MCLaughlin Crater
Groundwater fed, lacustrine clays and carbonates
A candidate landing site for Mars 2020

Joe Michalski, Paul Niles & Sarah Stewart Johnson

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By 3.5 Ga, Mars was probably mostly hyperarid, cold, acidic, bathed in UV and generally a bummer.
CONSIDERATIONS FOR DEEP BIOSPHERES
THE MARTIAN SUBSURFACE
ALL THE INGREDIENTS FOR LIFE WERE/ARE PRESENT
SEDIMENTARY
-OR-
“SURFACE”

HYDROTHERMAL
-OR-
“SUBSURFACE”
UPWELLING SHOULD OCCUR FIRST IN DEEP BASINS

McLaughlin might be the best candidate for upwelling on Mars.
EVIDENCE FOR ALTERATION BELOW A BASE LEVEL

- **TOPOGRAPHY**
- **TES SILICA INDEX**
- **NIGHTTIME IR**
- **TES FE-CLAY INDEX**
**McLaughlin Crater**

- Channels in wall, terminate ~500 m above the floor
- Ejecta from Keren on floor
- Lobate materials
- Layered sed rx

Michalski et al., Nature Geoscience, 2013
CRISM RESULTS
CLAYS AND CARBONATES

Michalski et al., Nature Geoscience, 2013
LAYERED SEDIMENTS AND LOBATE MATERIALS
Dark unit
(igneous, stratigraphic marker)
Ejecta from Keren Crater and/or debris flow (unambiguously aqueously altered)
MORPHOLOGY OF DEBRIS FLOW
Ridges in the Debris Flow/Ejecta
Debris flow/ejecta: was it wet?
DEBRIS FLOW/EJECTA: WAS IT WET?
EVIDENCE FOR IGNEOUS PHASES?

McLaughlin Crater

Derived mineral abundances OCK 3437
- On DF
  - Feldspar 30(4)
  - High-silica 25(4)
  - Pyroxene 27(3)
  - Sulfate 8(2)
  - Carbonate 6(1)
  - Olivine 4(2)
  - Other 2

Michalski et al., Nature Geoscience, 2013
Mystery #3: Why isn’t the dark unit altered?
MYSTERY FEATURE
Clues to youthful surfaces?

Few craters, reworking by sand
Layered floor sedimentary rocks
>3.78 Ga
(unambiguously aqueously altered)
Layered sediments and lobate materials

channels
light-toned deposits
c
b
Keren Crater
plains
ejecta
dunes
flows?
flows?
N
CRISM RESULTS
CLAYS AND CARBONATES

Michalski et al., Nature Geoscience, 2013
Layered units on the crater floor
HiRISE Imaging
Clues to youthful surfaces?
Few craters, eroded buttes, reworking by sand
INTERESTING BEDDING IN THE FLOOR UNIT
Layered floor materials
(clearly altered in places, less well exposed)
Floor materials are widespread!
Igneous airfall

Clays and carbs!

Probable clays and carbs!

Ejecta/debris flow (clays and carbs)

fluvial
APPEAL OF ALKALINE SYSTEMS

• Soda lakes are often characterized by high productivity (>10gcm⁻² per day)
• Home to diverse functional groups of microbes (methanogens, methanotrophs, phototrophs, denitrifiers, sulfur oxidizers, sulfate reducers, syntrophs...)
• Abundant in terrestrial deserts and steppes, believed to have existed throughout Earth’s geological history
**Lonar Crater Lake**

- Only impact crater in the Deccan Traps
- Ca/Mg-Rich
- High Microbial Diversity, High Cell Counts (Wani et al., 2006; Antony et al., 2012)
- Spatial Heterogeneity of Lipid Biomarkers (Sarkar et al., 2014)
Ophiolite-hosted Alkaline Springs

- Del Puerto Ophiolite has been studied as a Mars Analog (Blank et al., 2011)
- Methane and hydrogen from the process of serpentinization serve as sources of energy for chemosynthetic organisms
**McLaughlin**

**Landing Site Factor**

<table>
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<th>Environmental Setting for Geochronology of Organics</th>
<th>Martian Mission and Decadal Priority Science Factors</th>
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<td>Bioturbation Preservation and Rhythmism of Organisms</td>
<td>Context: Martian History Sampled by Timing Constraints</td>
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<tr>
<td>Type 1A &amp; 1B Samples: Aqueous Mineral Assemblages</td>
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<td>Type 2 Igneous</td>
<td>Stratigraphy of units well-defined</td>
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<td>Pre- or Early-Noachian Megabreccia</td>
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<td>2nd Igneous unit</td>
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<td>Igneous unit (e.g., lava flow, pyroclastic, intrusive)</td>
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<td>Ferric Ox./Ferrous clays</td>
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<td>Crustal phyllosilicates</td>
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<td>Recent exposure</td>
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<td>No diageneric overprinting</td>
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<td>Fluvial/Alluvial</td>
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<td>Hydrothermal (&lt;100°C) subsurface</td>
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<td>Hydrothermal (&lt;100°C) surface</td>
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<td></td>
<td>Lacustrine (evaporitic)</td>
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<td>Deltaic or Lacustrine (perennial)</td>
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</tbody>
</table>

**Landing Site Factor**

- **layer, nearly flat-lying floor materials, carbonates, Fe-Mg-clays, termination of channels in wall**
  - same as above, but also unconformities in wall stratigraphy could mean the lake dried up
  - likely involved authigenic formation of clays and carbonates in deep water environments, at least during some periods
  - lake almost certainly fed by subsurface fluids, clear alteration minerals, but lacks obvious high-T phases; ejecta/debris flow certainly contains subsurface materials
  - No

- **Channels in wall, fan deposits (colluvium or weakly developed delta?)**
  - difficult to know

- **evidence for sand erosion, few small craters, eroding buttes, fresh surfaces**
  - almost certainly exhumed by Keren Crater, but not clearly proven

- **Very strong evidence for high Fe clays in layered floor and in ejecta/debris flow**
  - no

- **very strong features of Mg-carbonates**
  - no

- **TES spectral index data and some THEMIS analyses Michalski et al., 2013**
  - clays likely contain some Fe2+

- **Cratered dark airfall unit; great time-stratigraphic marker in the MV area**
  - model-based evidence; no direct observation; geologically highly reasonable, however
  - no

- **IF this is the same marker bed as in Mawrth (3.78 b.y.)**
  - there are active eolian processes today/recently
  - yes, floor stratigraphy is clear
  - yes, probably airfall
Groundwater activity on Mars and implications for a deep biosphere

Joseph R. Michalski1*, Javier Cuadros1, Paul B. Niles3, John Parnell4, A. Deanne Rogers5 and Shawn P. Wright6

By the time eukaryotic life or photosynthesis evolved on Earth, the martian surface had become extremely inhospitable, but the subsurface of Mars could potentially have contained a vast microbial biosphere. Crustal fluids may have weaved up from the subsurface to alter and cement surface sediments, potentially preserving clues to subsurface habitability. Here we present a conceptual model of subsurface habitability of Mars and evaluate evidence for groundwater upwelling in deep basins. Many ancient, deep basins lack evidence for groundwater activity. However, McLaughlin Crater, one of the deepest craters on Mars, contains evidence for Mg-Fe-bearing clays and carbonates that probably formed in an alkaline, groundwater-fed lacustrine setting. This environment strongly contrasts with the acidic, water-limited environments implied by the presence of sulphate deposits that have previously been suggested to form owing to groundwater upwelling. Deposits formed as a result of groundwater upwelling on Mars, such as those in McLaughlin Crater, could preserve critical evidence of a deep biosphere on Mars. We suggest that groundwater upwelling on Mars may have occurred sporadically on local scales, rather than at regional or global scales.

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Figure 1 | Distribution of exhumed deep crustal rocks on Mars. Detections of deep crustal rocks reported previously are overlaid on global surface geology. Exhumed clays in Noahian terrains represent subsurface hydrothermal processes early in Mars’s history. Insets show textures of two examples of exhumed crustal hydrated minerals along with mafic mineralogy exhumed from a 2.5-km-deep unawned crater at 30.4°E, 20°S (left) and Fe−Mg clays and Fe3C carbonates exhumed from 6-km deep in Leighton Crater (right).

1 Near-infrared remote sensing data of Mars have revealed hundreds of ancient deposits of Fe-Mg-rich smectite clay minerals within the crust with relevance to past habitability. Diagnostic metal-OH infrared spectroscopic absorptions used to interpret the mineralogy of these phyllosilicates occur at wavelengths of 2.27−2.32 μm, indicating variable Fe:Mg ratios in the clay structures. The objective of this work is to use these near infrared absorptions to constrain the mineralogy of smectites on Mars, using Fe-Mg-rich outcrop clay minerals as mineralogical and spectroscopic analogs for Martian clay minerals. We show how crystal–chemical substitution and mixed layering affect the position of the diagnostic metal-OH spectral feature in smectite clay minerals. Crystal-chemistry of smectites detected on Mars were quantitatively constrained with infrared data and categorized into four mineralogical groups. Possible alteration processes are constrained by comparisons of clay chemistry detected by remote sensing techniques to the chemistry of candidate protoliths. Of the four groups identified, three of them indicate significant segregation of Fe from Mg, suggestive of alteration under water-rich and/or oxidizing conditions on Mars. The fourth group (with low Fe:Mg ratios) may result from alteration in reducing or water-limited conditions, potentially in subsurface environments. Some samples are interpreted as clinoptilolite clay minerals that have characteristics of diocahedral clay minerals but clear chemical evidence for trioctahedral shear. Approximately 70% of smectite deposits previously detected on Mars are classified as Fe-rich (FeO(MgO) > 10). Only 22% of deposits are trioctahedral and relatively Mg-rich. An additional ~8% are difficult to characterize, but might be very Fe-rich. The segregation of Fe from Mg in Martian clay minerals suggests that Mg should be enriched in other contemporaneous deposits such as carbonates and carbonatites.

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1. Introduction

Near-infrared remote sensing data of Mars collected by two instruments, OMEGA (Observatoire pour la Minéralogie, l’Étude, les Glaciers et l’Activité) and CRISM (Compact Reconnaissance Imaging Spec- trometer for Mars), have revealed thousands of detections of an- cient Fe-Mg-rich smectite clay minerals (in addition to other clay minerals) within the Martian crust (Poulet et al., 2005; Murawie et al., 2009; Elkins-Tanton et al., 2011; Carter et al., 2012). Elkins-Tanton et al. likely formed through aqueous chemical alteration of pyroxene, olivine, and mafic glass within volcanic and impact-fragmented materials (Christensen et al., 2001; Poulet et al., 2007). Because these clay minerals are key indicators of aqueous activity, they are of astrobiological interest and important for understanding the clima- te history of Mars (Bibring et al., 2006). Despite the fact that remotely detected Martian smectites are unlikely to be pure clay deposits, the spectra of the clay mineral components contain key information about their crystal chemistry and structure. However, the precise mineralogy of the Fe-Mg-rich smectites is not well un- derstood, limiting the ability to connect these deposits to their protoliths through their geochemistry, or to understand the na- ture of aqueous processes from whence they formed on ancient Mars.
McLaughlin Crater Summary

• Evidence for lacustrine setting
• Alkaline, saline, Mg-Ca-Fe-rich fluids
• Origin of fluids?
  – Precipitation?
  – Groundwater Upwelling?
ALKALINE LAKE IN LONAR CRATER
Dioctahedral clays are relatively straightforward.

Di-trioctahedral clays are complicated, but too important to ignore!

The position of metal-OH feature versus crystal chemistry is illustrated in the diagrams. The wavelength of M-OH absorption (mm) is plotted against different crystal chemistry parameters. The correlation coefficients (R²) for each graph are 0.93, 0.74, and 0.50, respectively.
McLaughlin Crater Summary

• Evidence for lacustrine setting
• Alkaline, saline, Mg-Ca-Fe-rich fluids
• Origin of fluids?
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