gas releases [13,14,15,16], but most of them suggest the presence of minor volatile-bearing, secondary minerals in the Rocknest fines. Preliminary abundance estimates are reported elsewhere [13]. Although the material is mainly composed of basaltic primary minerals, SAM data strongly suggests the presence of minor phase indicators of aqueous alteration. The source and detection of N-bearing gases is under investigation [17, 18,19]. SAM experiments revealed of the presence of chlorinated hydrocarbons at nanomolar levels [20,21]. Although the source of these compounds remains unclear, a much more complex distribution of organics would have been expected if they were derived from carbonaceous meteorite infall or endogenous organics. No definitive evidence for organics of martian origin in Rocknest sediment has been identified.

Discussion: The first order question about habitability assessment is: what are the minimal required metrics to determine the habitability potential? On Earth, that number is established by correlation with total biomass and/or diversity. On Mars, the answer is unclear, so a large data set is required to establish correlations among non-biological environmental factors. This may be critical for establishing strong anticorrelations between environmental factors and habitability on Mars. We presently do not know the minimum number of parameters for determination of habitability potential, but they are certainly greater than 1 or 2 [1]. As we gain data for new locations, we can establish correlations between metrics and determine whether they are independent or dependent measures.

The second order question is what is the relative importance of the habitability factors in a numerical ranking? More data will enable trending of parameters in order to rank relative habitability potential for each environment investigated.

Summary: Curiosity is only a few months into a minimum of two Earth years of investigation, and already has a complete set of new observations that address factors that may affect habitability potential. Assessment will continue not only through the martian seasons, but also back in time as we study what is recorded in the depositional history of the rocks in Gale Crater.

References:

[1] Conrad, P.G., et al (2009), *40th Lunar Plan. Sci.* 1384. [2] Vasavada, A. et al (2012) AGU U13A-02, [3] Franz, H.B. et al (2013)this mtg [4] Webster, C.R. et al (2013) this meeting [5] Wong, M. H. (2013 this mtg [6] Haberle, R.M. (2013) this mtg [7] Hassler, D. et al (2012) AGU U113A-04 [8] Blake, D.F. et al (2013) this mtg [9] Schroeder, O.S., et al (2013) this mtg, [10] Meslin, P-Y, et al (2013) this mtg [11] Kocurek, G. et al (2013) this mtg [12] Mahaffy, P.M. et al (2013) this mtg [13] Archer, P.D. et al (2013) this mtg, [14] Sutter, B., et al (2013) this mtg, [15] Franz, H.B. et al (2013) this mtg [16] McAdam, A. et al. (2013) this mtg [17] Navarro-Gonzalez et al. (2013) this mtg.[18] Stern et al. (2013) this mtg. [19] Wray et al. (2013) this mtg.
[20] Glavin et al. (2013) this mtg. [21] Eigenbrode et al. (2013) this mtg.

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