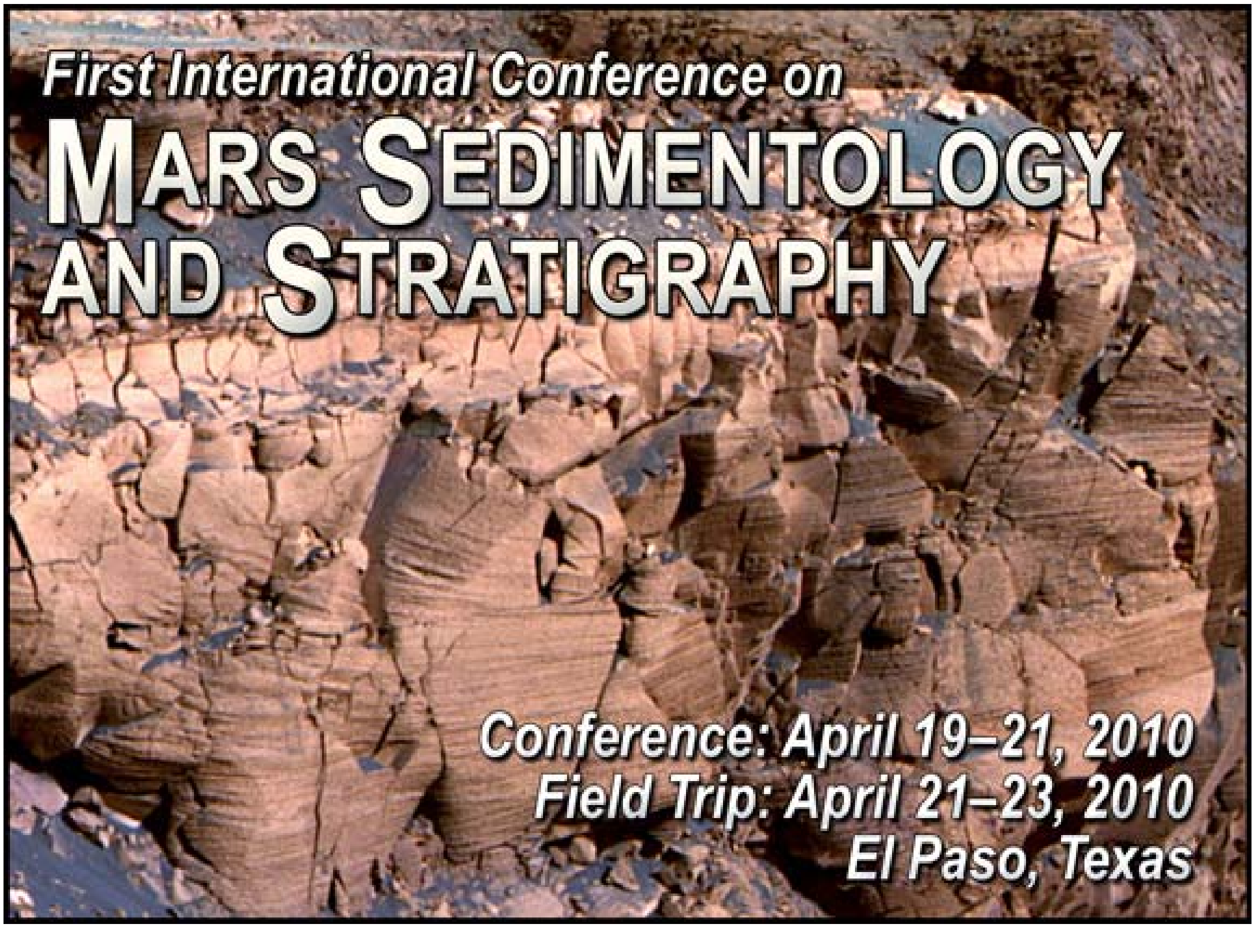

Program and Abstract Volume

LUNAR AND PLANETARY INSTITUTE

LPI Contribution No. 1547

First International Conference on
MARS SEDIMENTOLOGY AND STRATIGRAPHY

April 19–21, 2010

El Paso, Texas

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Preface

This volume contains abstracts that have been accepted for presentation at the First International Conference on Mars Sedimentology and Stratigraphy, April 19–21, 2010, El Paso, Texas.

Administration and publications support for this meeting were provided by the staff of the Publications and Program Services Department at the Lunar and Planetary Institute.

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Program

Monday, April 19, 2010
PLANETARY CONTEXT OF THE MARTIAN SEDIMENTARY SYSTEM
8:00 a.m. Franklin Ballroom

Chairs: **Dawn Sumner**
Sanjeev Gupta

8:00 a.m. Beaty D. W. Grotzinger J.
Welcome and Introduction

8:15 a.m. Grotzinger J. *
Sedimentary Rocks on Mars: Distribution, Diversity, and Significance **[#6068]**

8:45 a.m. Milliken R. E. *
The Mineralogical Evolution of Sedimentary Systems on Mars **[#6046]**

9:05 a.m. Andrews-Hanna J. C. * Zabrusky K. J. Arvidson R. E. Wiseman S. M. Murchie S. L. Wray J. J. Squyres S. W.
The Sedimentary Rocks of Early Mars: Global and Regional Hydrological Context **[#6062]**

9:25 a.m. Dohm J. M. * Davila A. F. Fairén A. G. Kim K. J. Mahaney W. C. Miyamoto H. Ori G. G.
Ancient Structurally-controlled Basins as Prime Martian Targets **[#6023]**

9:45 a.m. DISCUSSION

10:00 a.m. BREAK

10:15 a.m. Howard A. D. * Moore J. M. Grant J. A. Irwin R. P. III
Sedimentary History of the Southern Mid-Latitudes Near 180° Longitude **[#6027]**

10:35 a.m. Oehler D. Z. * Allen C. C.
Sediment Prediction Through Basin Analysis: An Example from Acidalia Planitia **[#6069]**

10:55 a.m. McLennan S. M. * [INVITED]
Geochemical Perspective of the Martian Sedimentary Rock Cycle

11:25 a.m. DISCUSSION

12:00 p.m. LUNCH BREAK

Monday, April 19, 2010
MINERALOGY AND STRATIGRAPHY
1:15 p.m. Franklin Ballroom

Chairs: **Ralph Milliken**
Gilles Dromart

1:15 p.m. Mangold N. * [INVITED]
Connecting Mineralogy to Morphology: A Key for Understanding Past Mars

1:45 p.m. Le Deit L. * Flahaut J. Quantin C. Bourgeois O. Hauber E.
Geologic Analysis of Various Hydrated Formations Exposed on the Plateaus Surrounding Valles Marineris, Mars **[#6032]**

2:05 p.m. Flahaut J. * Mustard J. F. Quantin C. Clénet H. Allemand P. Thomas P. Dromart G. Roach L. H.
Morphological and Spectral Evidence for Phyllosilicate-rich Layers and Major Geological Discontinuities in the Walls of Valles Marineris, Mars **[#6042]**

2:25 p.m. Wiseman S. M. * Arvidson R. E. Morris R. V. Seelos F. P. Andrews-Hanna J. C.
Stratigraphy of Al- and Fe-rich Phyllosilicates in Southern Sinus Meridiani **[#6058]**

2:45 p.m. DISCUSSION

3:00 p.m. BREAK

3:15 p.m. Loizeau D. Mangold N. Michalski J. Ansan V. Poulet F. Carter J. Bibring J.-P.
Mawrth Vallis: Stratigraphy of the Phyllosilicate-rich Unit at the MSL Landing Site **[#6029]**

3:35 p.m. Vaniman D. T. *
Mineralogy of Mars Analog Exploration Targets in the Todilto Formation **[#6035]**

3:55 p.m. Bristow T. F. * Milliken R. E. Grotzinger J. P.
Criteria for Identifying Neoformed Lacustrine Clays on Mars **[#6047]**

4:15 p.m. FOCUSED DISCUSSION: Geologic Time Scale

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POSTER SESSION
6:00 p.m. Sky Lounge

First author last names A–L will present posters 6:00–7:30 p.m.
First author last names M–Z will present posters 7:30–9:00 p.m.

Amos K. J. Gupta S. Goddard K. Kim J.-R. Muller J.-P.
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Denticles on Chain Silicate Grain Surfaces and Their Utility as Indicators of Weathering Conditions on Earth and Mars **[#6056]**

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Tuesday, April 20, 2010
PHYSICAL STRATIGRAPHY: SOURCE TO SINK
8:00 a.m. Franklin Ballroom

Chairs: **Abby Allwood**
Scott Mclennan

8:00 a.m. Ori G. G. * [INVITED]
Introduction to Fluvio-Deltaic Depositional Systems on Mars

8:30 a.m. Wilkinson M. J. *
Fluvial Sediment Accomodation and Mesoscale Architecture — Some Neglected Perspectives **[#6065]**

8:50 a.m. Metz J. M. * Grotzinger J. P. Mohrig D. McEwen A. Weitz C.
A Complete Depositional System in Melas Chasma, Mars **[#6001]**

9:10 a.m. Ehlmann B. L. * Mustard J. F.
Stratigraphy of the Nili Fossae and the Jezero Crater Watershed: A Reference Section for the Martian Clay Cycle **[#6064]**

9:30 a.m. DISCUSSION

9:45 a.m. BREAK

10:00 a.m. Kocurek G. * [INVITED]
Source to Sink: An Earth/Mars Comparison of Boundary Conditions on Aeolian Systems

10:30 a.m. Vasavada A. R. * Szwast M. A. Richardson M. I.
Surface Dust Redistribution on Mars as Observed by the Mars Global Surveyor **[#6059]**

10:50 a.m. Edgar L. A. * Grotzinger J. P. Hayes A. G. Rubin D. M. Squyres S. W. Bell J. F. III
Large-Scale Eolian Bedforms and Stratigraphic Architecture at Victoria Crater, Meridiani Planum, Mars **[#6007]**

11:10 a.m. Bishop M. A. * Wheeler A. J.
Sedimentological Anemometers: Ripples and Scour Flutes of the Strzelecki Desert, Earth and Hellespontus Intracrater Dunefields, Mars **[#6022]**

11:30 a.m. DISCUSSION

12:00 p.m. LUNCH BREAK

Tuesday, April 20, 2010
CRATER INFILL STRATIGRAPHY
1:15 p.m. Franklin Ballroom

Chairs: **Gary Kocurek**
Gian Ori

1:15 p.m. Gupta S. * Goddard K. Kim J.-R. Lin S.-Y. Muller J.-P. Mortimer E. Jordan O. Amos K. J. [INVITED]
Interpreting Deltaic Stratigraphy on Earth and Mars: How Easy is it and How Valid are Our Interpretations? **[#6061]**

1:45 p.m. Irwin R. P. III * Pendrill F. Maxwell T. A. Howard A. D. Craddock R. A.
Wind-eroded Floor Deposits in Noachian Degraded Craters on Mars **[#6063]**

2:05 p.m. Anderson R. B. * Bell J. F. III
Geomorphology and Inferred Stratigraphy of the Gale Crater Central Mound and Proposed Mars Science Laboratory Landing Site **[#6036]**

2:25 p.m. Switzer S. B. *
Origin, Evolution and Demise of the Eberswalde Crater Lake **[#6070]**

2:45 p.m. DISCUSSION

3:00 p.m. BREAK

3:15 p.m. Chan M. A. * Nicoll K. Jewell P. W. Parker T. J. Bills B. G. Okubo C. H. Komatsu G.
Geomorphic Evolution of Pleistocene Lake Bonneville: Temporal Implications for Surface Processes on Mars **[#6016]**

3:35 p.m. Rice M. S. * Bell J. F. III
Sedimentary Features Within the Proposed Mars Science Laboratory (MSL) Landing Ellipse in Eberswalde Crater **[#6038]**

3:55 p.m. Grant J. A. * Irwin R. P. III Wilson S. A.
Late Noachian Alluvial and Lacustrine Depositional Systems in Southwest Margaritifer Terra, Mars **[#6028]**

4:15 p.m. DISCUSSION

Wednesday, April 21, 2010
HABITABILITY AND PRESERVATION POTENTIAL
OF THE MARTIAN SEDIMENTARY RECORD
8:00 a.m. Franklin Ballroom

Chairs: **John Grant**
Nicolas Mangold

8:00 a.m. Sumner D. Y. *[INVITED]
Formation and Preservation of Microbial Biosignatures in Sedimentary Rocks

8:30 a.m. Allwood A. C. * Kanik I.
Formation of Stromatolites and Other Potential Microbially Influenced Structures and Textures in Terrestrial (and Martian?) Chemical Sediments **[#6039]**

8:45 a.m. Nicoll K. * Beer L. L.
Geobiology and Sedimentology of the Hypersaline Great Salt Lake, Northern Utah, USA: Analogues for Assessing Watery Environments on Mars? **[#6020]**

9:00 a.m. Summons R. E. *[INVITED]
Preservation of the Martian Organic and Environmental Records in Sedimentary and Other Environments

9:30 a.m. DISCUSSION

10:00 a.m. BREAK

10:15 a.m. CONFERENCE DISCUSSION

11:00 a.m. FIELD TRIP INTRODUCTION

12:00 p.m. Permian Basin Field Trip departs

FORMATION OF STROMATOLITES AND OTHER POTENTIAL MICROBIALLY INFLUENCED STRUCTURES AND TEXTURES IN TERRESTRIAL (AND MARTIAN?) CHEMICAL SEDIMENTS

A.C. Allwood[1], Isik Kanik[1], Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, USA. Abigail.C.Allwood@jpl.nasa.gov

The widespread occurrence of sulfates on Mars [e.g. 1, 2] suggests that chemical sedimentation was an important process in aqueous sedimentary environments in the martian past. The potential habitability of chemical sedimentary environments, such as evaporites, makes them a prime target for astrobiological exploration: in addition to being habitable, the rapid *in situ* mineralization that prevails in chemical sedimentary systems can promote the formation and preservation of biosignatures such as stromatolites and microbially-influenced textures, fossilized cells and organic material, and chemical fossils. However, the diagenetic processes in these systems may alternatively destroy biogenic features, partially overprint them, or otherwise confound their detection and interpretation. In addition, limited understanding of how microbes specifically influence or mediate sedimentation further complicates the interpretation of potential biosignatures. Much of what is known arises from studies of carbonate sediments and post-Archean environments (i.e. a period when the biosphere was well-established), and may therefore have limited applicability to sulfate systems on a planet where life may have flourished only briefly.

A better understanding of what microbially mediated structures may look like in an ancient martian evaporite deposit can be gained by examining partial analogues on Earth. Messinian (~6 Ma) gypsum stromatolites of Cyprus and Crete are well developed terrestrial examples of microbial sedimentary structures in ancient evaporitic sulfate deposits. Early Archean (3430 Ma) stromatolitic carbonates of the Strelley Pool Formation in the Pilbara, Australia, on the other hand, contain examples of probable microbially-influenced sedimentary structures formed in a very young biosphere [3, 4]. Between them, these formations provide important insights to some of the processes involved in formation of microbially-influenced structures and textures in Mars-relevant, chemical sedimentary systems.

Both the Messinian gypsum and Early Archean carbonate stromatolites show evidence of a complex mix of syn- and post-depositional, biological and non-biological processes. Those processes can include: chemical precipitation at the sediment-water interface; precipitation and settling of crystals from the water column; laterally or temporally heterogenous microbial mat development; templated mineral precipitation on microbial mats or adhesion of crystals to mats; displacive, replacive or inclusive growth of crystals in the subsurface; and early diagenetic dissolution-reprecipitation reactions. In the gypsum deposits, very early diagenetic processes (in the top few cm of the sediment pile) sometimes strongly influenced not only the textural evolution of the sediments and organic preservation, but also the development of high standing stromatolitic structures at the sediment-water interface. Conversely, there are also instances where the pre-existence of a stromatolite evidently influenced diagenetic crystal growth. The structures and textures found in these systems cannot therefore be considered simply as biotic or abiotic features formed at the sediment-water interface and subsequently affected by diagenetic processes, because in many cases the formation of diagenetic and syndepositional features was intrinsically linked.

To maximize the potential for detection and interpretation of potential microbial signatures in chemical sedimentary deposits, an in situ Mars rover mission would need significant exploration and measurement capabilities. These capabilities would include, for example: the ability to make mineralogical measurements, and to relate sub-mm and larger scale structure and texture to mineralogy; the ability to detect and map organic deposits in relation to visible features at mm- to cm scales; the ability to map basin architecture, stratigraphy and facies; and the ability to map the nature and distribution of potential bio-mediated features across the basin in relation to the palaeoenvironment. A mission with these capabilities would be well positioned to detect any biosignatures if they existed at the landing site. Alternatively, if no biosignatures are found, these capabilities would be essential to understand why the site may have been uninhabitable or unfavorable for biosignature preservation, and where we might next focus our search.

References: [1] Bibring J.P. et al. (2005) *Science, 307***,** 1576-1581. [2] McLennan, S.M. et al., (2005) *Earth Planet. Sci Lett., 240*, 95-121. [3] Allwood, A.C., Walter, M.R., Kamber, B.S., Marshall, C.P., Burch, I.W. (2006**)** *Nature, 414*, 714-718. [4] Allwood, A.C., Grotzinger, J.P., Knoll, A.H.., Burch, I.W., Anderson, M.S., Coleman, M.L., Kanik, I. *PNAS, 106*, 9548-9555

WHERE EPHEMERAL FLUVIAL SYSTEMS TERMINATE ONTO A PLAYA: THE TERMINAL SPLAY COMPLEXES OF LAKE EYRE, AUSTRALIA. EARTH ANALOGUES FOR MARTIAN DELTAS?

K. J. Amos[1], S. Gupta[2], K. Goddard[2], J-R. Kim[3], J-P. Muller[3]. [1]Australian School of Petroleum, University of Adelaide, Australia; [2]Dept. Earth Science & Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, UK; [3]Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Surrey, RH5 6NT, UK.

Introduction: Putative deltaic systems on Mars are a primary target for future robotic missions to Mars as they provide excellent potential sedimentary environments for signatures of life. However, interpreting sediment depositional bodies as deltas that developed at the margins of lacustrine systems is not straightforward. Prior to selecting future landing sites, we require detailed information on potential Earth analogues of martian deltas. Here, we analyze the morphology and sedimentology of sediment bodies formed at the terminations of ephemeral river systems and consider their potential as martian sedimentary analogues.

Lake Eyre setting: Lake Eyre is the world's fifth largest playa and depocentre for a 1.14 million km^2 dryland continental interior basin. Around the playa margin, ephemeral fluvial systems terminate in fan-shaped sedimentary deposits, called 'Terminal Splay Complexes' (TSCs). The northeastern rivers are mud-dominated, characterized by extensive catchments and receive the highest precipitation from tropical cyclones in far-northern Australia, whereas rivers in the western part are sand-dominated, have smaller catchments and comparatively little precipitation. These TSCs are used as a modern analogue for a number of ancient dryland fluvial-lacustrine sandstone successions and hydrocarbon reservoirs. The sedimentology of five Terminal Splay Complexes have been described, but these have only recently been compared in a way which enables some key conclusions to be drawn regarding their characteristics. Here, we present these conclusions alongside a new summary model for the sedimentology of TSCs.

Terminal Splay Complex systems: It is proposed that the morphology and sedimentology of Terminal Splay Complexes can be categorized into two groups: Confined and Unconfined. Confined TSCs contain well-developed channels in the proximal region, and amalgamated unconfined splay lobes in the distal reaches. The sedimentology of Unconfined TSCs is similar to that found in the distal reaches of Confined TSCs. Unconfined TSCs are a complex of amalgamated splay lobes, with flow at low discharges being generally concentrated between bars and splay lobes; they do not contain channels with well-defined banks or in-channel bars, as occur in the proximal-medial reaches of the Confined TSCs. The sizes of the studied Lake Eyre TSCs range from 80 km^2 to 0.1 km^2, with grain sizes ranging from clay to gravel. Confined and Unconfined TSCs cannot be grouped according to TSC area, catchment area or grain size. TSC area is not related to catchment area, although it appears that TSC width scales to the width of the fluvial channel at the TSC apex. This is unsurprising considering the spatial and temporal variability and discontinuity typical of ephemeral rivers, and could provide a useful predictive tool for geological modeling. Using these observations, the classification of TSCs within the context of splays and alluvial fans will be explored.

Relationship to fluvial discharge: In addition to an understanding of TSC geomorphology, understanding temporal variability in dryland systems is critical for usefully applying modern analogues to the geological record. Temporal variations on a short time-scale (tens to hundreds of years) include fluvial discharge and lake filling events during dry phases. These can result in wave and wind-tide reworking of sediments, producing characteristic wave and tidal sedimentary structures amongst an ephemeral fluvially-dominated deposit. Due to the ephemeral nature of sedimentation in these systems and low slopes, discrete lobes will be active during small discharge events which may have differing sediment characteristics to each other, and the TSC will accrete laterally as it progrades. Over longer time-periods, prolonged lake-level highstands during wet phases may result in the deposition of lacustrine muds over the TSC, and the sub-aqueous deposition of fluvially-sourced sediments may produce shallow lacustrine delta facies. These temporal variations in sedimentary processes have major implications for understanding the internal architecture characteristics of TSCs.

Mars analogues: We compare the Lake Eyre Terminal Splay Complexes to putative crater-lake deltas on Mars. We consider first the large-scale planform morphostratigraphy as observed in partially exhumed deposits. We then analyze HiRISE images draped on HiRISE DTMS to analyze stratigraphic elements and compare these to predicted stratigraphy in the TSCs in Lake Eyre.

GEOMORPHOLOGY AND INFERRED STRATIGRAPHY OF THE GALE CRATER CENTRAL MOUND AND PROPOSED MARS SCIENCE LABORATORY LANDING SITE. R. B. Anderson[1] and J. F. Bell III[1], [1]Cornell University, Department of Astronomy, Ithaca, NY 14850 (randerson@astro.cornell.edu)

Introduction: Gale Crater is located at 5.3°S, 222.3°W and has a diameter of ~150 km. It has been a target of interest due to the >5 km tall mound of sedimentary material that occupies the center of the crater, and its status as one of six possible landing sites for the Mars Science Laboratory (MSL) [1]. Proposed origins for the mound include: aeolian, lacustrine, pyroclastic, and spring mound deposits. [2-7] We have assessed these hypotheses by conducting a study of the proposed Gale Crater landing site and central mound [8], using data products from: CTX, HiRISE, MOC, THEMIS, CRISM, OMEGA, MOLA, and HRSC.

Results: Figure 1 shows an idealized cross-section of the units identified in the proposed landing site and the central mound. The upper mound (UM) exhibits a pattern that we interpret as cross-bedding (Figure 2), suggesting an aeolian origin for that unit. The UM lies unconformably atop the lower dark-toned layered yardang-forming unit (DTY), as shown by a channel in the western mound that ends at the UM. Layers within the DTY are parallel, planar and sometimes traceable for >10 km. This is inconsistent with a spring mound origin, but consistent with both lacustrine and aeolian origins. Volcanic and pyroclastic processes were probably not the dominant depositional processes due to the large distance between Gale and the nearest volcanoes. We interpret polygonal erosion-resistant ridges on the DTY as altered or cemented fractures, suggesting post-depositional aqueous activity. The phyllosilicate-bearing unit (PHY), first identified in CRISM observations [9], occurs in a trough formed by the light-toned ridge unit. PHY may be either altered material trapped in the trough, or the exposed surface of a thin phyllosilicate-bearing mound layer.

The landing site is centered on a fan-shaped unit subdivided into a proximal low-thermal inertia unit (LTIF) and a distal, stratigraphically lower high-thermal inertia unit. The apex of the LTIF occurs at the end of a branching channel extending from the crater rim. Elsewhere, the crater floor comprises hummocky plains (HP) of varying thermal inertia. A mesa-forming pitted or ridged "mound-skirting" unit (MSU) is common and appears to overlie floor units and some lower mound units. Both the HP and MSU preserve sinuous ridges which we interpret as inverted channels.

Conclusion: The UM appears to be aeolian in origin, based on the presence of textures interpreted as crossbeds. The origin of the remaining mound units is less clear, and could be consistent with aeolian and/or lacustrine but not spring mound deposits. The large exposed stratigraphic section at Gale crater, and the significant portion of Martian history which that section preserves, would be best understood by in-situ observations by a landed mission such as MSL.

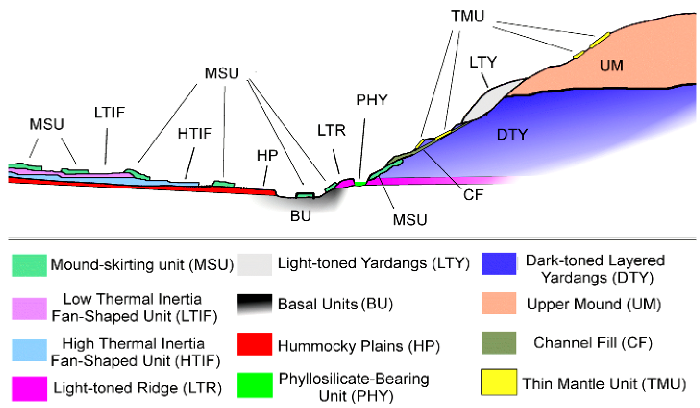

Figure 1: An idealized cross section (not to scale) through the proposed MSL landing site and central mound in Gale Crater.

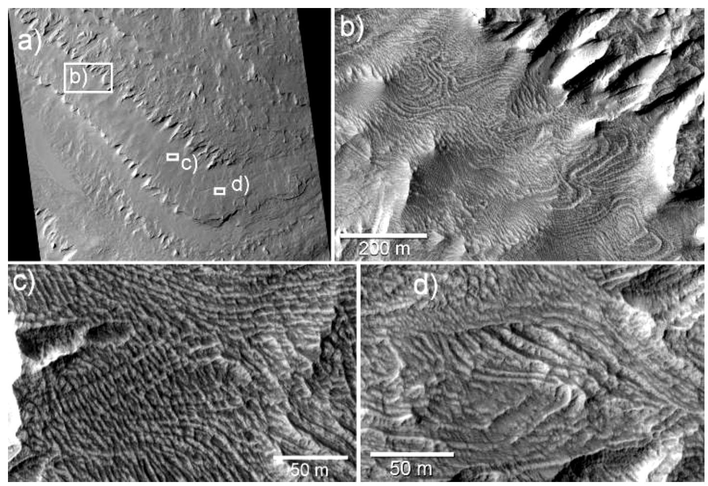

Figure 2: a) Subframe of HiRISE image PSP_001620_1750 of the upper Gale mound. b) An example of the unusual surface texture of the "bench" portion of the upper mound. c) Another location on the bench of an upper mound layer, exhibiting bands that appear to "zig-zag". d) A third location, with curved groups of bands that truncate each other, similar to aeolian crossbeds.

References: [1] http://marsoweb.nas.nasa.gov [2] Scott, D. H., et al. (1978). USGS Misc. Inv. Series Map I-1111. [3] Greeley, R., and J. E. Guest (1987). USGS Misc. Inv. Series Map I-1802-B. [4] Malin, M. C. and Edgett, K. S. (2000), Science 290, 1927-1937. [5] Scott, D. H., and M. G. Chapman (1995) USGS Geol. Series Map I-2397 [6] Cabrol, N. A. et al. (1999), Icarus 139, 235-245. [7] Rossi, A. P. et al. (2008) *JGR*, 113, E08016 [8] Anderson, R. B. and Bell, J. F. III (2010) *Mars* (Submitted). [9] Milliken, R. E. et al. (2009) *GRL* (In Press)

THE SEDIMENTARY ROCKS OF EARLY MARS: GLOBAL AND REGIONAL HYDROLOGICAL CONTEXT. J. C. Andrews-Hanna[1], K. J. Zabrusky[2], R. E. Arvidson[3], S. M. Wiseman[3], S. L. Murchie[4], J. J. Wray[5], and S. W. Squyres[5]. [1]Department of Geophysics and Center for Space Resources, Colorado School of Mines, Golden, CO, e-mail: jcahanna@mines.edu. [2]Department of Geology, Colorado School of Mines, Golden, CO. [3]Department of Earth and Planetary Sciences Washington University, St Louis, MO. [4]Applied Physics Laboratory, Laurel, MD. [5]Department of Astronomy, Cornell University, Ithaca, NY.

Introduction: The past decade of remote sensing and in situ exploration of the martian surface has revealed widespread sedimentary deposits. We synthesize recent observations and theoretical work that places these deposits within a global and regional hydrological context. Early observations revealed finely layered sedimentary rocks [1] and associated hematite [2] in Arabia Terra. Subsequent study by the Opportunity rover at Meridiani Planum revealed sulfate rich sandstones that formed in a playa environment in the presence of a fluctuating water table [3-7]. These deposits are part of a high thermal inertia unit that appears to be an erosional remnant of a once larger deposit [8]. Hydrated sulfates have also been identified in layered deposits elsewhere in Arabia Terra [9], in Valles Marineris and nearby chaos regions [10,11], and in Columbus crater [12]. These deposits record a period of widespread evaporitic sulfate deposition in the Late Noachian to Early Hesperian.

Global and regional hydrology: Hydrological modeling demonstrated that Meridiani Planum and the surrounding Arabia Terra region would have been characterized by a shallow water table and sustained groundwater upwelling, as a result of the unique topography of Arabia Terra [13-14]. Regional infilling of craters is followed by widespread sedimentary deposition over the plains of Meridiani. The predicted distribution of deposits where not buried by younger materials agrees well with locations of known sulfate-containing deposits (Figure 1). The widespread deposits predicted across Arabia Terra are supported by observations of large intra-crater deposits, pedestal craters, and other remnant deposits. Model predictions also agree with the locations of other sulfate deposits, including the interior layered deposits in Valles Marineris [15], sulfates within chaos regions at the sources of outflow channels [10], and sulfates within Columbus crater and other highland craters [12]. The modeled deposition rate is in agreement with the rate calculated by correlating the rhythmic bundling of layers with the obliquity cycle [16]. The dip direction and angle of the modeled deposit surface agrees well with the observed values [17].

Conclusions and implications: Morphological and mineralogical similarities among many of the widespread sulfate deposits argue for a commonality of origins. Hydrological models successfully predict the distribution, thickness, dip, and deposition rate of the deposits, and provide a global theoretical context in which to interpret the observed deposits. The hydrological cycle responsible for the groundwater upwelling that drove deposition requires both surface temperatures above freezing across much of Mars and low rates of precipitation to recharge the aquifers. The observed deposits appear to be an erosional remnant of a more extensive deposit that once covered much of Arabia Terra and infilled the Valles Marineris canyons.

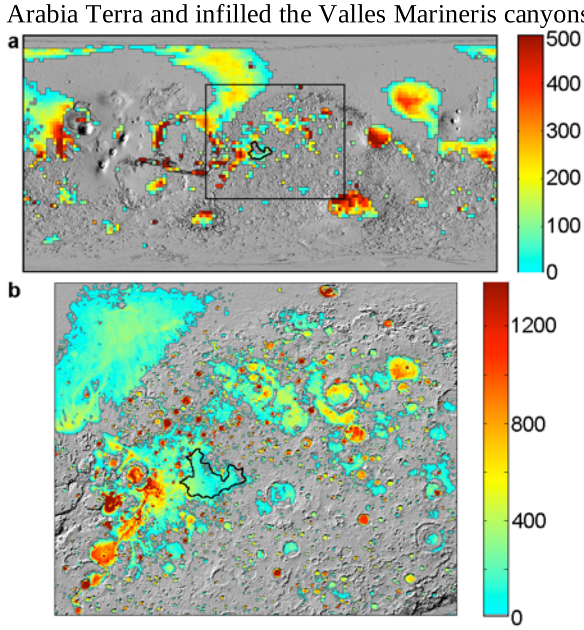

Figure 1. Predicted distribution and thickness (m) of evaporitic sulfates from (a) global and (b) regional hydrological modeling [14]. Location of the etched terrain [8] is outlined.

References: [1] M.C. Malin and K.S. Edgett (2000) Science 290 1927-1936. [2] P.R. Christensen (2001) JGR 106 22,823-22,871. [3] J.P. Grotzinger, et al. (2005) EPSL 240 11-72. [4] S.M. McLennan, et al. (2005) EPSL 240 95-121. [5] S.W. Squyres and A.H. Knoll (2005) EPSL 240 1-10. [6] S.W. Squyres, et al. (2009) Science 324 1058-1061. [7] R.E. Arvidson, et al. (2006) JGR 111 E12S08, doi:10.1029/2006JE002728. [8] B.M. Hynek (2004) Nature 431 156-159. [9] S.M. Wiseman, et al. (2010) J. Geophys. Res., doi:10.1029/2009JE003354, in press. [10] T.D. Glotch and P.R. Christensen (2005) JGR 110 E09006, doi:10.1029/2004JE002389. [11] A. Gendrin, et al. (2005) Science 307 1587-1591. [12] J.J. Wray, et al. (2010) in preparation for submission to JGR [13] J.C. Andrews-Hanna, et al. (2007) Nature 446 163-166. [14] J.C. Andrews-Hanna, et al. (2009) JGR doi:10.1029/2009JE003485, in press. [15] S.L. Murchie, et al. (2010) JGR 114 E00D05 doi:10.1029 /2009JE003343. [16] K.W. Lewis, et al. (2008) Science 322 1532-1535. [17] B.M. Hynek and R.J. Phillips (2008) EPSC 274 214-220.

TERBY IMPACT CRATER: AN EVIDENCE FOR A NOACHIAN SEDIMENTARY FILLING BY SUBAQUEOUS FAN DELTAS. V. Ansan[1], D. Loizeau[2], N. Mangold[1], S. Le Mouélic[1], J. Carter[2], F. Poulet[2], G. Dromart[3], A. Lucas[1], J-P. Bibring[2], A. Gendrin[2], B. Gondet[2], Y. Langevin[2], Ph. Masson[4], S. Murchie[5], J. Mustard[6], G. Neukum[7], [1] Laboratoire de Planétologie et Géodynamique de Nantes, Université de Nantes/CNRS UMR6112, 2 rue de la Houssinière, BP 92208, 44322 Nantes, France (veronique.ansan@univ-nantes.fr), [2] Institut Astrophysique Spatiale, Université Paris-Sud/CNRS, UMR 8617, 91405 Orsay, France, [3] Laboratoire de Sciences de la Terre, ENS Lyon/CNRS/Université Lyon 1, UMR 5570, 69622 Villeurbanne, France, [4] Lab. IDES, CNRS UMR 8148, Université Paris-Sud/CNRS, 91420 Orsay cedex, France, [5] Johns Hopkins Univ, Appl. Phys. Lab., Johns Hopkins Rd, Laurel, MD 20723 USA, [6] Brown Univ, Dept Geol Sci, Providence, RI 02912 USA, [7] FU, Berlin, Germany

Introduction: The 174 km diameter Terby impact crater (28.0°S - 74.1°E) located on the northern rim of the Hellas basin displays anomalous inner morphology [e.g. 1,2], including a flat floor and light-toned layered deposits [3, 4, 5]. An analysis of these deposits was performed using multiple datasets with visible images for interpretation, infrared data for mineralogic mapping, and topography for geometry. The geometry obtained was consistent with that of clastic sediments that settled mainly in a sub-aqueous environment during the Noachian period [6].

To the north, the thickest sediments displayed sequences for fan deltas, as identified by 100 m to 1 km long clinoforms, as defined by horizontal beds passing to foreset beds dipping by 6°-10° toward the center of the Terby crater [6]. The identification of distinct subaqueous fan sequences, separated by unconformities and local wedges, showed the accumulation of sediments from prograding/onlapping depositional sequences, due to lake level and sediment supply variations. The mineralogy for several layers with hydrated minerals, including Fe/Mg phyllosilicates, supports this type of sedimentary environment.

The volume of fan sediments was estimated as >5,000 km^3 [6] (a large amount considering classical Martian fan deltas such as Eberswalde (6 km^3) [7]) and requires sustained liquid water activity. Such a large sedimentary deposition is characteristic of the Noachian/Phyllosian era where the environment favored the formation of phyllosilicates, the latter detected by spectral data in layered deposits in three distinct sequences.

During the Hesperian period, the sediments experienced strong erosion, possibly enhanced by more acidic conditions (in the Theiikian), forming the current morphology with three mesas and closed-depressions. Small fluvial valleys and alluvial fans formed subsequently, attesting to late fluvial processes dated as late Early to early Late Hesperian. After this late fluvial episode, the Terby impact crater was submitted to aeolian processes and permanently cold conditions as confirmed by viscous flow features.

Therefore, the Terby crater displays, in a single location, geologic features that characterize the three main eras on Mars, with the presence of one of the thickest sub-aqueous fan deposits reported on Mars.

References: [1] De Hon (1992) *Earth, Moon, Planets 56*, 95-122 [2] Cabrol N. and Grin E. (1999) *Icarus 142*, 160-172. [3] Leonard, G. J. and Tanaka, K. L. (2001) USGS Geologic Investigations Series I-2694. [4] Malin, M. C. and Edgett, K. S. (2000) *Science 290*, 1927-1937. [5] Ansan V. and Mangold N. (2004) Mars. Early Mars Conference, Jackson Hole, USA. [6] Ansan V. et al. ,submitted to *Icarus*. [7] Malin, M. C.and Edgett, K. S. (2003). *Science 302*, 1931-1934..

MARS LOWLAND SEQUENCE STRATIGRAPHY – A CONCEPTUAL APPLICATION. D. C. Barker[1] and J. P. Bhattacharya[2], [1]University of Houston (University of Houston Geosciences, 4800 Calhoun Road, 77004), [2]University of Houston (University of Houston Geosciences, 4800 Calhoun Road, 77004).

Introduction: Sequence stratigraphic principles based primarily on stratal stacking patterns, sequence position and bounding surfaces [1, 2] are applied to describe an approach to the geochronological reconstruction of the Martian northern plains. Based on the hypothesized presence of an early ocean [3, 4], sediments associated with the erosion of the valley networks and later outflow channels, are expected to have been widely distributed throughout the lowlands [5, 6]. Regional scale unconformities are therefore postulated to result from these catastrophic floods throughout the end of the Hesperian and possibly into the Amazonian.

However, global environmental changes and a progressively cooling climate would have led to a protracted loss of surface water and eventual cold-trapping within the cryosphere or at higher latitudes -- resulting in a prolonged forced regression [7] within the depositional environment. Detrital sediments deposited onto the northern plains would constitute a Falling Stage Systems Tract (FSST) [8, 9]. A Highstand Systems Tract (HST) would have been emplaced at the time of maximum ocean level; and a sequence boundary (SB), which by definition is delineated when sea level first begins to drop and would lie between the HST and the FSST. Intermittent or cyclic episodes of flooding, erosion, icing and burial after the depletion of the early ocean would emplace additional sequences to the overlying and confining stratigraphy of the lowlands.

The Messinian Crisis [10, 11] is proposed as a potential terrestrial analogue of the depositional consequences of the removal of large standing bodies of water. This short lived event is estimated to have transformed as much as 6% of the Earth's ocean salt into a giant regressive evaporitic deposit that diachronously drapes the Mediterranean sea floor.

The model proposed herein is graphically depicted in Figures 1 and 2. Figure 1a shows an early Mars with the hypothesized northern ocean. This is followed by the progressive freezing, sublimation, and redistribution of water to the cryosphere and higher latitudes, resulting in a reduction of sea level as depicted in Figures 1b and 1c. This long term progressive loss of water constitutes the Martian forced regression. Figure 2a shows the early Hesperian with an established, dust and ice covered northern lowland sea and the beginnings of a phase of regional cyclic, flood-incurred stratigraphy. Finally, Figure 2b depicts the present surface covering the northern plains.

We therefore suggest that the evolution of such conditions on Mars would have led to the emplacement of diagnostic sequences of deposits and regional scale unconformities consistent with intermittent reponding, resurfacing, and the progressive loss of an early ocean by the end of the Hesperian.

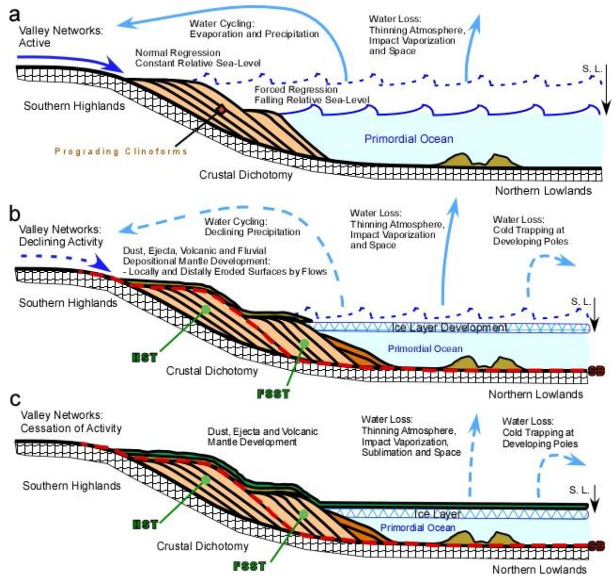

Figure 1. a) Early Noachian; b) Middle and Late Noachian; c) Early Hesperian.

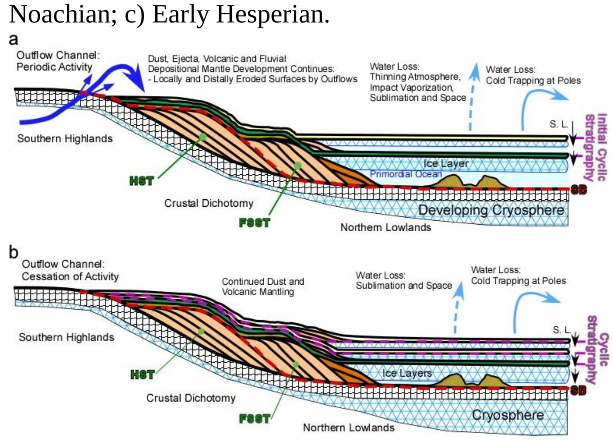

Figure 2. a) Middle and Late Hesperian; b) Amazonian.

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SEDIMENTOLOGY, STRATIGRAPHY AND ASTROBIOLOGY ON MARS IN 2018, POTENTIALLY USING TWO ROVERS. D.W. Beaty[1], A.C. Allwood[1], J. Vago[2], and F. Westall[3], [1]Mars Program Office, JPL/Caltech, [2]European Space Agency, [3]CNRS, France. Correspondence address: dwbeaty@jpl.nasa.gov.

Detailed study of the sedimentary record on Mars, both by *in situ* methods and by means of sample return, is becoming progressively more important as our Mars exploration strategies evolve from "follow the water" and "seeking habitable environments" to "seeking evidence of life" [1]. A key mission in the future exploration sequence is the proposed 2018 joint NASA-ESA rover mission, that would have both advanced capabilities for *in situ* science, and would collect and cache samples for possible subsequent return to Earth.

Present plans for the 2018 mission envision landing two rovers at the same site. The potential NASA-provided Mars Astrobiology Explorer-Cacher (MAX-C) rover and the ESA-provided Exo-Mars rover would have separately defined objectives related to seeking evidence of past - and possibly also present - life on Mars, in an environment with high inferred habitability potential. Possible collaborative science for the two rovers operating together is under discussion. The landing site for this potential two-rover mission probably would contain sedimentary rocks, as subaqueously deposited sediments are among the most prospective kinds of geologic environments in which to pursue these objectives.

If a sedimentary site is chosen for this proposed mission, the rovers would need to carry out a robust sedimentological field study, not only to maximize the chances of detecting potential biosignatures and selecting the best samples for analysis or possible return, but – crucially – to have the necessary contextual information to interpret potential biosignatures if any are found either *in situ* or upon return to Earth.

Science measurement capabilities: The two rovers would have different and complementary measurement approaches. The potential MAX-C science payload would have an approach similar to that on the Mars Exploration Rovers (MER), focused on analysis of outcrops through arm- and mast-mounted instruments, rather than onboard analysis of samples. However, MAX-C would have significantly updated instruments compared to MER, with the arm-mounted instruments capable of compositional micro-mapping rather than bulk compositional analysis. MAX-C would also have an instrument capable of detecting and micro-mapping organics. In effect, the envisioned MAX-C payload could carry out spatially-resolved geochemistry and rudimentary field petrography. These capabilities would be crucial for interpreting depositional and post-depositional history, and for discerning the possible influence of microbiological processes. The proposed MAX-C rover would also collect and cache shallow (~10cm depth) core samples for possible return to Earth by a future mission.

The ExoMars rover would include cameras and a close-up imager for surface studies, and would be able to investigate the shallow subsurface stratigraphy with ground penetrating radar, drill to 2m depth, measure compositional variations of the borehole walls, and collect and analyze small core samples with an on-board analytical laboratory. The laboratory would include a mass spectrometer for detecting and characterizing a broad array of organic molecules, a competitive immunoassay laboratory-on-a-chip sensor for detecting specific biomarkers, a microscope (15 µm resolution), and instruments for mineralogy analyses including X-ray diffraction and IR and Raman spectrometers. A range of potential collaborative possibilities arise from the currently envisioned payloads of the two rovers, or from small modifications of those payloads.

Possible exploration strategies: The rover *Opportunity* demonstrated the first *in situ* sedimentology/stratigraphy studies on another planet, and that experience constitutes a valuable guide for future exploration approaches. If the MSL (2011) landing site is in sedimentary terrane (that decision is still pending), the MSL rover's experiences will further expand our understanding of exploration strategies. For the proposed 2018 rovers, there are two important kinds of open planning questions. Firstly, how should the two rovers be equipped (in the case of MAX-C, the instruments have not yet been selected). Secondly, how should the rover capabilities be used, separately and jointly, to interrogate sedimentary rocks? Another important consideration would be how to balance the collection of compelling samples (which are best recognized after a certain amount of field analysis has been conducted) against the ticking mission clock and limited number of opportunities to collect samples.

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SEDIMENTOLOGICAL ANEMOMETERS: RIPPLES AND SCOUR FLUTES OF THE STRZELECKI DESERT, EARTH AND HELLESPONTUS INTRACRATER DUNEFIELDS, MARS. Mark A. Bishop[1,2] and Andrew J. Wheeler[1], [1]Barbara Hardy Centre [Terrain Analogue Understanding (TAU) research], School of Natural and Built Environments, University of South Australia, Adelaide, SA, 5000, Australia, [2]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106 Tucson, AZ 85719-2395, USA, bishop@psi.edu.

Introduction: Aeolian landscapes comprise a range of landform dimensions that are capable of differentiating global (regional) and local variations in wind direction and relative strength through time. Dune slipface orientation and associated metrics are commonly used as a reference for past and present sediment mobility [1], however little use has been made of micro-scale sedimentological features such as ripples and scour flutes, for either terrestrial or extra-terrestrial studies. Previously, Sharp [2], Howard [3], and Bishop [4] have used surficial sedimentological features formed by air flow over and around dunes to successfully determine antecedent wind conditions. Using a suite of features inclusive of ripple patterns, Bishop [4] showed that trimodal seasonal and diurnal wind directions and relative intensities were accurately recorded for the Strzelecki desert. Furthermore, it was found that the genesis and evolution of scour flutes around obstacles of aeolinite also identified the variability and intensity of wind direction. Scour development required that a cementing agent (montmorillonite) act cohesively on the unconsolidated substrate. Such processes and agents also occur on Mars, and are likely to significantly contribute to the relative immobility of dunes and large-scale ripples.

Results: Ripple Patterns for Hellespontus: Data from the High Resolution Imaging Science Experiment (HiRISE) offers an orbital perspective of Mars at a spatial resolution (25.5 cm/pixel) that identifies large-scale (mega-) ripples and scour around obstacles such as boulders (Fig. 1). Image ESP_06036_1370 comprises an intracrater dunefield (42.7°S, 38.0°E) that shows ripple morphologies that are likely to be associated with changes in grain-size and breaks in slope, alongside differences in shear stress and air flow velocity. The southern portion of the dunefield (Fig. 1) shows a suite of ripple patterns, ranging between straight, bifurcating, sinuous and catenary-to-lunate forms. Interference patterns are prevalent across the entire range of morphologies, which for those of catenary shape, form a reticulate or network arrangement [Fig.1. (B)]. Raised rectilinear ridges (spurs) parallel to flow [5] also assist with the reticulate form of adjoining ridges.

Ripple trains are oriented both parallel [Fig.1 (A)] and orthogonal [Fig. 1 (C)] to the direction of dune migration which indicates a bidirectional wind regime. The north-south (orthogonal) patterns are secondary ripple-sets formed by lower intensity winds relative to the west-east oriented primary ripple trains. Ripple troughs and crests are differentiated by albedo, which in terrestrial settings represents grain-size sorting and often, heavy mineral separation. The absence of any significant disturbance to ripple form by cross-cutting dust devils suggests the ripples to be chiefly composed of granules and/or be indurated bedforms. Similarly, the occurrence of numerous boulder induced scour flutes may infer sediment cohesion.

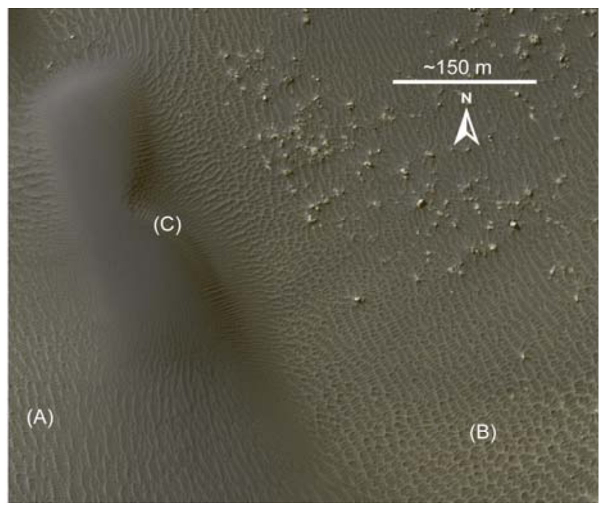

Fig. 1. Southern part of intracrater dunefield showing interference ripple patterns across the boulder laden floor of an unnamed crater (Image: ESP_06036_1370_COLOR, NASA/JPL/University of Arizona).

Conclusions: Surficial sedimentary structures offer detailed data from which planetary boundary conditions at the surface-air interface can be better interpreted, and for conducting risk analyses for siting and operating landers and rovers on planetary surfaces. Monitoring studies of ripples and scour features would also better define aeolian erosion rates and sediment mobility for Mars, than does dune monitoring alone.

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EARLY ARCHAEAN SHALLOW WATER SEDIMENTS AS ANALOGUES FOR NOACHIAN SEDIMENTS ON MARS. N. Bost[1], F. Westall[1], C. Ramboz[2], and M. Viso[3], [1]Centre de Biophysique Moléculaire-CNRS-OSUC, Rue Charles Sadron, 45071 Orléans, France nbost@cnrs-orleans.fr), [2]Institut des Sciences de la Terre-CNRS-OSUC, 1a rue de la Férollerie, 45071 Orléans, France, [3] Centre Nationale d'Etudes Spatial, 2 place Maurice-Quentin, 75039 PARIS CEDEX 01, France.

Introduction: The geological and environmental conditions of Mars and Earth during their youth were, in some respects, similar in that Mars had considerable quantities of water during the Noachian and possibly the Hesperian, including large, water-filled basins/impact/volcanic craters [1]. Associated sedimentary deposits derived from the volcanic materials that covered the planet would include volcaniclastics and products of aqueous and hydrothermal alteration. These kinds of igneous and sedimentary materials were common in Early-Mid Archaean (3.5-3.3 Ga) rocks in South Africa (Barberton) and Australia (Pilbara), making them good analogues for the martian Noachian period (3.8 to 3.5 Gy). Study of the mineralogy, texture, structure, and traces of life in these materials provides an extremely useful indication of what could possibly be expected in martian rocks, especially in view of the planned ESA-NASA two rover mission 2018. The mission objective for the European ExoMars rover is the search for traces of life, past or present, on Mars, whereas the NASA Max-C rover objectives are to cache suitable samples for return to Earth by a subsequent mission.

The 3.45 Ga-old Kitty's Gap Chert: The 3.45 Gy-old Kitty's Gap Chert (fig.1) consists of silicified volcanic sediments deposited in a coastal mudflat environment [2-4]. The black and grey banded rock consists of millimetre to centimetre-thick layers of volcaniclastic sediments exhibiting structures such as parallel, wavy, ripple, flaser, and channel bedding, intraformational breccia etc, that document an infilling tidal channel. These structures are highlighted on the exposed rock surface by weathering. The sediments were silicified during early diagenesis, the silica coming largely from silica-saturated seawater as well as a minor local hydrothermal source. Prior to silicification, the volcanic particles were altered to phyllosilicates by aqueous activity and then partially replaced by silica during silicification. The Kitty's Gap Chert contains a variety of cryptic carbonaceous biosignatures. Small colonies of 0.5-0.8 µm-sized coccoidal microfossils coat the volcanic particles and occur in the fine dust layers. Hiatus surfaces are coated with a biofilm consisting of coccoids, chains of coccoids, filaments (~0.3 µm diameter), rods (<1 µm long), polymer and resedimented portions of torn-up microbial mats. These structures are not defintively identifiable by optical microscopy – high resolution SEM and in situ analyses are necessary to determine their biogenicity. Bulk C contents and isotope compositions of individual layers are 0.01-0.05 % and ~-26 to – 28 ‰ respectively.

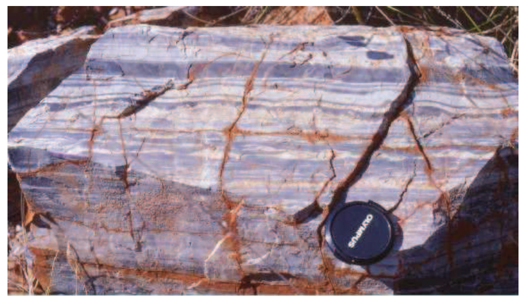

Fig.1 : Outcrop of Kitty's Gap chert in Pilbara.

The 3.3 Ga-old Josefsdal Chert consists of silicified volcaniclastic sediments deposited in a similar shallow water environmental setting to the Kitty's Gap Chert. The sediment exhibits a variety of structures including, importantly, macroscopic biolamination. Carbonaceous layers represent the remains of anaerobic photosynthetic microbial mats, as well as sedimented bio-detritus [5]. The microbial mats were constructed by small 0.25 µm thick microbial filaments that are individually not visible optically. Bulk carbon contents of this rock range up to 0.01-0.07% and C isotopes from – 23 to -27‰.

Conclusions: Early Archaean terrestrial sediments are useful analogues for Noachian sediments. The methods necessary for studying the traces of the primitive anaerobic life that they contain demonstrate the limitations and constraints of *in situ* missions such as the 2018 Max-C and ExoMars mission and emphasise the necessity of returning samples to Earth.

Acknowledgements: CNES, OSUC for funding.

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THE USE OF CHEMCAM ON MSL FOR SEDIMENTOLOGICAL AND STRATIGRAPHIC STUDIES

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Introduction: The investigation of sedimentology and stratigraphy will be a paramount objective of the Mars Science Laboratory (MSL). The ChemCam instrument, with the ability to remotely determine the elemental composition of rocks and soils, combined with high resolution imaging, will provide both tactical and scientific data for the rover.

Instrument Description: ChemCam uses a laser to ablate a thin layer of material to form a plasma. Emitted light is detected by 3 spectrographs, from which characteristic emission lines are read. This technique, known as laser-induced breakdown spectroscopy (LIBS), has been used in the laboratory [1-4], providing an extensive calibration library under terrestrial pressure or vacuum (such a library for Mars conditions is under construction by the ChemCam team), and was first proposed for planetary investigation in the early 1990s [5]. The laser spot size is ≤ 1 mm and range is 1.5-7 m, providing the ability to remotely determine the fine-scale elemental composition of rocks and soils with a precision of ±10% . The same telescope optics for the laser are also used in a passive mode, with light fed to a CCD imager. This Remote Micro-Imager (RMI) has a pixel scale of 21-22 μrad, which translates to a resolution of ~100 μrad [6].

Science Objectives: ChemCam provides measurements applicable to 3 of the 4 MSL science themes 1) Organic geochemistry and biosignatures, 2) inorganic chemistry and mineralogy, and 3) geology. ChemCam investigations to support these objectives include rapid remote rock identification [7], soil and pebble surveys, detection of hydrated minerals, analysis of weathering rinds, remote identification of organic minerals, and geomorphology and rock texture studies.

Role and Operations on MSL: ChemCam plays both a tactical and scientific role on MSL. Over the course of the mission, ~20,000 LIBS analyses are anticipated, dictated by the expected laser lifetime. Mission planning exercises project 6-20 analyses per sol. ChemCam will be used to assess regions of interest, with the results fed into tactical planning of where to send the rover for in situ investigation by the analytical instruments (APXS, CheMin, and SAM). A standards library will be compared to the ChemCam LIBS results to provide rapid elemental abundance measurements and rock identification [7].

Sedimentological and Stratigraphic Studies: Sedimentary rocks are one of the most important lithologies that MSL will visit, irrespective of what landing site is chosen. With its <1-mm laser spot size, ChemCam will be able to map out the elemental abundance of individual stratigraphic beds at fine scale. Chemical changes related to grain size and texture can be determined. These measurements include those on steep scarps or rough terrain, that are inaccessible to MSL. Elements sensitive to redox state (e.g., S, Fe, and Mn) can be identified and minerals related to pH (e.g., jarosite, alunite, kaolinte, carbonates) can be inferred based on elemental abundance. Remote micro-imaging will provide information on texture and rock fabric, including aeolian, playa and fluvial-lacustrine textures that form in dry to sub-aqueous environments. LIBS will provide information on diagenetic components, including matrix cements, silica and carbonate and concretions, such as the "blueberries" at Meridiani. Organic carbon that may be present, especially in lacustrine clay deposits may also be detected. LIBS will be able to "clean" off dust and weathering rinds to measure the pristine composition of sedimentary layers. For example, simulations with the "Slow Motion Field Test" (a rehearsal of MSL science activities, with natural targets and blind identification by the instrument teams) show the ability of ChemCam to remotely identify mudstone, dolomite, and sulfate [8]. Similarly, multivariate analysis of LIBS spectra show that igneous standards and a variety of sedimentary rocks can be identified [4]. On Mars, ChemCam will provided detailed elemental abundance and imaging data of these and any other sedimentary rocks that MSL finds.

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CRITERIA FOR IDENTIFYING NEOFORMED LACUSTRINE CLAYS ON MARS.

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Introduction: Mg/Fe smectites are widely reported from the Martian surface [1]. They are found interbedded with sulfate deposits in stratified sediments that fill craters and other depressions [2], and have been detected in deltas and other distributary deposits interpreted as supplying basins with water and sediment [2-5]. However, the origin and locus of formation these clays remains an open question.

On Earth, Mg-smectites such as saponite, stevensite and other Mg and Fe-rich authigenic clays are common constituents of modern and ancient lake sediments deposited under alkaline/saline conditions [6]. They form via transformation of detrital precursors washed into the basin, or by direct precipitation from pore fluid or solution. The clay assemblage that forms, as well as the types of accompanying authigenic minerals reflect local chemical conditions and the availability of reactive detrital clays in sediments. Therefore the identification of neoformed clays in lacustrine deposits on Mars could yield information about the physio-chemical conditions within lakes and the hydrological history of basins.

Neoformed clays on Mars: The identification of neoformed clays in putative Martian lacustrine strata is made difficult because the surface is largely basaltic. Saponites and nontronites are typical weathering and hydrothermal alteration products of basalts [6], and so there are probably ample external sources of clays that could be reworked by wind or water and deposited in basins. Even with detailed crystallographic, textural and chemical information the mineralogy alone is probably inadequate to prove that a particular clay formed in a lake. The types of clays found in terrestrial lake deposits may also differ from clays that might form in lakes on Mars. For instance, carbonate minerals and species in solution play an important role in the chemical evolution of lake waters on Earth and the precipitation reactions of some clays [7]. But carbonates seem to be a minor phase in Martian sediments and are not detected in most clay-bearing strata [8]. We propose that a better strategy for identifying clays forming in lacustrine settings on Mars is to look at the spatial and temporal distribution of clays and other authigenic mineral phases via the stratigraphic record. Looking for diagnostic stratigraphic patterns in the distribution of clays in Martian sediments provides a more robust means of distinguishing neoformed clays than mineralogy alone because these patterns are a determined by physical processes that ultimately control sedimentation and the hydrology of lacustrine basins.

Tests: The following criteria may help identify neoformed clay minerals in Martian lake deposits. More detailed information on these criteria will be presented based on terrestrial examples of modern and ancient lacustrines systems.

1) Recognizing differences in clay mineralogy of hydrologically closed vs. open basins. Neoformation of clays mainly occurs during periods of hydrological closure when clays become an important terminal ionic sink. At other times when a basin has an outlet the clay mineralogy is dominantly detrital and reflects mineral inputs from the catchment [9]. Identification and comparison of the Martian deposits formed in open and closed systems (for which there may be independent geomorphic or sedimentological evidence [10]) may demonstrate clay neoformation.

2) Concentric zonation of clays and other authigenic minerals. When a basin contains neoformed clays they often display concentric distribution that will also be expressed in other authigenic minerals such as zeolites, silica, phosphates and evaporites [11].

3) Stratigraphic changes in mineral assemblages. The hydrological balance in closed basins is particularly sensitive to external forcing, such as orbitally induced insolation changes. Concentric mineralogical facies are a temporal snapshot and over time their distribution and composition will continuely evolve with lake level. If clay neoformation is occurring then these changes should show up in the stratigraphic record, perhaps in a cyclical fashion, if there is a regular forcing mechanism [12].

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VOLUMETRIC ANALYSIS OF THE REULL VALLIS FLUVIAL SYSTEM IN THE EASTERN HELLAS REGION OF MARS: INVESTIGATION INTO THE CONTRIBUTIONS OF WATER. Eileen J. Capitoli[1] and Scott C. Mest[2], [1]Department of Earth and Environmental Science, University of Pennsylvania, 240 South 33rd Steet, Phildelaphia, PA 19104-6316, ecap@sas.upenn.edu [2]PSI, Planetary Geodynamics Laboratory, Code 698, NASA Goddard Space Flight Center, Bldg. 34, Rm. G288, Greenbelt, MD 20771, mest@psi.edu.

Introduction: This study evaluates the fluvial and erosional history of the eastern Hellas region of Mars by investigating the sources of water that carved the Reull Vallis (RV) outflow system**.** RV is located east of Hellas Basin in the Hesperia Planum and Promethei Terra regions of Mars (Figure 1). We estimate the volumes of the morphologically distinct segments of the RV system in order to determine the contributions of water to the system. Its source area (segment 1; S1) is believed to have provided the water for the main canyon (segments 2 and 3; S2 and S3) [4]. A large topographic depression, the Morpheos Basin (MB), separates S1 and S2, and is believed to have stored the effluents of S1 plus water from adjacent highland terrains until its divide was breached, thus carving S2 and S3 [1,3]. Teviot Vallis (TV) is identified as an additional source area that is believed to have enlarged S3 downstream [4].

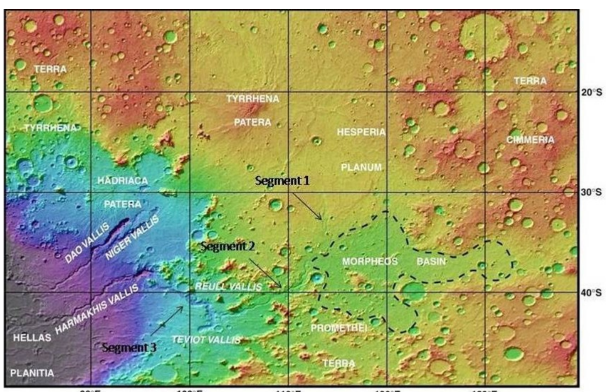

Figure 1. MOLA topographic map of the eastern Hellas region. Segments 1-3 of Reull Vallis are shown along with its side canyon - Teviot Vallis. The Morpheos Basin, as defined by [2, 3] is outlined by the black dotted line.

Method: Volumes were estimated using the MOLA 64 pixels/degree DEM with the IDL-based module GRIDVIEW [5]. In order to obtain the most accurate volumes, we divided each segment of RV into subsegments, such as subsegment 2I of S2. For each subsegment, the contour where the slope of the plains intersects the slope of the canyon wall is used to define the canyon rim. In this example, we use the 250 m contour as the topographic rim of this subsegment. Subsegment volumes were then added together to provide the total cavity volume for each segment. For MB, we measured its volume using different contour levels (650, 600, 550, 500, and 450 m) as its extent,

Results:. We estimate the volumes of S1 and S2 to be roughly equivalent, 2,377.2 km^3 and 2,320.5 km^3, respectively. The volumes of TV and S3 were estimated to be 3,917.8 km^3 and 8,159.4 km^3, respectively. Lastly, the volume of MB at the 650 m contour was found to be 17,138 km^3.

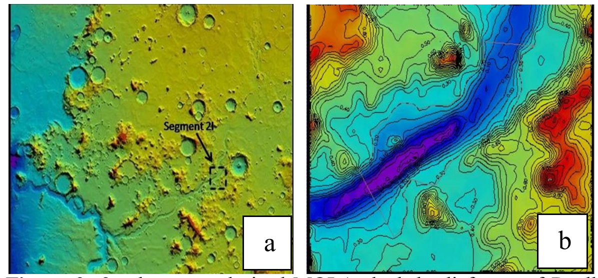

Figure 2. 2a shows a colorized MOLA shaded relief map of Reull Vallis, and the location of subsegment 2I (black dashed box). 2b shows a close-up MOLA contour map of subsegment 2I.

Discussion: Our estimates of S1 and MB suggest that water expelled from S1 could not have filled the basin to the 650 m contour. If MB was filled to the 650 m level, its release would have formed a much larger S2 than is currently observed. Our results show that S1 was likely the sole source for the water that carved S2, suggesting only the western side of the basin may have contained water, possibly to either the 450 m (160.5 km^3) or 500 m (983.5 km^3) contour levels, assuming that there was only one pulse of water released from S1. However, it is possible that more than one pulse of water was released from S1 based on the much greater combined volume of S2 and S3 (10,479.9 km^3) compared with that of S1 and TV (6,295.0 km^3), leaving 4,184.9 km^3 worth of water missing. If S1 and TV were the sole sources of water for S2 and S3 combined, than those volumes should be equivalent. Since the volume of the canyon is much greater than that of its sources, it is possible that there were multiple pulses of water released from S1 which may have filled the MB to the 550 m level (4,142.5 km^3) instead, which could account for the missing water since it is equivalent in volume. It is also possible that a second pulse of water was released from TV which could account for the missing water. This may explain why S3 is significantly greater than its source areas - S2 and TV - combined (6,238.3 km^3). This additional pulse of water may have contributed to the enlargement of S3. Some other possible factors include; 1) the presence of a pre-existing aquifer in the area around S3; 2) the drastic slope increase in the lower part of S2 may have increased eroding power of the water as it approached S3; 3) sediment buildup on the floors of the source channels could be underestimating their volumes; and/or 4) a blocked connection between the terminus of RV and the head of Harmakhis Vallis may have resulted in backcutting of S3.

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Continuous Particle Size Mapping of Alluvial Fan Material in Mojave Crater from HiRISE Imagery. P. E. Carbonneau[1] K. Goddard[2], S. Gupta[2]. [1] Durham University, Dept. Geography, Science Laboratories, DH1 3LE, UK. patrice.carbonneau@dur.ac.uk. [2]Dept. Earth Science & Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, UK.

Introduction: In terrestertrial environments, the need to understand sediment size distributions across entire watersheds has prompted much research and progress in the field of fluvial remote sensing [1]. As a result, it is now possible to continuously map riverbed material grain sizes at submetric resolution with the use of high resolution airborne imagery [2]. In these fluvial environments, image texture is strongly correlated with the particle size of the exposed material. Once this relationship is calibrated, it is possible to measure grain sizes continuously over very large areas with the use of high resolution aerial photography. Calibration of these methods usually requires field measurements of grain size [2]. However, it has also been demonstrated that grain sizes can be continuously mapped without the need for such field-based calibration data [3]. Furthermore, the findings of [2] show that the minimal grain sizes that can be measured with this method approach half-pixel sizes. When applied to HiRISE imagery having a resolution of 25cm, these methods could potentially measure particles as small as large cobbles, continuously, for extended areas. To our knowledge, no comparable data exists for this size range. Such data could allow for significant advances in our understanding of alluvial fans on Mars where the full understanding of the dynamic processes responsible for the formation of these fans is currently hindered by the lack of data on particle size [4]. Consequently, this paper discusses the use of recent grain size mapping methods developed for terrestrial rivers in a Martian context. Specifically, we show that HiRISE images of Mojave crater are of sufficient spatial and radiometric resolution to allow for large scale, continuous, size measurements of coarse (cobble and above) sediments.

Methods: A method dubbed 'aerial photosiving' [3] was employed in order to collect a calibration data set. This involves direct, on-screen measurements of boulders in HiRISE images of Mojave Crater. A boot strapping approach, combined with a Monte Carlo parameter optimization, is then employed to find the optimal texture parameters. This then allows for the production of optimized grain size maps.

Preliminary Results: The initial results derived from a 250 point calibration dataset showed that texture was correlated with visible particle sizes with an r^2 of 0.32. This relationship is significant at the 99.99% confidence level. Whilst weaker than those observed [2,3], it clearly demonstrates that grain size information can be derived from HiRISE imagery. Figure 1 shows an example of an image and the associated grain size map. Future work, to be presented at the conference, will focus on improving the optimization with additional calibration points and on the estimation of reliable error bounds for the grain size estimates.

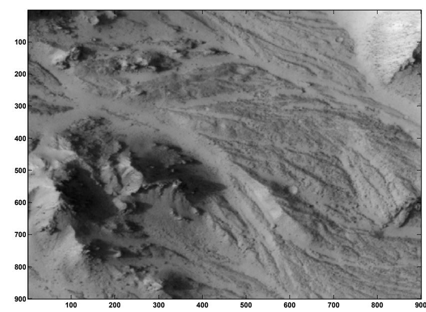

Figure 1A: Sub-image of Mojave Crater extracted from HiRISE tile PSP_002167_1880

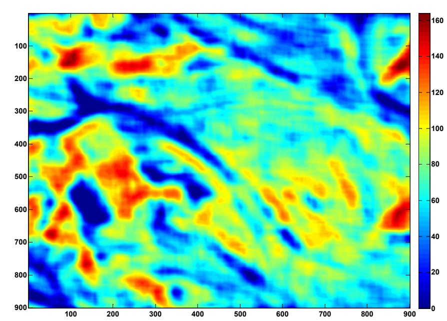

Figure 1B: Grain size map for the sub-image in 1A. The map gives median grain size for local areas of 45X45 pixels (11.25m). Fine grained channel patterns are identified as well as coarse boulders and crags.

Conclusion: This work demonstrates that cobble and boulder sized materials can be continuously measured from HiRISE imagery. Such information is highly valuable and will help to constrain the geomorphic processes which have created these alluvial fans.

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GEOMORPHIC EVOLUTION OF PLEISTOCENE LAKE BONNEVILLE: TEMPORAL IMPLICATIONS FOR SURFACE PROCESSES ON MARS. Marjorie A. Chan[1], Kathleen Nicoll[2], Paul W. Jewell[1], Timothy J. Parker[3], Bruce G. Bills[3], Chris H. Okubo[4], and Goro Komatsu[5]. [1]University of Utah, Department of Geology and Geophysics, 115 S. 1460 E. Rm. 383 FASB, Salt Lake City, UT 84112-0102, marjorie.chan@utah.edu, [2]University of Utah, Department of Geography, Salt Lake City, UT 84112, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [4]U.S. Geological Survey, Flagstaff, AZ 86001, [5]International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy.

Introduction: Pleistocene Lake Bonneville of the Great Basin offers unparalleled insight into temporal constraints for understanding the development of similar analog environments and processes on Mars. The extensive and well preserved lake system exhibits many intact features that include: prominent shorelines, spits, bay mouth barriers, deltas, gullies, outburst channels, and playa lake features, including patterned grounds and downwind aeolian systems. Although water is recognized as a geomorphic agent on Mars, remotely sensed datasets by themselves have limited utility for inferring how long it took for the formation of specific features. With the Lake Bonneville analog, we can address how long standing water might be geomorphically effective, and infer the rate of development for specific landforms (e.g., coastlines, wave-cut terraces, outflow channels, rills).

A wealth of recent data collected by instruments such as Mars Odyssey's THEMIS (Thermal Emission Imaging System), Mars Reconnaissance Orbiter's CTX (Context Camera), CRISM (Compact Reconnaissance Imaging Spectrometer for Mars), and HiRISE (High Resolution Imaging Science Experiment), and the Mars Exploration Rovers' Athena payload, allow new outcrop-scale analyses that were not previously possible. Terrestrial analogs provide ground-truth to aid in interpretation of these Mars datasets [1].

Background: Two decades ago, Lake Bonneville was proposed as an analogue for understanding putative lakes on Mars because it was a better comparison than Earth's tidal oceans, given the anticipated lack of tides on Mars. [2,3,4]. Current Mars datasets can greatly improve these past interpretations. Correspondingly, we also have enhanced our knowledge of Lake Bonneville history, the subtleties of superimposed landforms, its stratigraphy and sedimentology, and surface water dynamics.

Justification: There are many easily accessible sites in close proximity within the Bonneville basin (~50,000 sq km), where the lack of vegetative cover is an advantage for remote imaging at various scales by satellite or robotic instruments. The dry, desert climate and modern wind processes of the Bonneville basin are comparable to Mars and its current surface.

Most importantly, Lake Bonneville is an ideal analogue for describing standing water as a geomorphic agent on Mars because of the following reasons.

(1) Its oscillating water levels left an extensive record of erosional and aggradational sedimentary features that developed over different timescales, ranging from gradual (e.g., wave-cut shoreline terraces, lobate fan deltas) to the sudden or catastrophic (e.g., outburst channels, boulder-strewn plains). The wide range of landforms, some showing cross-cutting relationships, is similar to Mars (gullies, channels, deltas, fans, shorelines).

(2) Evaporates in the lowstand, remnant Great Salt Lake have similar mineralogies to the Burns Formation on Mars, with the potential for understanding life (astrobiology) in extreme environments.

(3) Lake Bonneville persisted at highstand around the Last Glacial Maximum (~20 ka BP in C-14 years) until a catastrophic outburst flood event ~14.5 ka BP. The warming climate produced rapid drying. We know the time constraints on outbursts as well as drying cycles.

(4) The extensional tectonic setting produced steep margin sides similar to the morphologies of Martian craters that held ancient lakes.

(5) Changing water loads of Lake Bonneville produced isostatic adjustments reflected in the shorelines; this can have important implications for understanding crustal properties on Mars.

Summary: Our inventory of sedimentary and landscape features from Pleistocene Lake Bonneville is valuable for interpreting new imagery from Mars missions. The temporal constraints from the Bonneville analog have critical implications for understanding the rate of geomorphic processes and the evolution on Mars.

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GENETIC MODELS OF IRON OXIDE CONCRETIONS ON EARTH AND MARS. Marjorie A. Chan[1], Sally L. Potter[1], Erich U. Petersen[1], and Brenda B. Bowen[2] [1]University of Utah, Department of Geology and Geophysics, 115 S. 1460 E. Rm. 383 FASB, Salt Lake City, UT 84112-0102, marjorie.chan@utah.edu, [2]Department of Earth and Atmospheric Sciences, Purdue University, West Lafaytte, IN 47907.

Introduction: Terrestrial studies of iron oxide concretions have been encouraged by the Mars Exploration Rover (MER) Opportunity discovery of similar "blueberries" in the Burns formation [1,2,3]. Although decades ago concretions were viewed simply as geologic "curiosities", it is now clear that the presence of concretions has important implications for groundwater movement and chemistry, diagenesis, host rock properties, and iron cycling through time.

The exact origin of iron oxide concretions and genetic models of how they form are not simple. There are many factors to consider including the nature of the open (vs. closed) system, supply of reactants, composition of the water(s), temperature, pH, water-rock interactions, diffusive rates, nucleation kinetics, biomediation, and fluctuating water table or reaction fronts. Jurassic Navajo Sandstone examples show a wide range of varieties, shapes and sizes indicating multiple diagenetic precipitation and mobilization events [4]. Cretaceous sandstone examples from the Western Interior associated with coal forming environments show pyrite precursors that typically alter to the iron oxide mineralogies [5]. Modern concretion examples form in extreme acid and saline syndepositional to early diagenetic conditions over short time scales of hundreds of years [6]. Laboratory bench tests cannot replicate the natural diagenetic settings, but they can simulate concretion-like nucleates with strong chemical solutions [7]. Mars is likely unique in its own particular setting of the sulfate and basaltic sandstone and extreme chemical solutions (by Earth standards). Thus, there are multiple genetic models that can arrive at a final end product of iron oxide concretions. These studies collectively can provide a better understanding of the subtleties and details of water-rock interactions on Earth and Mars.

Discussion: The common occurrence of terrestrial concretions in a wide range of mineralogies (carbonates, iron sulfides, and iron oxides) suggest that concretion formation is a common geologic process in near surface, porous sediments and sedimentary rocks, and thus is is not surprising that similar concretions were discovered in sedimentary deposits of Mars. There can multiple chemical pathways and successive transitions from initial different iron-rich mineralogies, ending at metastable goethite or stable hematite end products.

Iron oxide concretions typically lack a nucleus, yet some cement textures show a component of inward growth (similar to a geode). Nucleation centers that produce smaller spheroids are far more abundant and commonly aggregate and coalesce to make larger forms. Kinetic factors and iron supply in addition to permeability/tortuosity paths likely affects the concretion mineralogy and geometry or spacing. Both terrestrial occurrences and the Mars examples with its extreme chemical settings suggest that concretion formation can span a wide range of temperature (diagenetic to even hydrothermal) and chemical conditions.

Areas for continued concretion research lie in several approaches. Eventually, if appropriate standards can be obtained, it should be possible to analyze iron isotopes *in situ* to look at subtle changes or gradients in cementation. Any modeling of the concretions is difficult because there are so many assumptions. However, sensitivity tests for different parameters in model equations can help show the magnitude of influence of those factors. Ancient concretions typically lack datable material to pinpoint the timing of diagenetic events, and the record that remains may represent a preservational bias. However, more detailed studies of the chemistry and textural and mineral relationships may help elucide the relative timing and perhaps even the role of biomediation.

Summary: Concretions are significant records of groundwater flow through porous sedimenetary deposits. It is likely that the "simple", solid, spheroidal Mars "blueberries" formed relatively quickly with abundant iron supply by diffusive mass transfer. Terrestrial examples record a longer and more complex diagenesis than Mars, perhaps because Earth has been a water planet for more of its history.

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INVESTIGATING THE PROCESSES CREATING GULLIES ON MARS. K.A. Coleman[1], J. Dixon[1,2], K. L. Howe[3], V. F. Chevrier[1] 1 W.M. Keck Laboratory for Space Simulations, Arkansas Center for Space and Planetary Science, MUSE 202, Fayetteville, Arkansas, USA < ksacolem@uark.edu>, 2 Dept. of Geological Sciences, 113 Ozark Hall, University of Arkansas, Fayetteville, Arkansas, USA.

Introduction: Since gullies were first identified on Mars by Malin and Edgett [1] the processes operating on the surface to create the gullies have been studied. [2-9]. We developed simulations to explore the parameters controlling gully formation on Mars. The simulations have included pure water and various water/ice slush concentrations in an attempt to constrain the processes creating gullies on Mars.

Methods: In attempt to address the enigmatic processes on Mars, we created a 1 m x 1 m flume filled with medium grain size sand and ran water down the slopes creating gullies with the same alcove, channel, apron form as gullies observed in satellite imagery from Mars [10-11]. Based on these simulations and suggestions that surface and subsurface ice could be partially melted by summer insolation [6] we developed a 3 m x 0.5 m hinged flume and began using water/ice slush [12] to better simulate the gradient of the slope observed on Mars.

Discussion: Our initial results showed that gullies could be created with morphometric forms similar to gullies observed on Mars using water. Statistically significant relationships were found between flow rates and several morphometric parameters. Evaporation rates have recently been shown to be lower on Mars than originally suggested [13, 14] which supports the presence of liquid water on the surface for periods of time sufficient to create gullies. As we adjusted the simulations by adding ice crystals to the slush and more closely emulate martian conditions, the forms created became more like those of traditional martian gullies. Length/width ratios have been calculated for traditional gullies on Mars and for the simulations. The pure water simulations have average gully length width ratios of 2.18 while the water ice simulation have an average length/width ratio of 2.10. Length/width ratios for traditional gullies calculated from HiRISE imagery of give values of 2.05 suggesting that the water/ice slush simulations are a better match for the processes overating on Mars than the pure water simulations.

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SULFATES FORMATION BY WEATHERING OF SILICATES AND SULFIDES ON MARS: EXPERIMENTAL APPROACH. E. Dehouck[1], V. Chevrier[2], A. Gaudin[1], N. Mangold[1], P.-E. Mathé[3], P. Rochette[3], [1]LPGN, CNRS/Univ. Nantes, 2 chemin de la Houssinière, 44322 Nantes Cedex 3, France, erwin.dehouck@univ-nantes.fr, [2]Arkansas Center for Space and Planetary Science, MUSE 202, University of Arkansas, Fayetteville, AR 72701, USA, [3]CEREGE, Europôle Méditerranéen de l'Arbois, BP80, 13545 Aix-en-Provence Cedex 4, France.

Introduction: Meridiani Planum shows a sulfate-dominated paragenesis in sediments that have been reworked by shallow water and eolian activity [1]. Several hypotheses have been proposed to explain the formation of these deposits (playa evaporates, volcanism, etc. [2,3,4,5]), but none of these models has been tested experimentally. In its original theoretical work, R. Burns suggested that sulfides like pyrite or pyrrhotite, abundant in martian shergottites, rather than atmospheric SO_2, were the source of sulfur in the alteration process [6]. In this study, we focused on the weathering of pure silicates and their mixtures with pyrrhotite.

Experimental protocol: We used several primary silicates previously observed on Mars, including olivine forsterite (a dunite, Ol1, and monocrystals from Pakistan, Ol2), orthopyroxene from Ronda, Spain (OPx), and clinopyroxene from Vesuvium, Italy (CPx1). All phases were also weathered as 50/50 wt% mixtures with hexagonal pyrrhotite $Fe_{0.9}S$ (HPy). 10 g of finely powdered phases/mixtures were put in the upper part of a desiccator, the lower part of which was previously filled with 1 L either of DI water (H_2O) or of water containing 33% of hydrogen peroxide (H_2O_2). The desiccators were then equilibrated with gaseous CO_2 at a pressure of 0.8 bar and the temperature was maintained in the range 15-20°C. The final products have been characterized using X-ray diffraction (XRD) and SEM.

Results: Based on preliminary XRD analyses (Table 1), we observe two different weathering assemblages.

Pure silicates. After 4 years, silicates did not show significant alteration. Only olivine showed development of minor nesquehonite $MgCO_3.3H_2O$ in 3 samples.

Mixtures with pyrrhotite. Contrary to pure silicates, mixtures showed extensive weathering, not only of the pyrrhotite but also of the silicates, as testifies the presence of Ca and Mg sulfates (Table 1). All samples showed the formation of elementary sulfur and gypsum. In addition, hexahydrite was observed in 5 out of the 6 samples and jarosite was observed in 3 samples of pyroxene, but not on olivine. Finally, goethite appeared in all samples.

Weathering processes: according to our preliminary results, we can draw the following observations:

1 – Weathering is very different in the presence of sulfides compared to silicates alone. For silicates alone, weathering appears very limited in intensity. Alternatively, in the presence of sulfides, silicates are readily weathered into Ca and Mg sulfates, depending on the primary silicate composition. This indicates that pyrrhotite alteration promotes silicates weathering probably through acidification of the medium. Alteration of pyrrhotite itself leads to the formation of jarosite and the excess of iron leads to goethite.

2 – Weathering is quite similar between the H_2O-bearing atmosphere and the ($H_2O+H_2O_2$)-bearing one.

Conclusion: Our experiments showed that the weathering of silicates and sulfides in simulated martian conditions leads to the formation of Ca, Mg and Fe sulfates, in addition to elementary sulfur and goethite. These results demonstrate that the sulfide-induced weathering hypothesis [7] is a plausible process for the formation of the Meridiani Planum paragenesis.

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	Initial assemblage				Sulfur & sulfates					
Samples (see text for meaning of the names)	Olivine	Clinopyroxene	Orthopyroxene	Pyrrhotite	Sulfur	Gypsum	Hexahydrite	Jarosite	Goethite	Nesquehonite
Ol1-H_2O	X		X							
Ol1-H_2O_2	X		X							X
Ol1-HPy-H_2O	X		X	X	X	X	X		X	
Ol1-HPy-H_2O_2	X		X	X	X	X	X		X	
Ol2-H_2O	X									X
Ol2-H_2O_2	X									X
CPx1-H_2O		X								
CPx1-H_2O_2		X								
CPx1-HPy-H_2O		X		X	X	X	X	X	X	
CPx1-HPy-H_2O_2		X		X	X	X		X	X	
OPx-H_2O			X							
OPx-H_2O_2			X							
OPx-HPy-H_2O			X	X	X	X	X		X	
OPx-HPy-H_2O_2			X	X	X	X	X	X	X	

Table 1. Summary of primary and secondary phases observed after 4 years of weathering, based on XRD analyses.

ANCIENT STRUCTURALY-CONTROLLED BASINS AS PRIME MARTIAN TARGETS.
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Introduction: On Earth, biology, hydrology, and geology are interwoven such that certain types of life are linked with specific geologic, hydrologic, and climatic conditions, which include rock type, pressure, temperature, and chemistry. Life has found a niche in diverse environments, and this presents the possibility that Mars, too, may record fossilized and/or extant life in diverse settings. Geologic, paleohydrologic, and climatic conditions through the evolution of Mars are similar in many respects to conditions occurring during the evolution of the Earth, and as such, may point to environments on Mars with potential to have supported living systems. Candidate environments include: long-lived magmatic complexes (including hydrothermal environments [1]), subterranean caverns [2], basins/aquifer systems [3], structurally-controlled conduits and basins [4], evaporite deposits such as salts [5], possible marine and lacustine sediments [6], Antarctic-like paleosols [7], vent structures such as mud volcanoes [8], and ice bodies such as ice lenses [9].

Of the listed environments, all of which are considered as prime targets for future international exploration of Mars, ancient structurally-controlled conduits and basins will be presented at the workshop.

Basins/aquifer systems: Tectonic structures of various relative ages of formation can reveal stress sources [10], strain magnitudes and history [11,12], and pre-existing structural controls that may be related to episodes of local to regional magmatism and tectonism [4,12] on planetary bodies such as the Earth and Mars [13]. In addition, tectonic structures can control the migration of fluids such as magma and water, as well as heat, in the subsurface, influencing volcanic and hydrogeologic activity, as observed for Mars such as within the Thaumasia highlands region [14] and for Earth such as noted for the Atacama Desert [15] and Solfatara Crater, Italy [16]. As energy plus water is often considered a prerequisite of life [17], such environments where magmatism, tectonism, and aqueous activity interact in space and time, as especially highlighted in the Atacama Desert, are considered to be environments of elevated life potential [18]. In the Atacama Desert, such interaction includes: (1) the formation of elongated basins/valleys through magmatic- and plate tectonic-driven deformation, which are subsequently partly infilled by evaporite and alluvial fan deposits, and (2) fractures, faults, and complex fault systems forming conduits for the migration of subsurface and surface flow of water (e.g., the flow of groundwater, which sources from the Andes, migrates across the Atacama Desert in the subsurface along basement structures having an influence on life, transects the Coastal Range, and eventually debouches into the Pacific Ocean). The Martian deposits such as identified in the structurally-controlled basins of Terra Sirenum [19] bear strong similarities to evaporitic deposits found in the structurally-controlled basins of the Atacama Desert [20], which have been recently recognized as an important niche for life in the extreme arid conditions [21]. Such environments ought to be targeted by international missions to Mars.

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LARGE-SCALE EOLIAN BEDFORMS AND STRATIGRAPHIC ARCHITECTURE AT VICTORIA CRATER, MERIDIANI PLANUM, MARS. L. A. Edgar[1], J. P. Grotzinger[1], A. G. Hayes[1], D. M. Rubin[2], S. W. Squyres[3], J. F. Bell III[3] . [1]Division of Geological and Planetary Sciences, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125, [2]USGS, Santa Cruz, CA 95060 [3]Cornell University, Ithaca, NY 14853. ledgar@caltech.edu

Abstract: The Mars Rover *Opportunity* has recently completed its observations of Victoria crater, the largest crater yet explored by the rover at Meridiani Planum. At ~750 m in diameter, Victoria crater exposes cliffs up to ~15 m high, revealing thick bedsets (3-7 m) of large scale cross-bedding, interpreted as fossil eolian dunes. *Opportunity* was able to drive into the crater at Duck Bay, located on the western margin of Victoria crater. Data from the Microscopic Imager and Panoramic Camera reveal details about the structures, textures, and depositional and diagenetic events that influenced the Victoria bedrock. Detailed stratigraphic analyses at Duck Bay, and nearby promontory Cape Verde suggest that these outcrops may be part of a larger-scale draa architecture. This insight is possible only due to the larger-scale exposures at Victoria crater, which significantly exceed the more limited exposures at previously explored Erebus, Endurance, and Eagle craters.

Stratigraphy at Duck Bay and Cape Verde: A lithostratigraphic subdivision of bedrock units was enabled by the presence of a light-toned band that lines the rim of the crater. *Opportunity's* ingress path intersects three stratigraphic units, named Lyell, Smith and Steno, in ascending stratigraphic order; Smith is the light-toned band. All three units consist of sulfate-rich cross-bedded sandstone, interpreted as fossil eolian dunes. Smith is interpreted as a diagenetic band, exhibiting a lighter tone and poor expression of lamination consistent with recrystallization. Evidence of the diagenetic unit reworked in the impact breccia indicates that Smith formed prior to the crater impact. Strike and dip measurements, calculated from Pancam stereo imagery, show that the units dip 2^o to the west (away from the center of the crater) likely as a result of the impact. The contact between Smith and Lyell is gradational, but the contact between Smith and Steno is erosional and dips $\sim 10^o$ to the southeast. These units, define the "Reference Section" for Victoria crater.

After completing its observations at Duck Bay, *Opportunity* made a close approach to nearby outcrop Cape Verde, which contains a light-toned band similar in thickness to that of Smith, overprinting well-laminated sandstone with low-angle cross-bedding. The base of the Cape Verde cliff face contains a truncation surface dipping $\sim 10^o$ to the southeast. Given that the erosional contact at the base of Steno also has a $\sim 10^o$ dip, and the two exposures of the surface lie in the same plane, we infer that the erosional contact at the base of Steno correlates with the erosional surface at the base of Cape Verde.

Reconstruction of Eolian Bedforms: The erosional surface likely represents the migration of a dune across a larger bedform, known as a draa [1, 2]. The erosional surface indicates deposition by the same bedform on pre-existing topography, with deposition occurring close in time between locations (note that the dune would have arrived at different locations at different times). Analysis of cross-bedding geometry reveals that strata below the erosional surface dip to the W/SW, while strata below the surface dip to the SE. This suggests that the erosional surface may represent a draa-scale reactivation surface, responding to shifting wind directions. This interpretation is consistent with observations of terrestrial draas, which may contain reactivation surfaces representing the migration of dunes across a draa in opposite directions [3]. Alternatively, the opposing dip directions of the strata above and below the erosional surface may represent the migration of sinuous-crested bedforms, which can produce cross-beds that dip toward nearly all azimuths.

Conclusions: The strata exposed at Duck Bay and Cape Verde indicate deposition in an eolian dune environment, with further modifications though diagenesis. In the Reference Section, Smith is interpreted as a secondary, diagenetic unit, whose lower boundary also coincides with a primary, erosional contact, but elsewhere in the crater the diagenetic unit cross-cuts the primary stratigraphic surfaces. Correlation with Cape Verde suggests that there is an erosional surface at the base of the cliff face that likely corresponds to the erosional contact below Steno. This surface is interpreted to represent the migration of a dune across a draa. Additionally, the presence of several orders of bedforms and a complex wind regime suggest that the strata may have been part of a very large sand sea, with no evidence for aqueous deposition as observed at Eagle and Endurance. Victoria crater not only reveals the regional extent of processes seen elsewhere in Meridiani Planum, but the greater size of its outcrop exposures reveals the building of ever larger eolian bedforms.

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STRATIGRAPHY OF THE NILI FOSSAE AND THE JEZERO CRATER WATERSHED: A REFERENCE SECTION FOR THE MARTIAN CLAY CYCLE. B. L. Ehlmann and J. F. Mustard, Department of Geological Sciences, Brown University (bethany_ehlmann@brown.edu).

Introduction: The last of the major Martian impact basins is the Isidis basin, which formed at ~3.96 Ga [1]. In and around its western margin are well-exposed sections of ancient Noachian crust that are covered in the south by Hesperian lavas of the Syrtis Major formation, emplaced at ~3.7 Ga [2]. Data from orbiting visible/near-infrared imaging spectrometers have revealed geographically extensive and diverse alteration minerals in these Noachian terrains including smectites, kaolinite, chlorite, zeolites, Mg carbonates and serpentine [3-7]. The area is also morphologically diverse: fractures hundreds of km in length concentric to the Isidis basin (the Nili Fossae) expose a deep stratigraphy and extensive fluvial dissection has both incised the crust to reveal stratigraphy and has produced sedimentary rock units. Particularly notable is the 15,000 km^2 system of valleys which comprises the watershed of Jezero crater, an open basin paleolake with a well-preserved delta comprised of clay and carbonate sediments [8-9].

In the clay cycle of Mars, tectonic processes (e.g., metamorphism, uplift) and burial diagenesis of sediments play a minimal role while impact processes, weathering, and fluvial transport are of utmost importance. The area in and around the Nili Fossae, including the Jezero crater watershed, preserves a record of all major elements of the Martian clay cycle. The diversity of clay forming and transporting environments observed in this region is unique on Mars. Data from this well-preserved stratigraphic sequence allows a coherent, time-ordering of alteration processes on Mars from middle Noachian to early Hesperian. Here we focus on sediment sources and sinks and evidence for the importance of weathering and fluvial processes.

Sediment sources: *(1) The megabreccia basement*: On Mars, the lowermost stratigraphic units are megabreccias, generated by impact processes early in the planet's history. Impacts were critical in the Martian clay cycle by (1) redistributing already formed clays and (2) generating hydrothermal systems in which new clay minerals formed. The Nili Fossae expose a >600-m thick unit of brecciated, Fe/Mg smectite clay-bearing materials resulting from disruption during Isidis basin formation [5]. The bulk materials are mafic but contain both unaltered (low calcium pyroxene-bearing) and altered (Fe/Mg smectite-bearing) breccia blocks, some of which exhibit fine-scale layering, i.e. they represent fragments of pre-existing stratigraphies. (2) *Ultramafic impact melt/lava:* Overlying the basement megabreccia unit along the easternmost fossae is a banded, draping unit enriched in olivine (~30 wt. %). It is thought to represent materials excavated from Mars' lower crust/upper mantle during the Isidis impact event and emplaced as impact melt [5] or komatiitic lavas emplaced shortly after the basin formed [10].

Pedogeneisis/near-surface alteration: Near-surface, in-situ alteration of the different precursor lithologies has resulted in distinctive stratigraphic sections. Along the eastern fossae, the olivine-bearing unit sometimes shows signs of alteration to magnesium carbonate and serpentine, as in alteration of ultramafic bodies on Earth [6-7]. The result is carbonate capping smectite clays. To the west, in some locations, rocks and sediments derived from the basement megabreccia are capped by a thin (<10s of meters), unit of kaolinite-bearing materials. A plausible scenario for this stratigraphy is the leaching of Fe, Mg, and Ca from the underlying materials and the transformation or neoformation of Al-rich clays as in pedogenesis [6].

Fluvial transport/deposition: Walls of topographic lows such as craters and the fossae are dissected by channels and infilled by sediments [4]. Weathering and fluvial transport processes were clearly active at the same time. For example, a one 40 km crater has been infilled by >1km of Fe/Mg smectite-bearing sediments. The upper 10-30 m of fill have been altered to form kaolinite, and this stratigraphy has subsequently been eroded (and hence exposed) by fluvial erosion.

Valleys sourced in and around the Nili Fossae drain into 45-km Jezero crater from the north and west and cut through the stratigraphy of megabreccia and the olivine rich unit. The ~800m (1,000 km^3) of fill in Jezero is far more than the 58 km^3 eroded to form the main valleys, consistent with landscape denudation by surface runoff within the watershed rather than erosion by sapping activity. Jezero crater hosted an open lake system and the western delta within has lobes indicating channel-switching events and epsilon cross-beds formed during lateral accretion. The minerals comprising the deltaic sediments are Fe/Mg smectite clays and Mg carbonates. Although neoformation in crater lake waters is possible, given this mineralogy, the simplest explanation is detrital transport. The assemblage suggests neutral to alkaline waters since acidic waters over long periods of time would destroy carbonates.

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MORPHOLOGICAL AND SPECTRAL EVIDENCE FOR PHYLLOSILICATE-RICH LAYERS AND MAJOR GEOLOGICAL DISCONTINUITIES IN THE WALLS OF VALLES MARINERIS, MARS. J. Flahaut[1], J. F. Mustard[2], C. Quantin[1], H. Clenet[1], P. Allemand[1], P. Thomas[1], G. Dromart[1] and L. H. Roach[2]. [1]Laboratoire de Science de la Terre, UMR CNRS 5570, Université Claude Bernard/Ecole Normale Supérieure de Lyon, 2 rue Raphaël Dubois, 696222 Villeurbanne Cedex, France (jessica.flahaut@ens-lyon.fr). [2]Department of Geological Sciences, Brown University, Providence, RI 02912.

Introduction: The early history of Mars is still unclear, and could be recorded in the walls of Valles Marineris, which are as deep as 11 km, and evidenced major discontinuities. Previous studies [1] show that the upper parts of the walls are likely made of layered basalts, related to Tharsis volcanism, in most of the chasmata. Beneath these basalts may be exposures of sedimentary deposits and Noachian crust [2,3].

The present study investigates the walls located in Coprates Chasma, using CRISM (The Compact Reconnaissance Imaging Spectrometer for Mars) and HiRISE (High Resolution Imaging Science Experiment) data. Coprates Chasma is an approximately 1000 km long and 150 km wide linear canyon which extends from Melas Chasma to Capri Chasma, at the outlet of Valles Marineris. As it has not been filled with large interior layered deposits (ILDs), Coprates Chasma has been proposed to be a graben that may have opened after that most of the canyons were already emplaced [4]. Therefore Coprates Chasma exhibits the most well-exposed cross-section of the upper-most material of the crust through its walls.

Spectral identification: CRISM multispectral and hyperspectral data were processed as in [5,6], and merged with CTX and HiRiSE data into a GIS. CRISM data have spatial resolutions ranging from 200 to 18 m/px while HiRiSE observations give details up to 25cm/px. Combining these data allows us to assess the units carrying the mineralogical signatures. Four spectral types were identified, corresponding to characteristic morphologies at different elevations. A typical cross-section of the walls in Coprates Chasma can then be established, and geological discontinuities can be assessed. The upper and middle part of the walls is generally depleted in any spectral signature. The mineralogy of the walls becomes really significative under -400 m in elevation, where Fe/Mg phyllosilicates are detected [7]. Low-calcium pyroxenes (LCP) are also identified within the walls [8]. They do not seem to be aligned at a constant elevation but are distributed -1400 and -2400m in the northern wall of Coprates Chasma. They are underlained by dark basal layers where olivine signature has been detected.

Morphological observations: The upper walls correspond to typical 'spurs and gullies' morphologies [9]; these dusty talus could reasonnably explain why we don't see any mineralogical signature. Phyllosilicates detections are generally associated to morphological dark boulders in the deepest spurs, and sometimes to some dusty talus inherited from the above boulders. At this depth, stratification is not visible anymore and the lower albedo of the rubbly deposits cropping out along the spurs suggests we have gradually reached another morphological unit in the stratigraphic sequence of the walls.

On the other hand, pyroxenes signatures are correlated with light-toned brecciated outcrops. There is a sharp contrast between this light-toned deposits, which look massive, indurated and made of bright clasts, and the overlying dark boulders of phyllosilicates. The typical 'spurs and gullies' leave place to a less competent bright material, forming a hole in the topography.

In the northern wall, this massive bedrock is underlained by thin dark layers, which correspond to by terraces that crosscut the walls around -4000m in elevation.

Nevertheless, in the central horst of Coprates Chasma, on one CRISM observation, this pyroxene-rich bright deposits seem underlained by another phyllosilicate-rich layer, sealed between two layers of volcanic rocks.

Conclusion: The cross-section of the walls of Valles Marineris exhibits different units, sometimes with sharp discontinuities, recording the past conditions of the surface. A simple lava stack cannot explain the entire cross-section observed in Coprates Chasma. The deepest exposures have compositions seen elsewhere in Noachian crust (enrichment in LCP and phyllosilicates). The uppermost Hesperian-aged layers are generally depleted of any infrared mineral signatures. The occurrence of a phyllosilicate –rich layer under the LCP-rich bright-deposits in the central horst could mark a alteration front, sealed by younger lava floods.

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MINERALOGY AND GEOLOGY OF THE SULFATE-RICH DEPOSITS OF CAPRI CHASMA, VALLES MARINERIS, MARS. J. Flahaut[1], C. Quantin[1], P.Allemand[1] and P.Thomas[1]. [1]Laboratoire des Sciences de la Terre, UMR CNRS 5570, Ecole Normale Supérieure de Lyon/ Université Claude Bernard, 2 rue Raphaël Dubois, 696222 Villeurbanne Cedex, France (jessica.flahaut@ens-lyon.fr).

Introduction: Sulfates were discovered by OMEGA the spectral imager, onboard Mars Express, at various locations on the planet Mars [1]. Sulfates have been detected in the Valles Marineris area, near the northern cap in Utopia Planitia and locally in plains as Terra Meridiani [2]. They have also been discovered in situ by the two Mars Exploration Rovers, Spirit and Opportunity in Gusev Crater and Meridiani Planum [3-5].

All these previous missions results have suggested that the sulfate occurrence is strongly linked with the water and climate history on Mars. The recent imaging spectrometer onboard the MRO spacecraft, CRISM, enabled to refine the distribution and mineralogical composition of the hydrated minerals previously detected by OMEGA [6]. Indeed with its spatial resolution up to 18m/px, CRISM is in average 15 times more precise than OMEGA. The present study focus on these deposits in a part of the Valles Marineris system called Capri Chasma. Valles Marineris is a important area to study as it represents the largest sulfates reservoir known on Mars, and it is associated to enigmatic terrains: the Interior Layered Deposits(ILD). ILD are eroded plateaus of several kilometers of layered material which appear on the floor of most chasmata. Their origin and age is still unknown [7]. Various hypotheses for the formation of sulfates in this area and in Valles Marineris in general, and their consequence on the ILD formation scenarios, are discussed in the present work.

Spectral identification: Hydrated minerals are identified with CRISM by investigating the overtones and combinations of fundamental vibrational absorption features in the 1.0- 2.6 µm interval. Three remarkable spectral types were detected. The most common spectral type has been observed on more than 20 CRISM observations and exhibit strong absorption bands at 2.1 and 2.4 µm. The 2.4 µm feature is common to all sulfates and characterizes the SO_4 group vibrations in the structure. The shift of the bound water vibration from 1.9 to 2.1µm in these spectra indicates the presence of a single water molecule in the sulfate structure. The combination of these two absorption features is diagnostic of monohydrated sulfates [1,8]. The general shapes of the spectra are coherent with Mg-monohydrated sulfates such as kieserite [1,8]. The second main spectral type is characterized by a broad 1.9 µm absorption band, strongly spatially correlated to the mapping of the 2.4 µm band. The coupling of these features is diagnostic of polyhydrated sulfates [1,8].

The third spectral type detected with CRISM data is found over the ILD material. This spectral type occurs very locally, and cannot be seen on OMEGA due to its spatial resolution. Spectral features include a strong doublet 2.2 µm absorption band, coupled with weaker 1.4 and 1.9 bands. Comparison with spectral libraries shows that it must be the signature of opaline silica.

Repartition and associated morphologies: Previous investigation in the area showed that the ILD constitute sedimentary deposits that had filled the canyon after its opening, during the Hesperian [7].All the sulfates detections occur in correlation with the outcrops of light-toned deposits of the ILD. Monohydrated sulfates signature are generally found in association with the very bright and massive high albedo deposits of the flanks of the ILD [7,8] while polyhydrated sulfates are detected over distinct layers, morphologically darker and flatter, and located respectively at the bottom and at the very top layer of the ILD mounds. The top of the ILD is covered with dust, morphologically flat and spectrally mute.

Opaline silica detection are limited to a gray material forming two small mounds, a hundred meters wide, lying over the ILD material [8]. Hydrated silica have already been reported in association with sulfates on some CRISM observations in other places of the surface of Mars [9].

Conclusion: Both types of sulfates are detected in Capri Chasma, with alternating layers of distinct albedo and morphological styles. Hydrated silica has also been found locally, over the ILD material. The presence of these aqueous minerals implies that water played a role in their formation, at the Hesperian [8]. The vertical organization of sulfate-rich layers, with at least one monohydrated layer embedded into some polyhydrated sulfates layers, argues for a primary origin of both types of sulfates in Capri Chasma (i.e., no transformation of polyhydrated sulfates in monohydrated sulfates and vice-versa), that could be part of some repeated evaporitic sequences. After analyzing and comparing sulfate formation mechanisms on Earth, we suggest that sulfates in Capri could have been formed by direct precipitation or weathering of pre-existing ILDs, either in a water basin, under an ice cover, or by the multiple raises of a groundwater table.

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CHARACTERISTICS OF THE EJECTA LAYER FROM THE 1.85 GA SUDBURY IMPACT EVENT: ARE ANALOGOUS SEDIMENTS PRESENT ON MARS? Philip Fralick, Department of Geology, Lakehead University, 955 Oliver Road, Thunder Bay, Ontario, Canada, P7B 5E1, philip.fralick@lakeheadu.ca.

At 1850 Ma an object, probably in excess of ten kilometers in diameter, struck the edge of Superior Craton in the area that is now Sudbury, Ontario. The impact produced the second largest known crater on the surface of the Earth, propelling an immense amount of material into the atmosphere. Twenty-five million years prior to the collision the southern margin of Superior Craton west of the impact site consisted of a continental volcanic arc separated from the continent proper by an extensional backarc basin collecting chemical sediment of the Gunflint Formation. At the time of the impact, orogeny to the south of present day Lake Superior had caused the sea to withdraw from the northern portion of the basin and possibly from the entire basin. The ejecta blanket landed in this setting, was altered by subareal diagenesis and fifteen million years later was buried by sediment of the transgressing ocean. Thus, in some areas preserving a record of deposition from what was probably the expanding base surge of the impact event.

Addison et al. (2005) first discovered this layer, which has since been described by Pufahl et al. (2007), Cannon et al. (2010) and Addison et al. (in press). To date over thirty outcrop and core sections through the layer have been found. It is extremely laterally variable, ranging from totally absent in some sections to tens of meters in thickness in others. Sections within a few hundred meters of one another can be composed of different material with contrasting textures and sedimentary structures. Common components of the deposits are: 1) pebbles to boulders of Gunflint chert and carbonate, 2) pebble and granule sized devitrified glass, 3) 3 to 20mm accretionary lapilli, 4) unshocked quartz and feldspar grains, and 5) quartz with planar features (PDFs). Where pebble-sized devitrified glass is common lapilli are usually absent. Conversely, sections with lapilli in grain-support commonly do not contain devitrified glass. Massive carbonate and silica replacement has occurred; with first blocky calcite cements developed then overprinting (including lapilli) by quartz and iron carbonate. This lithified material occasionally collapsed forming boulder piles along what were probably fault scarps.

The two most typical types of successions are: 1) up to 7 meters thick boulder conglomerates with devitrified glass ± lapilli, and 2) thin (averaging approximately 50 cm) graded sand- to granule-sized material with lapilli. The thick successions commonly overlie fractured to shattered bedrock with large rotated blocks. In other areas the boulder conglomerates overlie what had been water-saturated mafic ashes that liquefied allowing sinking of brecciated, solidified chert layers. Calculations suggest this area would have experienced an earthquake of approximately magnitude 10, quite capable of producing these effects. The overlying disorganized pebble to boulder conglomerate contains clasts up to 3.5 meters in length that are commonly in matrix support, but in some areas are in clast support. Pebbles to cobbles of devitrified glass can be mixed throughout the matrix or may appear only in the upper half of the conglomerate. Rarely, the matrix-supported conglomerate is separated from the underlying rock by approximately one meter of clast-supported, trough cross-stratified lapilli, with possible chute and pool structures, interlayered with sand to granule-sized material. In some areas the conglomerates are organized as a series of stacked channels that decrease in size upwards with small channels near the top filled with the first appearance of lapilli. In other areas lapilli are scattered between the disorganized boulders of the massive deposit. Parallel laminated lapilli in clast support or massive lapilli in clast or matrix support can overlie the conglomerate. Alternatively, in places it is overlain by a massive layer of devitrified glass pebbles or a thick succession of massive or large-scale cross-stratified sand-sized material. These thicker successions appear to fill depressions. The thinner units overlie intact bedrock, which apparently was swept clean of the earthquake debris. They commonly show grading, consisting of either: 1) one or more successions that are normally graded from sand and granules, with lapilli, to silt, or 2) are reverse then normally graded with the granules and lapilli concentrated in the middle of the tens of centimeters thick unit.

This talk will present photographs of the various layering successions, allowing the audience to contemplate any similar features they have observed in photographs from Mars.

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MORPHOLOGY AND FORMATION PROCESSES OF PUTATIVE ALLUVIAL FANS IN A YOUTHFUL CRATER: MOJAVE CRATER.
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Introduction: The link between the formation of crater-infilling alluvial fans and localized climate change resulting from the impact cratering process is a subject of much debate. During the Noachian 'late heavy bombardment' period it is thought that hot ejecta production and steam release led to global scale warming and precipitation regimes [1]. Noachian to early Hesperian craters containing catchment-alluvial fan systems are not unusual [2], but younger examples are rare [3]. However, there has been a recent discovery of the ~Hesperian/Amazonian aged [4] Mojave crater (7.6°N, 227°W, within an outflow channel between Tiu and Simud Valles) containing at least two generations of alluvial fans, formed in multiple stages [4]. If precipitation played a part in fan formation then this implies at least one recent climate fluctuation, possibly linked to crater formation, during a presumed cold and dry period. Fan-building timescales and formation processes within this crater are so far a subject of speculation [4]. Whilst the broad morphology of fans has been described [4], no attempt to discriminate between fan surfaces or describe their morpho-stratigraphic relations has been made.

Mojave catchment-fans: Complex arrangements of catchment-fan systems are evident in Mojave crater. Small catchment-fan systems (fans <800 m in length) emanate from topographic highs within inner rim terraces, and are characterized by distinct surfaces of varying textures and elevations. Bedrock channels begin on ridge crests of drainage divides, suggesting precipitation as a possible water source [4]. We observe catchments that have 'cannibalized' older fan surfaces, indicating temporal variation in fan building. A 'regional' sediment routing system, comprised of fans (<2 km in length), superposes these small fans in places (Fig. 1A), and was probably active during, and for a time after, these. Formed from material originating from areas of ponded impact melt [5] within the flat terraces, they appear to comprise a sediment routing system reaching from the rim towards the crater floor. Regional fan formation seems linked to the impact melt material, and our research will aim to develop ideas on the underlying mechanisms.

Results/proposed methods: Preliminary mapping of cross-cutting channels and relative surface heights using HiRISE images (25 cm/pixel resolution) and anaglyphs shows that differentiable surfaces are present within fans (Fig. 1B). Elevations and textures (color, presence of boulders, channelization) are used to map discrete surfaces, and determine relative age. A terrestrial river remote sensing technique has been used to determine grain size distribution [6]. Results indicate a decrease in grain size on younger surfaces, and smooth decreases in grain size with increased distance from fan apexes. Currently, we are building a ~1 m resolution DTM from a HiRISE stereo pair, and also a ~20 m resolution DTM made from a CTX stereo pair. Catchment-fan slopes will be extracted using the DTM. The long profile of these systems can tell us much about the denudation process operating. De-trending of data from the individual fan surfaces to analyze roughness and relief will also provide a key to identifying sediment transport modes. Furthermore, by crater counting the ejecta blanket and outflow channel we aim to further constrain the age of Mojave's formation.

Conclusions: Our analysis will add to our knowledge of impact induced climate change and fan building processes which have shaped youthful craters.

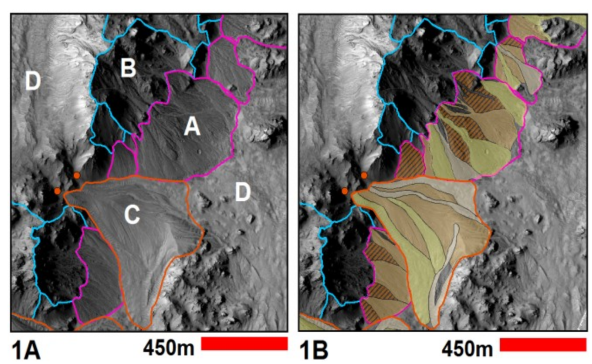

Figure 1A: A is a small fan with catchment (B). C is a regional fan, with the source area being the terrace behind the massif. D is ponded impact melt.

Figure 1B: Surfaces are dated relative to neighbouring surfaces. Darker shades (red-orange) are older than lighter shades (yellow-beige).

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RESURGE PROCESS OF THE CHICXULUB CRATER AND RELEVANCE FOR IMPACT CRATERS ON MARS. K. Goto[1], S. Yamamoto[2], and T. Matsui[3], [1]Disaster Control Research Center, Tohoku University (6-6-11-1106 Aoba, Aramaki, Sendai 980-8579, Japan), [2]Institute of Low Temperature Science, Hokkaido University (Kita-19, Nishi-8, Kita-ku, Sapporo 060-0819, Japan), [3]Planetary Exploration Research Center, Chiba Institute of Technology (2-17-1 Tsudanuma, Narashino, Chiba 275-0016, Japan).

Introduction: Presence of ancient oceans, seas, and lakes on Mars have long been discussed [e.g., 1, 2]. Ormö et al. [3] and Horton et al. [4] suggested based on the analogy of the oceanic impact craters on Earth that some seafloor craters may have been formed during the Martian history, although such craters might be covered by thick sediments. Therefore, Ormö et al. [3] proposed that ground penetrating radar surveys are critically important to find the possible oceanic impact craters on Mars.

Morphology and internal sedimentary structures of the impactite in the oceanic impact craters, especially those of large craters (>100 km in diameter), are poorly understood even on Earth. Among the possible large oceanic impact craters, the Chicxulub crater at Mexico, which was formed at 65 million years ago and resulted the Cretaceous/Tertiary boundary mass extinction, is one of the important example. Resurge process of the Chicxulub crater have been studied based on the drilling cores in and around the crater. Goto et al. [5] reported possible resurge deposits in the top of the impactite layer of the YAX-1 core, which was obtained from approximately 60 km from the center of the crater (inside the crater).

In this study, we further investigated the early modification stage of the crater using UNAM 5 and 7 cores, 105 and 127 km from the center of the crater (outside the crater), based on the comparison to that of the YAX-1 core.

Results: Schönian et al. [6] subdivided the impactite in UNAM5 and 7 cores into 6 units, and correlated them to those of the YAX-1. On the other hand, based on the lithology of the impactite comparing to that in the YAX-1 core, we subdivided the impactite in UNAM5 into 5 units. Among them, the suevite in top two units in the UNAM 5 core have characteristics similar to resurge deposits in the YAX-1 core. For example, these units are composed of dark greenish, relatively well-sorted suevites, and has cross lamination at the top, suggesting the influence of current during the sedimentation of this interval. Moreover, at least 8 pulses of deposition are observed in the strata deposited in the upper part of the section in the UNAM 5.

On the other hand, impactite layer in the UNAM7 core is mainly composed of matrix-supported suevite with abundant altered melt fragments. No sediments, which are similar to those of the resurge deposit in the YAX-1 core, were found in this core.

Discussion: Goto et al. [5] interpreted that top two units in the YAX-1 core were the resurge deposits that were formed by the ocean water invasion into the crater based on the presence of cross lamination, at least 10 pulses of upward fining/coarsening layers, presence of well preserved nannofossils in the matrix, and reverse chronology of nannofossils.

Similar resurge deposits can be found in UNAM 5 core, which was drilled outside of the crater rim. This suggests that the influence of currents was not local but prevailed both inside and outside the crater. The thickness of the resurge deposit in UNAM 5 core become thinner comparing with that in the YAX-1 core. Moreover, no resurge deposits can be found in UNAM 7 core. The crater-ward thickening trend of the resurge deposits probably suggests that the sediments once deposited outside of the crater were eroded and transported crater-ward by the high-energy resurge of ocean water into the crater.

The crater-ward thickening trend of the resurge deposits, cross lamination, and several pulses of sediment layers, which are characteristically observed in the resurge deposits in and out of the Chicxulub crater, are also reported from different scales of oceanic impact craters on Earth [e.g., 7, 8]. Therefore, these features can be considered as the characteristic features of oceanic impact craters. Such internal structures and sedimentary characteristics might be useful to identify the oceanic impact craters on Earth and Mars.

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LATE NOACHIAN ALLUVIAL AND LACUSTRINE DEPOSITIONAL SYSTEMS IN SOUTHWEST MARGARITIFER TERRA, MARS. J. A. Grant[1], R. P. Irwin, III[1], and S. A. Wilson[1], [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 6th St. at Independence Ave. SW, Washington, DC 20560, grantj@si.edu.

Introduction: Impact craters on Mars create deep enclosed drainages, and their raised rims often derange exterior drainage courses [1-5]. Noachian-aged craters [6] in southwestern Margaritifer Terra provide examples of both drainage patterns and preserve deposits associated with past alluvial and lacustrine activity.

Crater Basins: A number of large (>40 km across) craters punctuate SW Margaritifer Terra and typically display 1–2 km of relief along their walls. At ~150 km in diameter, Holden crater (26.0°S, 325.8°E) is the largest, with alluvial and likely lacustrine beds extending across its lower walls and floor [7]. Erosion of wall alcoves sourced the fans and lake [7] and transported phyllosilicate-bearing materials were mostly incorporated into lower strata [8]. Eberswalde crater (23.9°S, 326.6°E) is superposed by Holden ejecta and overlying fluvio-lacustrine sediments, including a delta on the western wall and lacustrine sediments on the crater floor [9, 10]. Ostrov crater (26.5°S, 332°E) is ~200 km east of Holden and is partially filled by alluvial fans that reach across the crater floor and embay the central uplift. Lake deposits appear largely absent, though beds near the basin center are consistent with a playa setting. An unnamed crater south of Ostrov (27.8°S, 332.8°E) also preserves broad alluvial fans fed from alcoves that are largest on the southwestern and northeastern walls. Despite a paucity of high-resolution coverage (by HiRISE), unnamed Noachian-aged [6] craters on the southwest (21.7°S, 320.6°E) and southeast (20.7°S, 324.3°E) rim of Vinogradov crater and ~150 km south (29.9°S, 326.4°E) and ~100 km southwest (27.3°S, 323.1°E) of Holden crater reveal evidence for comparable fans and/or lacustrine deposits.

Some craters show evidence for significant infilling by other processes (e.g., possibly volcanic or eolian) that may bury older alluvial or lacustrine deposits. Nevertheless, craters excavating fill in Chekalin crater (24.0°S, 333.2°E) reveal light-toned materials that may represent underlying water-lain deposits. Hence, late-Noachian alluvial and/or lacustrine deposits may be widespread in craters, but are ancient, often buried, or only rarely exposed by later erosion and imaged at high resolution (to date).

Uzboi Lake: Regional drainage is dominated by Uzboi Vallis (centered at ~28°S, 323°E), the southernmost segment of the northward-draining Uzboi-Ladon-Morava (ULM) meso-scale outflow system [3-5]. Formation of Holden crater blocked the ULM and created a large (>4000 km^3) geologically short-lived lake in Uzboi during the late Noachian [5], before the crater rim was overtopped and water drained into Holden [7]. Tributaries to the Uzboi lake [5] incised a regional phyllosilicate-bearing layer [11], whose sediments were transported and deposited in the basin.

Discussion: The preservation of alluvial and likely lacustrine sequences in craters and a lake basin in Uzboi Vallis in southwest Margaritifer Terra implies widespread water-related degradation during a geologically brief period in the late Noachian [5, 12, 13]. Craters preserving these aqueous deposits are at varying elevations, and there was little to no standing water in some (e.g., Ostrov). Source alcoves eroded well into the rim of some craters and, coupled with evidence for regional runoff into the Uzboi lake [6], suggest that synoptic precipitation was the dominant water source.

The morphometry and sedimentology of these alluvial and lacustrine deposits record the hydrologic and climatic conditions present during their emplacement. The short duration of wet conditions responsible for the formation of the deposits suggests most incorporated phyllosilicates are allocthanous and are derived from older deposits [14] and/or are related to impact alteration. Nevertheless, their preservation and (in some instances) relative accessibility suggests that they are high-priority targets for future exploration aimed at understanding the past habitability of Mars.

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WORKING TOWARDS A CLASSIFICATION SCHEME FOR SEDIMENTARY ROCKS ON MARS.

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Introduction:

An analysis is presented here of sedimentary rocks on Mars using various data sets such as the High Resolution Imaging Science Experiment (HiRISE) and Context Imager (CTX) on the Mars Reconnaissance Orbiter (MRO), and the Mars Orbiter Camera (MOC) on the Mars Global Surveyor (MGS). This is a systematic study for the purpose of distinguishing various types of sedimentary rocks, and then for their further subdivision into subtypes.

Methods and Analysis:

Images are being examined from the three data sets for evidence of layering in bedrock (polar deposits excluded). The HiRISE camera takes images at resolutions up to 26 cm/pixel that are 6 kilometers wide and of variable length. The Context Imager takes images at 6 m/pixel at a width of 30 kilometers. MOC narrow angle images are at a resolution of 1.5 to 12 m/pixel.

There is a diversity of sedimentary rocks on the surface of Mars that represent eolian, fluvial, and possibly lacustrine depositional environments. In addition, we recognize that pyroclastic and also impact-generated deposits could be present. Using a comparative approach of these data sets, all acquired HiRISE images are being inspected within the latitude range of 60 degrees north and south. Layered deposits are classified as being inside or outside of craters, and then the process is repeated with CTX data. Due to the large volume of CTX data, areas that have no HiRISE coverage, or areas suspected to have layered deposits based on similar morphologies seen in nearby images are being examined first. From there, the layered deposits are further subdivided based on criteria such as morphology, blockiness, relative thickness, tone, types of layers, and if there is CRISM coverage, what types of mineralogical correlations are seen among different types of layers. While the project begins at a global mapping scale, more detailed analysis will be done on specific areas where layers are particularly well exposed.

The global and regional mapping of layered deposits is based on characteristics such as tone/albedo, apparent (and in some cases, true) thickness of stratification, weathering characteristics, larger scale textures and patterns, and whether the layers are found inside or outside of crater walls and canyon walls. As a first pass using visual inspection, layered bedrock of any kind was searched for (volcanic, sedimentary, etc.) and then plotted to create a global map with their locations. From there we are attempting to distinguish if the rocks can be classified as sedimentary and whether it's a definitive case, suggestive, or not possible to distinguish the type of stratified material. The locations of the layers can also be compared based on elevation, age of terrain, relationship to valley networks and impacts with lobate debris aprons. The goal is to make regional and global maps of stratified terrains with probably sedimentary origin based on these defining characteristics and then build a stratigraphy for regions of Mars.

The data sets that are being created with locations of layered deposits are being made for GIS. Ultimately, when classification schemes for the various deposits has been completed, there will be a comprehensive set of files for GIS which can be sorted based on all the criteria used.

Additional Information:

HiRISE data can be found at http://hirise.lpl.arizona.edu and CTX data can be found on the PDS at: http://pds-imaging.jpl.nasa.gov/Missions/MRO_mission.html

SEDIMENTARY ROCKS OF MARS: DISTRIBUTION, DIVERSITY, AND SIGNIFICANCE J. P. Grotzinger, Division of Geological and Planetary Sciences, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125 grotz@gps.caltech.edu

Mission results over the past decade have demonstrated that a diverse suite of sediments and sedimentary rocks exists on the surface of Mars that represent eolian, fluvial, and possibly lacustrine environments [1]. Sedimentary rocks on Mars can be classified based on broadly-defined attributes that usefully characterize particular types of strata. These include tone/albedo, apparent thickness of stratification and presence of apparent cyclicity, weathering character (rough, blocky vs. smooth), larger-scale textures and patterns (e.g. polygonal, or recticulated), and spectral signature as seen in visible-near infrared and thermal infrared data, including the distinct lack of signatures most often attributed to dust, but possibly also associated with a distinct class of sedimentary rocks possibly composed of ancient lithified dust. These strata form as relatively thin (tens to humdreds of m thick) fluvial deposits in smaller crater basins; thicker deposits (hundreds to thousands of m thick) of uncertain origin in larger crater basins; and as widespread, locally complexly folded strata within the lower depths of Vallis Marineris and also of uncertain origin. Widespread sheets of strata occur within the Arabia region, not obviously confined within a topographic depression, and also at Terra Meridiani.

Sedimentary materials were formed during erosion of older, presumably basaltic, rocks to form siliciclastic sediments and sedimentary rocks, deposited mostly as alluvial fans or eolian sand sheets. In areas affected by volcanism, reworking of volcanic deposits to form volcaniclastic sediments and sedimentary rocks may have occurred. Finally, where water was available and also charged with dissolved ions, evaporation of possibly shallow bodies of water or discharging groundwaters to form chemical sediments appears to have occurred over relatively widespread regions. These deposits of chemical origin are dominated by sulfates and possibly chlorides, though the search for large carbonate reservoirs continues [2]. Chemical and fine-grained siliciclastic sediments and sedimentary rocks are viewed as prime targets for future *in situ* geobiological analysis or sample return [3].

In situ studies at Meridiani Planum and in Gusev Crater featured analysis of ancient eolian/fluvial and volcaniclastic deposits at meter to millimeter scales and, in large part, with fidelity that is comparable to many of the detailed stratigraphic studies that have been carried out on Earth [4]. In a complementary fashion, orbiters have demonstrated the regional extent and geologic context of various types of sedimentary rocks [5]. Both scales of observation provide important constraints on the composition, stratigraphy, and geologic history of Mars.

Mars may have a distinct history of aqueous events that left distinct time-dependent patterns embedded within the rock record [2]. The current hypothesis is that the long-term environmental evolution of the planet is delineated in the history of mineral assemblages, from a planet characterized by aqueous alteration of impact-brecciated ancient crust forming phyllosilicate minerals, to a planet marked by vast terrains of bedded sulfate minerals, and that this was followed by a terminal shift to the current dry state during which anhydrous iron oxide minerals accumulated.

The principles of sequence stratigraphy also are applicable to Mars [6]. High resolution stratal geometries can be mapped using sequence stratigraphic principles has been shown for SW Melas Chasma. HiRISE, MOC, and CTX imagery will permit detailed mapping of this particular succession of strata, and others like it; the results will likely shed light on the origin of the strata and facies distributions within the succession. In the future, construction of Digital Elevations Models from HiRISE image data will allow mapping of stratal geometries at meter scale, laterally, for distances of hundreds to thousands or meters of more.

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INTERPRETING DELTAIC STRATIGRAPHY ON EARTH AND MARS: HOW EASY IS IT AND HOW VALID ARE OUR INTERPRETATIONS? S. Gupta[1], K. Goddard[1], J-R. Kim[2], S-Y. Lin[2], J.-P. Muller[2], E. Mortimer[3], O. Jordan[5], K.J. Amos[5]. [1]Dept. Earth Science & Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, UK, [2]Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Surrey, RH5 6NT, UK. [3]University of Leeds, UK, [4]Statoil, Bergen, Norway, [5]Australian School of Petroleum, University of Adelaide, Australia,

Reconstructing ancient sedimentary environments on Earth is not a trivial task. Sedimentologists typically use detailed analysis of sedimentary features in rocks together with geometrical stratigraphic relationships and couple this with models of modern systems to reconstruct palaeo-deltaic landform features and environments. However, the fidelity of these reconstructions is dependent on good outcrop control and an understanding of how geomorphic elements become frozen in the stratigraphic record.

On Mars reconstruction of ancient deltas is even more difficult. Whilst we can observe point-sourced sedimentary bodies within craters typically emanating from channels that enter the crater, interpreting these as deltaic and determining the type of delta is hazardous. Prior studies have largely focused on establishing geomorphic relations from the large-scale planform bedrock morphology, however, this is dependent on the preservation state. It is not always clear what is actual geomorphology or an erosional remnant.

On Earth, we reconstruct ancient deltas by careful analysis of sedimentary bedding patterns as observed in vertical sections. By lateral tracing of bedding we constrain the morphostratigraphy of depositional elements and the surfaces that bound them. The stratigraphy preserved however is not a static state of the 'delta', but instead is a complex of surfaces and sediment bodies that records lateral migration and vertical accumulation of landscape elements.

The integration of HiRISE imagery with HiRISE digital terrain models enables Mars sedimentologists and stratigraphers to explore bedding patterns exposed in martian canyons. Whilst we cannot get a handle on the internal sedimentology of these deposits, the analysis of architectural elements and their geometrical disposition enables us to reconstruct the large-scale architecture of the putative martian deltas. Understanding this architecture is crucial to informed interpretation of such sedimentary deposits.

In this presentation, I will review the sedimentary architecture of a variety of Earth deltas that we have worked on for the past 10 years, including examples from the Suez Rift, Gulf of California, Greece and the Cretaceous Western Interior Seaway of North America. We will examine large scale bedding geometries of the sort visible in spacecraft imagery, and consider how best one can make interpretations.

These examples will be compared with martian examples where we can investigate in detail bedding architecture. We consider how these bedding panels might be interpreted in the light of our examples of Earth delta architecture.

SEDIMENTS AND THE CHEMICAL COMPOSITION OF THE UPPER MARTIAN CRUST. B. C. Hahn[1] and S. M. McLennan[2], [1]Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996 (bhahn1@utk.edu), [2]Department of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100 (scott.mclennan@sunysb.edu).

Introduction: For Earth, many past studies have used sediment compositions to help constrain estimates of the composition of the terrestrial upper continental crust [1,2]. Weathering, sedimentary transport, and deposition naturally sample a wide array of source rocks with the resultant chemistry being an efficient mixture of source terrains. However, significant partitioning of the major elements occurs among distinct sedimentary lithologies through various aqueous processes. Accordingly, sediment chemistry alone is not the most reliable means of determining bulk major element composition of the upper continental crust, and major element abundances are thus determined using weighted averages of major rock provinces. Averages of sedimentary rock chemistry do provide a good proxy for the relatively insoluble trace element abundances found in the continental crust.

For Mars, phyllosilicates, sandstones, an assortment of evaporates, and most recently, carbonates have been detected in varying amounts at various locations around the planet through remote sensing and in situ rover observations [3-6]. However, the dominant sedimentary products that have been recognized and characterized to date are the martian dust and basaltic loose regolith or soils. Chemical alteration is mostly local and often confined to the very near rock surfaces, as would be expected in a water-limited weathering environment. As such, while there is some addition of altered components such as sulfates, the martian soils are a largely unaltered and unfractionated representative of the primary lithologies from which they have been derived (***Figure 1, right***) and therefore generally preserve the bulk chemistry of those sources.

After carefully screening soil samples from all landing site measurements, renormalizing to a S- and Cl-free composition, and adjusting for a meteoritic component [7], the estimate for the bulk chemistry of the upper martian crust is listed in ***Table 1 (right)***. Martian sediments only sample the upper crust and, as such, chemical composition estimates may not be applicable to the total martian crust.

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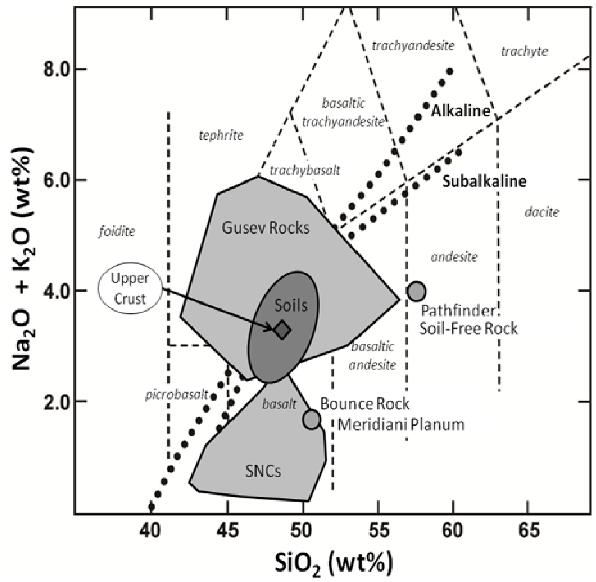

Figure 1: *TAS classification diagram of Martian sediments and selected APXS landing site rock analyses. Calculated average upper crust plots in the basalt field just below the subalkalic fractionation line. Martian soils plot within the cluster of Martian rock measurements SNC analyses indicating they represent a physical mixture of primary sources without extreme chemical fractionation [8].*

Table 1. *Unscreened/screened average soil compositions and renormalization corrections*

	Unscreened value	**SD**	**Screened value**	**SD**	**Screened and Renormalized**
SiO_2	*45.7*	*9.7*	*45.7*	*1.9*	***49.0***
TiO_2	*0.89*	*0.2*	*0.89*	*0.2*	***0.95***
Al_2O_3	*8.87*	*2.1*	*9.58*	*1.0*	***10.3***
FeO	*18.6*	*6.3*	*17.5*	*2.9*	***18.8***
Cr_2O_3	*0.35*	*0.1*	*0.37*	*0.1*	***0.40***
MnO	*0.31*	*0.1*	*0.34*	*<0.1*	***0.34***
MgO	*7.88*	*1.9*	*8.52*	*1.6*	***9.13***
CaO	*6.02*	*1.4*	*6.36*	*0.6*	***6.82***
Na_2O	*2.44*	*0.7*	*2.67*	*0.5*	***2.86***
K_2O	*0.41*	*0.1*	*0.45*	*0.1*	***0.48***
P_2O_5	*0.93*	*0.7*	*0.84*	*0.1*	***0.90***
Ni (ppm)	*540*	*220*	*500*	*130*	***305 (ppm)***
Zn (ppm)	*310*	*160*	*310*	*160*	***310 (ppm)***
SO_3^{**}	*6.94*	*5.7*	*5.92*	*1.8*	
Cl^{**}	*0.67*	*0.2*	*0.70*	*0.2*	
Σ	***100.0***		***100.0***		***100.0***

***Screened SO_3 and Cl averages are subtracted from the Screened soil average and renormalized to 100%*

STRATIGRAPHY OF THE NORTH POLAR LAYERED DEPOSITS ON MARS. K. E. Herkenhoff, C. Fortezzo, G. Cushing, R. L. Kirk, L. A. Soderblom, and L. Weller, U. S. Geological Survey Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (kherkenhoff@usgs.gov).

Introduction: The Martian polar layered deposits (PLD) have long been thought to be the best source of information about the recent climate history of Mars [1-3], but the detailed mechanisms of accumulation are still a mystery [4]. The polar layers are sedimentary deposits composed of water ice and varying amounts of dust or other impurities [5]. Because climate changes are likely recorded as variations in composition or deposition/erosion rates between layers, the detailed stratigraphy of the PLD is of great interest. Layer thicknesses of ~10 to 50 m were observed in Viking Orbiter images of the north PLD [6], and MGS MOC images resolve layers with similar or lesser thicknesses in both polar regions [7]. In order to accurately determine the thickness of layers and interpret PLD stratigraphy and structure, the topography of exposures must be known. Previous studies have modeled brightness variations in the PLD in an attempt to link them to orbital/axial variations [8-10], but lack of detailed topography has hindered stratigraphic interpretations. More recently, MRO HiRISE images have shown that brightness variations between layers can be caused by mantling deposits of frost and other (dusty) material and are therefore probably not related to the internal composition of the layers [11]. Therefore, brightness variations alone cannot be used to infer PLD stratigraphy; high-precision topographic information is needed. Here we describe results of our continuing study to evaluate the topography and stratigraphy of the north PLD using photoclinometry on MOC images taken in the spring, when the surface was covered by seasonal frost and albedo variations are minimized.

Approach: We used a 2-dimensional photoclinometric technique [12] constrained using simultaneously-acquired MOLA data. This technique is well suited to images taken at high latitudes when the surface was covered by seasonal frost and the solar elevation angle was low so that albedo variations and their effects are minimized and topographic modulation is emphasized. The high density of MOLA data in the polar regions allows gridded topographic products to be generated at higher spatial sampling (~115 m/pixel) than is possible at lower latitudes (Fig. 1). The MOLA gridded data are used to initialize the photoclinometric solution and constrain surface and atmospheric scattering parameters. The ability to discern the layers facing the sun in the photoclinometrically-derived digital elevation model (DEM) is at essentially the same spatial resolution as the original image.

Results: Individual layers visible in the MOC images are typically 20-40 m thick, as noted in previous studies and consistent with digital elevation models derived from HiRISE stereo pairs [13]. Many layers are characterized by a raised "rim" or "lip." While it is possible to correlate stratigraphy in the data shown here, correlation is difficult in other areas due to unconformities and other structural complexity. Further analysis of MOC photoclinometric models of PLD exposures will be presented at the conference.

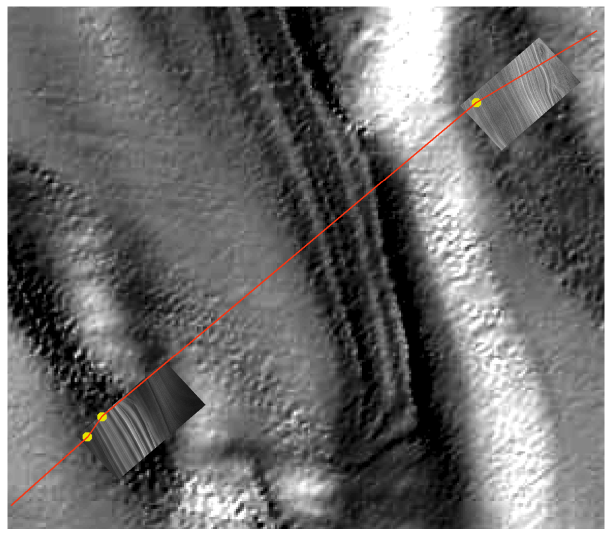

Figure 1. MOC images on MOLA shaded relief, with illumination from left.

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SEDIMENTARY HISTORY OF THE SOUTHERN MID-LATITUDES NEAR 180° LONGITUDE. A. D. Howard[1], J. M Moore[2], J. A. Grant[3], R. P. Irwin III[3,4], [1]Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22904-4123, ah6p@virginia.edu, [2]NASA Ames Research Center, Moffett Field, CA 94035, [3]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, [4]Planetary Science Institute, Tucson, AZ 85719.

Introduction: The region approximately bounded by 30–50°S and 150–210°E contains a wealth of sedimentary deposits spanning the earliest Noachian to the Amazonian Periods. The earliest deposits, probably of airfall origin, are exposed in deformed and eroded structures and are related to extensively degraded large craters (also called quasi-circular depressions (QCDs). Mid-Noachian to Hesperian deposits include extensive lacustrine deposits, the Electris deposits of probable airfall origin, and the enigmatic knobby chaos of the major basins. Gorgonum basin was occupied by an ice-covered lake at about the Hesperian-Amazonian transition.

Early Noachian: Highly degraded Early Noachian craters 200+ km in diameter are widespread on Mars [*1*, *2*]. The relief of these basins is much smaller than expected for fresh basin-scale impacts [*3*, *4*] due to infilling by ejecta from large impacts [*5*], viscous relaxation [*3*], infilling with volcanic deposits [*6*], and extensive mantling. The muted and rounded form of QCD rims in this region suggests degradation by mantling [e.g., *7, 8*] is more important than volcanic infilling or relaxation. A thick series of weakly layered and eroded deposits is exposed on an anticlinal, possibly diapiric structure in Atlantis basin at 36.5°S, 182°E and as inward-dipping, eroded beds flanking Atlantis and Gorgonum basins. The form and occurrence of these deposits imply they are eroded Early Noachian mantles and are largely responsible for QCD degradation.

Late Noachian & Early Hesperian Activity: A putative airfall mantle (the Electris deposits [*7*, *8*]) covered most of the region and has been differentially eroded by fluvial erosion and scarp retreat. This deposit dips beneath later sediments in the major basin centers. Prominent 1–4-km knobs up to 500 m tall occupy portions of the Ariadnes, Atlantis and Gorgonum basin centers as well as other smaller knob clusters [*9*]. These light-toned knobs locally exhibit spectra of hydrated and phyllosilicate minerals [*10*], and are often capped by a blocky, more resistant layer. Among the uncertainties about the knob deposits are their bulk composition, the depositional environment, their original extent, whether they were preferentially deposited or preferentially preserved in the basin centers, and the processes of erosion of the deposit to form knobs. Their age relative to the Electris deposit is also uncertain, but probably younger. Basin centers in the region are mantled with smooth deposits of probable lacustrine origin that overlie and onlap against knob and Electris deposits. Extensive lakes occupied the region during the late Noachian, overflowing to erode Ma'adim Valles [*11*, *12*]. Evidence for lakes of various depths during this time interval includes the undissected convex-to-concave profiles of smooth mantling deposits in basin centers, possible shoreline features, scour features at divides between basins, and a channel and fan-delta formed by basin overflow.

Hesperian & Amazonian: Lakes evaporated, sublimated, or infiltrated after the Noachian-Hesperian transition. At about the Hesperian-Amazonian boundary, shallow fluvial channels formed on the interior slopes of Newton and Gorgonum basins [*13*], probably by melting of snow/ice deposits on the basin rims. At the same time, an ice-covered lake appears to have occupied the lowest parts of Gorgonum basin [*14*]. The ice cover was up to 300 m thick, and convoluted benches formed at the base of the ice. Ejecta of craters straddling the shoreline were preferentially eroded on the basinward side, and distinctive deposits and topography mark the former lake [*13*, *14*].

Conclusions: The region discussed here contains one of the most complete sedimentary records on Mars, spanning the earliest Noachian to Amazonian. During much of this time lakes occupied basin centers.

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REDOX CHEMISTRY AND THE ORIGIN OF ACIDITY ON THE ANCIENT SURFACE OF MARS. J. A. Hurowitz[1]*, W. W. Fischer[2], N. J. Tosca[3], and R. E. Milliken[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109, [2]Division of Geological and Planetary Sciences, 107 North Mudd Laboratory, California Institute of Technology, Pasadena, CA 91125, [3]Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, United Kingdom, *joel.a.hurowitz@jpl.nasa.gov.

Introduction: *In-situ* and orbital exploration have demonstrated that surface waters at Meridiani Planum, Mars were acidic [1-4]. However, the origin of this acidity is unknown. Constrained by chemical and mineralogical analyses from the Mars Exploration Rover *Opportunity* [5-8], we show that Fe-oxidation and Fe^{3+}-mineral precipitation yields an excess of acid relative to the amount of titrant available in outcrop [9]. Our results indicate that Fe^{2+}-bearing subsurface waters, buffered to circum-neutral pH and anoxia, were subject to rapid oxidation and acidification upon exposure to O_2 and/or UV light (**Fig. 1**).

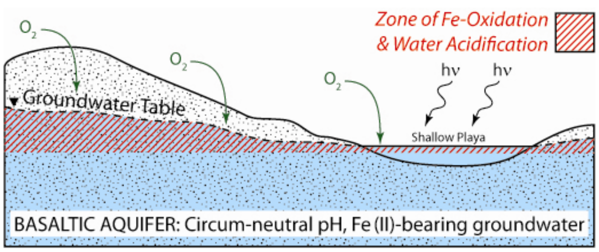

Fig. 1: Schematic cross-section showing the oxidation and acidification of groundwater at Meridiani Planum.

Approach: *In-situ* measurements of Meridiani outcrop chemistry and mineralogy make it possible to quantify the amount of acid consumed or produced during Fe-oxidation and Fe^{3+} mineral precipitation. The acid produced can then be "titrated" against the available base anion content measured in outcrop (i.e., SO_4^{2-}, Cl^-, PO_4^{3-}, and CO_3^{2-}), yielding a net proton balance reflective of the parent fluid. For our titration method, we sum the number of moles of H^+ generated during precipitation of the measured quantity and distribution of jarosite, hematite, and schwertmannite, using data collected through sol 548 of the *Opportunity* mission on 19 Meridiani Planum outcrop targets. Our approach is based on a straightforward accounting of the number of moles of acid produced when Fe^{3+} minerals are formed from dissolved Fe^{2+}, e.g.,:

(1) Fe^{2+} (aq) + $0.25O_2$ (aq) + H^+ = Fe^{3+} (aq) + $0.5H_2O$

(2) Fe^{3+} (aq) + $0.667SO_4^{2-}$ + $0.33K^+$ + $2H_2O$ = $0.33KFe_3(SO_4)_2(OH)_6$ (jarosite) + $\mathbf{2H^+}$

Results: For all outcrop analyses there is an excess of H^+ generated in forming the observed secondary Fe^{3+} mineral phases relative to the available titrant in outcrop (**Fig. 2**). Our calculations imply that so long as redox conditions in the aquifer were conducive to the transport of Fe^{2+}(aq), oxidation and formation of jarosite, hematite, and schwertmannite would have resulted in the generation of low-pH fluids at the site of Fe^{3+}-mineral precipitation (**Fig. 1**). Accordingly, input of additional acid volatiles (e.g., SO_2, H_2SO_4) at the site of sediment formation [10, 11] is not required and SO_4^{2-} can be considered a background constituent of the aquifer fluid.

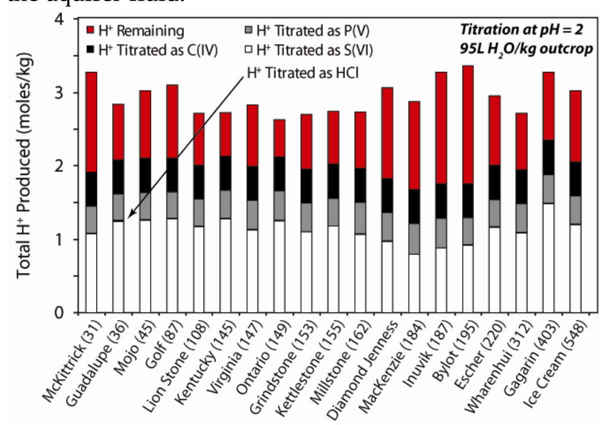

Fig. 2: Total acid production and titration against a pH=2 base species distribution for analyses collected between sols 31 and 548 on abraded outcrop targets.

Finally, because gaseous H_2 is a by-product, Fe-oxidation processes have an impact on the redox state of the atmosphere. We will show that the Martian sedimentary record provides quantitative insight into the magnitude and timing of atmospheric H_2 loss processes required for oxidation at Meridiani Planum.

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WIND-ERODED FLOOR DEPOSITS IN NOACHIAN DEGRADED CRATERS ON MARS. R. P. Irwin III[1,2], F. Pendrill[3], T. A. Maxwell[2], A. D. Howard[4], and R. A. Craddock[2], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719, irwin@psi.edu. [2]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, MRC 315, 6th St. at Independence Ave. SW, Washington DC 20013-7012. [3]University of Gothenburg, SE-405 30, Gothenburg, Sweden. [4]Department of Environmental Sciences, University of Virginia, Charlottesville VA 22904.

Introduction: The role of water in Noachian crater degradation is key to understanding the paleoclimate of early Mars. Most global- to regional-scale geologic maps suggested widespread volcanic resurfacing of impact crater floors in the early Hesperian [1,2]. Large degraded craters often have flat floors that are consistent with volcanic resurfacing, as the Mars Exploration Rover Spirit found in Gusev crater [3]. Many Noachian craters regardless of size have floors with high thermal inertia [4]. However, the topography of degraded crater rims and interior deposits indicates a dominant role for fluvial erosion and deposition, particularly in craters <60 km in diameter [5,6].

We examined >1000 floors of Noachian craters from 0–30ºS, 0–165ºE to identify friable deposits that (unlike basalts) were susceptible to aeolian deflation. We used visible-wavelength orbital imaging at 0.25–18 m/pixel from the High Resolution Imaging Science Experiment, Mars Orbiter Camera, Context Camera, and Thermal Emission Imaging System.

Erosional Resistance of Crater Floors: The morphology of Noachian crater floors varies greatly, suggesting diverse fill materials and/or weathering and erosion processes [7]. Some floor materials retain abundant small, post-depositional craters, but they are otherwise smooth. At the opposite extreme are knobby floors (Fig. 1), some of which have exposed layers. In many cases we noted light-toned, seemingly friable material overlain by a more resistant, darker unit. During post-depositional modification, deflation of the darker-toned surface layer removes much of the small-crater population and may expose the underlying light-toned layer, whereas less effective deflation leaves patchy exposures of deeper materials. These friable, wind-eroded deposits are confined to the floors of craters and intercrater basins.

Spatial Distribution of Wind-eroded Crater Floors: Knobby, deflated crater floors are concentrated in a southern band within the study area, except between 60–90ºE, where we found no north-to-south increase in floor erosion. Light-toned outcrops on basin floors are concentrated south of 20°S. The area from 20–25°S, 25–100°E contains about a third of the outcrops of light-toned material in the study area, with concentrations near the rim of Hellas and southwest of Huygens crater (~20–25°S, 40–50°E). The observed concentration of fracturing in light-toned outcrops in these areas may be due to better image coverage.

Discussion: Possible reasons for the diverse Noachian crater-floor morphology are: 1) different resurfacing processes around the Noachian/Hesperian transition; 2) different intensity of post-Noachian aeolian modification; and/or 3) different surface weathering rates, possibly related to material properties. The concentration of knobby terrain and light-toned layers in crater or intercrater basins suggests that these units are not an airfall mantle, and that any enhanced weathering processes must have been focused in the basins. Wind-eroded crater floors appear concentrated in low-albedo, dust-free regions, so increased aeolian efficiency may be partly responsible.

Conclusions: Many Noachian craters have friable, wind-eroded deposits restricted to their floors, some with deeper light-toned material exposed, suggesting aqueous depositional environments. These craters are concentrated in low-albedo, dust-free highland regions. In many cases, basaltic volcanism was not the last significant resurfacing process in these craters.

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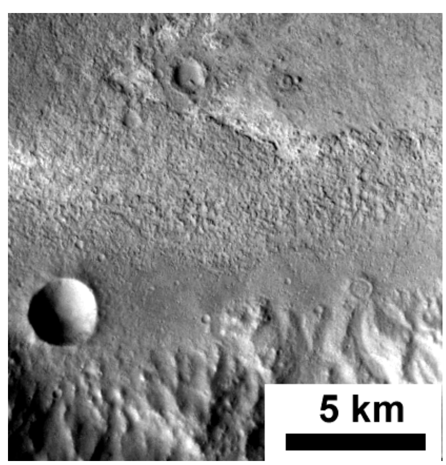

Fig. 1. Gullied Noachian crater wall and etched floor, THEMIS V07923006, 28.1°S, 129.8°E.

A SOURCE OF SULPHUR AND CHLORINE FOR FORMATION OF LARGE SALT DEPOSITS ON THE SOUTHERN HIGHLANDS OF MARS. G.G. Kochemasov, IGEM of the Russian Academy of Sciences, 35 Staromonetny, 109017 Moscow, Russia, (kochem.36@mail.ru).

Several orbital and on land missions of the last about 20 years firmly established that a very characteristic feature of the southern highlands of Mars is very extensive development of salt deposits (along with hydrated silicates and zeolites). Usually light colored they all have another very important physical characteristics – a low density. And this is understandable from a physical point of view. In a rotating planet all its variously elevated tectonic blocks tend to equilibrate their angular momenta to diminish an energetic status of a body (tensions between blocks). In the martian case deeply subsided northern lowlands must be filled with denser material than the highly uplifted southern highlands to equilibrate their angular momenta. Indeed, dense Fe-basalts of the north are opposed by the lighter (by color and density) rocks. Among them are already found andesites (Pathfinder), dacites (MGS-THEMIS), alkaline rocks (Spirit), hydrated silicates and large amounts of salts. Orbital gravity mapping [7] clearly showed that the needed equilibration is nearly achieved. But it is also clear that thin upper veneer of light material is not enough to produce a significant fall of overall southern crust density. To understand the important flux of SO2 and Cl solutions making the vast salt covers one have to admit massive development of primary igneous SO2 and Cl bearing minerals at depth [1-6]. The best candidates are feldspathoids of alkaline rocks such as sodalite and nosean. So, if at Earth with its lower elevation range between continents and oceans (20 km) dense difference between andesites (an average continental crust composition) and tholeiites is satisfactory, for Mars with its higher elevation range (about 30 km) this difference must be higher: Fe-basalts of lowlands against syenites + salts of highlands. **Fig. 1** (PIA05485, MOC image of MGS, Meridiani Planum) shows that distribution of light salt rich deposits around and between craters on Meridiani Planum tend to follow some intersecting directions (N-S, NE, NW, W-E). These directions (well known planetary lineaments) control an arrangement of the craters draining SO2 and Cl rich liquids (solutions) from depths. **Fig. 2** (TRA_000873_1780) shows in a local scale that light salt rich deposits cover a wide area around Victoria Crater (800 m in diameter) and are seen under a thin eolian coat The Opportunity's heat shield impact crater also exposed light colored salt rich rocks under a thin dark eolian cover.

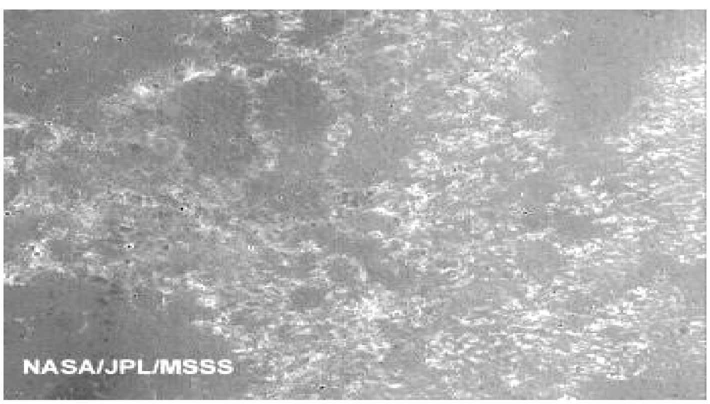

Fig. 1 Meridiani Planum

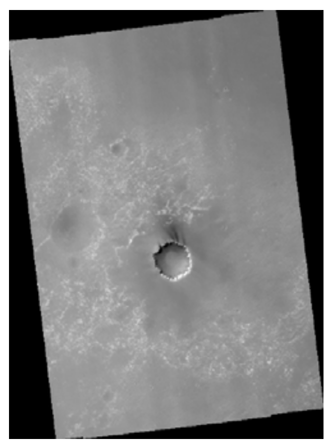

Fig. 2. Crater Victoria

References:

[1] Smith D.E., Sjogren W.L., Tyler G.L et al. (1999) Science, v. 286, 94-97. **[2]**Kochemasov G.G. (1999) Fractionated crust of Mars as an adequate response to its body wave warping // Ninth annual V.M. Goldschmidt conference, Abstract # 7065. **[3] -"-** (2001) High chlorine content in martian rocks and soils as an indication of acid highland lithologies // Eleventh annual V.M. Goldschmidt conference, Abstract # 3070. **[4]** –"- (2001) The composition of the martian highlands as a factor of their effective uplifting, destruction and production of voluminous debris // Field trip and Workshop on the martian highlands and Mojave desert analogs, Abstract # 4002. **[5] –"-** (2005) Fluidized ejecta of martian lbate craters and composition of the highland rocks // Workshop on the role of volatiles and atmospheres on martian craters, Abstract # 3002. **[6] –"-** (2006) Sulfates and salts on the martian surface have their source deep in the crust // Workshop on sulfates as recorders of atmospheric-fluid-rock interactions, Abstract # 7016. **[7]** –"- (2007) Martian dichotomy expressed in relief, crustal chemistry, polar caps,atmosphere // Seventh International Conference on Mars, Absrtact # 3033. v. 286, 94-97.

Frozen Dune Dynamics, Accumulation and Preservation of Aeolian Cross-Stratification in the Cavi Unit in the North Polar Region of Mars. G. Kocurek[1] and R. C. Ewing[2], [1]University of Texas at Austin, Department of Geological Sciences, 1 University Station C1100, Austin, TX, 78712, garyk@mail.utexas.edu, [2]Princeton University, Department of Geosciences, Guyot Hall, Princeton, NJ, 08544, rewing@princeton.edu.

Analysis of surfaces within the aeolian cross-stratified Planum Boreum Cavi Unit of the north polar region of Mars demonstrates the nature of niveo-aeolian dune dynamics and the accumulation and preservation of aeolian dune stratification on Mars. An upward gradational transition from the sediment-dominated Cavi Unit into the ice-dominated ice cap layers of Planum Boreum 1 Unit reflects climatic change.

All Cavi surfaces visible on HiRISE images TRA_000863_2640 and PSP_010636_2660 were identified and mapped as (1) stabilization bounding surfaces marked by pronounced polygonal fractures of interpreted permafrost origin that, in some cases, are overlain by ice deposits, (2) stabilization bounding surfaces showing lesser polygonal fracturing, (3) erosional bounding surfaces lacking evidence of permafrost, and (4) internal set cross-strata. The overall unit architecture consists of preserved dune topography in which (1) stacked dune stoss-slope deposits are bounded by erosional surfaces or surfaces showing lesser polygonal fracturing, (2) down-lapping lee-face deposits are bounded by surfaces of pronounced polygonal fractures, and (3) interdune areas show the amalgamation of pronounced polygonally fractured surfaces and ice deposits.

Cavi dune architecture is interpreted as showing cycles of dune reactivation and stabilization by freezing. During reactivation stoss slopes are initially deflated, with subsequent, renewed deposition causing lee faces to prograde as downlapping wedges that taper onto interdune floors. During stabilization the entire dune develops a permafrost surface and wind-blown snow may accumulate in interdune hollows. Only the stoss slopes of dunes are ever deflated to remove the permafrost surface, whereas these surfaces remain intact on the lee slopes and within the interdune areas.

Because dune topography is preserved during stabilization, it serves as the antecedent boundary condition during subsequent reactivation such that renewed deposition conforms to the existing dune topography. Remnant dune topography is carried upward through the Cavi Unit, resulting in exceptionally high angles of bedform climb. The upward persistence of remnant dune topography is most evident in sections parallel to the dune migration direction, whereas in more oblique sections dunes migrate into the section.

Dune migration is eastward, arguing for the existence of circum-polar wind belts during Cavi deposition. The period of cycles of dune stabilization and reactivation are unknown. The Cavi Unit is clearly transitional into the overlying layered ice cap accumulations (Planum Boreum 1 Unit), which show alternating darker, sediment-rich ice layers, and lighter sediment-poor ice layers. The darker sediment-rich layers show the lateral inclusion of preserved dunes with cross-strata of both sediment and ice, and ice that continues as cross-strata lee of dune topography, demonstrating that snow/ice behaved as clastic grains. Lower polar ice caps strata of darker sediment-rich layers and lighter sediment-poor layers are interpreted to mirror Cavi cycles of dune reactivation and stabilization, respectively. Martian climatic change from the Cavi Unit into the layered ice cap, therefore, is one marked primarily by the onset of greatly enhanced snow/ice deposition and decreased sediment availability.

Although the accumulation and preservation of Martian dune strata in the Cavi Unit are most analogous to isolated examples in the Antarctic of Earth, the dynamic processes can be more broadly contrasted with Earth warm-climate deserts as a function of profoundly different source-to-sink boundary conditions. Accumulation of aeolian strata by dune stabilization through freezing is analogous to “stabilizing aeolian systems” on Earth where stabilization most commonly occurs as vegetation. This type of accumulation contrasts sharply with most warm-climate dune systems where accumulation of only basal portions of dunes occurs through spatial and temporal deceleration of winds or a rise in the water table. Freezing on Mars also allows for the preservation of the dune accumulations to yield the Cavi Unit, which rises well above the adjacent plains. This mode of preservation is in contrast to Earth systems where preservation of aeolian accumulations occurs with subsidence and burial, and/or a regional relative rise in the water table that is typically related to sea level.

EXAMINING TERRESTRIAL SILICA-CEMENTED INVERTED CHANNEL DEPOSITS AS A POTENTIAL MARTIAN ANALOG.
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Introduction: There have been numerous observations of elongated, relatively sinuous, positive relief landforms on Mars, such as the putative delta system in Eberswalde crater [1] and the sinuous ridge in Miyamoto crater [2]. These features appear morphologically similar to inverted channel deposits (ICDs) on Earth, which represent exhumed cemented fluvial deposits [e.g. 2, 3]. Terrestrial fluvial sediments may be preserved as positive relief features by cementing processes within the channel, either during evaporation or after burial during diagenesis [4, 5]. Subsequent deflation of the region by aeolian processes reveals these sediments as positive relief features. If similar features are found on Mars, this would have implications for the presence of persistent liquid water on the surface, past climate regimes, and potential diagenetic processes. Common cements for terrestrial ICDs include carbonates and amorphous silica [e.g. 6]. While carbonates appear relatively rare on Mars [7], silica has been observed at the surface [8, 9], and is consistent with the current understanding of martian weathering processes [e.g. 10].

Study goals: Our goal is to investigate the morphologic and spectroscopic characteristics of ICDs that could help to identify them from orbit as paleofluvial deposits. Specifically, the presence of cemented materials in conjunction with inverted terrain may help to identify potential ICDs on Mars. In this study, we examine silica cements in terrestrial ICDs located in the Cedar Mountain formation in Green River, Utah, U.S.A. If some martian inverted features are similarly cemented, they may not initially appear to be sedimentary features in infrared (IR) spectroscopy remote sensing data, especially if their constituent sediments are basaltic. Here, we report on the nature of the silica cement from SEM studies; additional work on thermal infrared spectroscopy measurements of the same samples are reported by [10] in this volume.

Methods: Compositional and morphological measurements were obtained on eight representative ICD samples using a JEOL 5800LV Scanning Electron Microscope (SEM) operating at an accelerating voltage of 20kV in full vacuum. Samples were prepared as carbon coated thin sections. Both backscattered electron (BSE) and cathodoluminescence (CL) data were obtained. ICD samples consisted of a range of materials including sandstone, quartzite, and a conglomerate with relatively large grains up to 1 cm present.

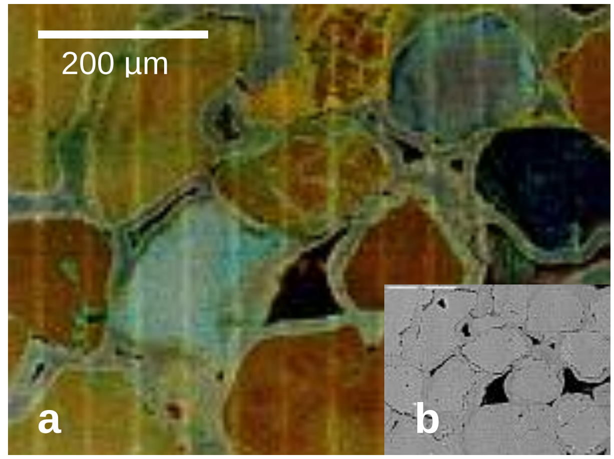

Fig.1. (a) Three color composite CL image of a quartzite ICD sample. Note that the overgrowth rims are also luminescing. (b) Inset BSE image of the same sample location. Detrital quartz grains and silica overgrowths are of the same composition.

Discussion: All eight samples were composed primarily of quartz grains cemented by amorphous silica, likely chalcedony. In some examples, significant quartz overgrowths are visible (Fig. 1). Although the presence of chalcedony suggests that this cement may be a silcrete (and thus formed near the surface), the CL observed in the overgrowths may indicate that cementation occurred at a greater depth. Additional study is required to determine the origin of the cement.

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GEOLOGIC ANALYSIS OF VARIOUS HYDRATED FORMATIONS EXPOSED ON THE PLATEAUS SURROUNDING VALLES MARINERIS, MARS . L. Le Deit[1], J. Flahaut[2], C. Quantin[2], O. Bourgeois[3], and E. Hauber[1], [1]Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, Germany (Laetitia.Ledeit@dlr.de), [2]Laboratoire des Sciences de la Terre, UMR CNRS 5570, Université Claude Bernard, 2 rue Raphaël Dubois, 696222 Villeurbanne Cedex, France, [3]Laboratoire de Planétologie et Géodynamique UMR 6112, CNRS, Université de Nantes, 2 chemin de la Houssinière, 44322 Nantes, France.

Introduction: Hydrated minerals were recently detected on different formations located both on the Noachian and the Hesperian plateaus surrounding the Valles Marineris Chasmata [1-11]. Their analysis may provide better constraints on the past geological history of the region. Here we report an inventory of these hydrated formations by presenting their morphology, their spatial distribution, their mineralogical composition, and their stratigraphy.

Fe/Mg-phyllosilicate-rich formations: The Fe/Mg-phyllosilicate-rich formations are enriched in Fe/Mg-smectite or possibly vermiculite locally (CRISM spectra exhibit absorption bands at 1.4 µm, 1.9 µm, and 2.3 µm). These light-toned formations are located both on Noachian and Hesperian terrains, and are characterized by various morphologies ranging from bouldery to thinly layered according to the geological contexts. A Fe/Mg-phyllosilicate-rich formation occurs along scarps such as in the upper parts of crater rims, valleys [9], and walls of Coprates Catena [4] and Ganges Chasma. Other formations are localised in central peaks, pits [6], and ejecta of impact craters that suggests these formations correspond to excavated layers. Layered formations correspond to valley and crater infillings, such as in Holden Crater [12] and in Shalbatana Vallis.

Al-phyllosilicate-rich formation: The Al-phyllosilicate-rich formation corresponds to dozens of thin light-toned exposures scattered over an area wider than 1000 x 600 km on the plateaus south of Coprates-Capri-Eos Chasmata, and west of Ganges Chasma [10]. They crop out locally on ejecta of large impact craters. This formation is also visible along scarps such as the upper parts of the walls of Coprates Catena [4] and Allegheny Vallis. The Al-phyllosilicate-rich formation corresponds to massive, rough, and polygonally fractured terrains enriched in Al-smectite and/or kaolinite (CRISM spectra display absorption bands at 1.4 µm, 1.9 µm, and a narrow band at 2.2 µm). All outcrops investigated so far are only present over Noachian terrains corresponding to volcanic materials and impact breccia (units Npl_1, Npl_2, and Nplh in [13]). This indicates that the Al-phyllosilicate-rich formation was formed either at the Noachian Epoch, or later by aqueous alteration of the Noachian rocks.

LD formation: The Layered Deposit (LD) formation occupies a large area of at least 40000 km^2 distributed at various elevations, both on plateaus and in shallow depressions north of Tithonium Chasma, south of Ius Chasma, around West Candor Chasma, and southwest of Juventae and Ganges Chasmata [1, 7, 8, 11]. The LD formation consists of a series of alternating light and dark beds, polygonally fractured, a hundred meters in total thickness that is covered by a dark unconsolidated mantle probably corresponding to lag deposits. The large spatial coverage of LDs and their location on highy elevated plateaus suggest that they mainly correspond to consolidated airfall dust and/or volcanic ash [7, 11]. The LD formation is composed of opaline silica or Al-phyllosilicate-rich layers being overlain by hydroxylated ferric sulfate-rich layers [1, 3, 7, 8, 11]. The stratigraphic relationships of the LD formation with the plateaus indicate that it was deposited during the Early to Late Hesperian, and possibly later depending on the region.

Stratigraphy: The Al-phyllosilicate-rich formation overlies the Fe/Mg-phyllosilicate-rich formation cropping out along the upper parts of scarps in several locations in the region. This sequence is topped by the LD formation. This kind of mineralogical stratigraphy is observed in other extended regions of Mars including Mawrth Vallis [14], and Meridiani Planum [15], which may have registered similar geological events. Such a mineralogical stratigraphy may be explained by an evolution of the aqueous conditions through time (e.g., alkaline to acidic alteration fluids, decreasing water/rock ratio), and by the different nature of the parent rocks (lavas, impact breccia, ash/dust).

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MAWRTH VALLIS: STRATIGRAPHY OF THE PHYLLOSILICATE-RICH UNIT AT THE MSL LANDING SITE. D. Loizeau[1], N. Mangold[2], J. Michalski[1], V. Ansan [2], F. Poulet[1], J. Carter[1], J-P. Bibring[1], [1] Institut Astrophysique Spatiale, Université Paris-Sud/CNRS, UMR 8617, 91405 Orsay Cedex, France (damien.loizeau@ias.u-psud.fr), [2] Laboratoire de Planétologie et Géodynamique de Nantes, Université de Nantes/CNRS UMR6112, 2 rue de la Houssinière, BP 92208, 44322 Nantes, France.

Introduction: The Mawrth Vallis region has been shown to display the largest clay-rich outcrops on the surface of Mars with data from Mars Express/ OMEGA and CRISM/Mars Reconnaissance Orbiter (MRO). These outcrops correspond to the eroded parts of a thick and large thinely layered unit (e.g. [1], [2], [3]) dated from the Noachian. Hence, this unit records a past environment where water was available for abundant alteration in the context of a sedimentary unit.

The next NASA rover to Mars, Mars Science Laboratory (MSL), has been designed to determine a planet's past or present habitability. In the context of this mission, one potential landing ellipse has been selected in the Mawrth Vallis region, directly on a large outcrop of the clay-unit (~35 km x ~20 km).

We discuss the stratigraphy of this landing ellipse and its close surroundings as known from the remote sensing data available today, both in terms of mineralogy and morphology.

Characteristics of the landing ellipse from orbital data:

Mineralogy. We have been using infrared hyperspectral datasets (OMEGA and CRISM) to detect and map phyllosilicates on the surface of the region. The ellipse shows the presence of two principal groups: Al-phyllosilicates are located principally on the western part of the landing ellipse, while Fe/Mg-phyllosilicates are mainly on the eastern part.

Cross-section. The stereoscopic HRSC/Mars Express data provided a Digital Terrain Model (DTM) of the region at ~50 m/pix and we used it to locate exactly the different phyllosilicates. In the landing ellipse, the eastern, Al-phyllosilicate-rich, part is higher in altitude. More locally all small Al-phyllosilicate-rich outcrops are also higher than Fe/Mg-phyllosilicate-rich ones, showing a constant stratigraphy with Al-phyllosilicates above Fe/Mg-phyllosilicates.

Mineralogical units mapped with near infrared CRISM and OMEGA data correspond to different color units in the HRSC and HiRISE/MRO color datasets. This allows an even higher mapping of the clay-unit at local scale.

Using the high-resolution mapping and the HRSC DTM, it was possible to build a constrained cross-section of the clay-unit on the landing ellipse (where HiRISE images cover the whole area), to understand the geometry of this unit. A similar work based only on HRSC color data has been made in [4].

This cross-section confirms the stratigraphy: Al-phyllosilicates on top of Fe/Mg-phyllosilicates, but also shows the presence of different sub-units in the Fe/Mg-phyllosilicate-rich layers.

It gives an estimation of the stratigraphic depth that MSL could reach (more than 100 m, for tens of layers). Furthermore, the presence of hydrated ejecta material, ~20 km south of the center of the ellipse, exhumed from a crater, 15 km in diameter, could give access to deeper rocks.

The presence of new HiRISE images on the neighboring Mawrth Vallis channel flank could also provide more information about the stratigraphy, but the capping unit partly covering the region hides large parts of the clay-unit.

Conclusion: The relation between alteration and deposition of the unit is not a simple one. The Fe/Mg-phyllosilicates are always in meter-scale layered rocks, whereas the upper Al-phyllosilicate sub-unit seems in several places to lie unconformably on the rest of the unit ([4], [5]), and the layering is almost undetectable on its outcrops, indicating a possible strong leaching of the upper strata, altering to Al-phyllosilicates, and erasing layers boundaries. This upper Al-phyllosilicate unit is observed very widely around the region ([6]) and could indicate a spatially extended last stage of alteration.

The action of liquid water has been extensive and long in the Mawrth Vallis region, making it one of the most important region where past-habitability is to be studied on Mars.

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CONNECTING FLUVIAL LANDFORMS AND THE STRATIGRAPHY OF MAWRTH VALLIS PHYLLOSILICATES: IMPLICATIONS FOR CHRONOLOGY AND ALTERATION PROCESSES, N. Mangold[1], D. Loizeau[2], A. Gaudin[1], V. Ansan[1], J. Michalski[2], F. Poulet[2], J-P. Bibring[2], [1] Laboratoire de Planétologie et Géodynamique de Nantes, Université de Nantes/CNRS UMR6112, 2 rue de la Houssinière, BP 92208, 44322 Nantes, France (nicolas.mangold@univ-nantes.fr), [2] Institut Astrophysique Spatiale, Université Paris-Sud/CNRS, UMR 8617, 91405 Orsay, France.

Introduction:
A layered phyllosilicate-bearing bedrock is widely exposed in the Mawrth Vallis region of Mars [1, 2]. The light-toned rocks can roughly be divided into a Fe/Mg-phyllosilicate-bearing unit, and an Al-phyllosilicate-bearing unit [2]. Local exposures of crater rims show that the whole layered unit is > 150 m in thickness, but this thickness may exceed 1 km if assuming the plateau being cut by the Mawrth Vallis outflow [2, 3]. However, more recent studies suggested that the layered deposits were formed after the Mawrth Vallis outflow channel, therefore being limited in thickness and being posterior to the outflow (dated of the Late Noachian or later) [4]. The cross-cutting relationships between the outflow channels and the layered bedrock are therefore important for establishing the chronology of events and the thickness of the altered unit. Moreover, fluvial valleys incising the bedrock may also inform us about the role of surface weathering in the formation of phyllosilicates. Thus, this work is motivated by understanding genetic and chronological relationships between fluvial landforms and altered rocks.

Observations on outflow channel slopes:
Previous observations indicated the presence of local layering on valley slopes outcrops, but most high resolution images show dark mantling material hiding the bedrock. New HiRISE and CTX images of the valley slopes and bottom reveal the presence of extensive layers eroded by the fluvial flow. One location at the foot of the valley displays >40 individual layers with subhorizontal dip present over a 120 m high section with a 5° slope. This location being found 500 m below the plateau top, it indicates that the layered deposits were thick, i.e. >600 meters.

Observations at outflow channel bottom:
The channel bottom displays several landforms that we interpret as related to the outflow channel activity in a periglacial environment. Small (few 100s m to 2 km large) closed depressions in the valley floor are interpreted as alases, i.e. thermokarstic depression due to the presence of melting ice at this location. Similar depressions are observed on the floor of Ares Vallis and in Siberia [5]. Polygonal cracking, at the scale of > 100 m, indicates the presence of water ice in the bedrock. These cracks cross all the layered unit present at the valley floor showing that they formed later than the sediments. These large cracks are uniquely found at the valley bottom, therefore implying a genetic link between the valley formation and the periglacial activity. Finally, blocks of layered deposits tilted in various dips were found throughout the valley bottom at different locations. These blocks are interpreted as having been transported by the fluvial activity. Their geometry fits that of blocks found at the bottom of Holden valley and formed either by the deposits of Uzboï vallis activity, or hydraulic fracturation [6]. In both cases, this indicates a formation and induration before the outflow channel activity, as well as their alteration into Fe/Mg phyllosilicates. Nevertheless, in several locations, the Al-bearing material appears "unconformably" over the tilted layers, therefore attesting of possible post-Mawrth Vallis alteration too for the Al-bearing material only. This suggests that the compositional layering is distinct from the depositional layering.

Observations of valley networks incision:
Valley networks are observed as deep valleys in places, or inverted channels in other places. Many valleys cross the slopes of Mawrth Vallis flanks, thus showing an activity subsequent to the outflow. These valleys are poorly branched, but attest of significant late fluvial activity. It was observed that these valleys are only present in locations where a Al-bearing phyllosilicates unit was present, thus at the top of the layered unit.

Conclusions:
New observations show (1) the presence of Fe/Mg phyllosilicate-bearing layers deep inside the Mawrth valleys slopes, attesting of a >600 m thick layered unit, (2) the erosion of Mawrth Vallis took place after the main episodes of layer deposition and alteration into Fe/Mg phyllosilicates, (3) the alteration having produced Al-rich material may have occurred later than the outflow formation. This late alteration may be due to a late weathering phase related the late fluvial activity as suggested by the association of fluvial landforms with Al-bearing outcrops.

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CHEMICAL AND MINERALOGICAL ESTIMATES OF PHYLLOSILICATES IN MARTIAN SOILS AT THE MER LANDING SITES. I. O. McGlynn[1], H. Y. McSween[1], C. M. Fedo[1], A. D. Rogers[2], [1]Department of Earth and Planetary Sciences and Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37996-1410 (imcglynn@utk.edu), [2]Department of Geosciences, Stony Brook University, Stony Brook, NY 11792-2100.

Introduction: Phyllosilicates are the most common product of water-rock interactions on Earth but are relatively uncommon on Mars. Orbital remote sensing from the Mars Express and Mars Reconnaissance Orbiter spacecraft have identified iron-bearing clays (chamosite and nontronite) and aluminum- bearing clays (montmorillonite [1], kaolinite, and saponite [2]). The presence of clays in geographically widespread settings indicates significant Noachian aqueous activity. Despite these discoveries, large quantities of clay minerals have not been found on the surface.

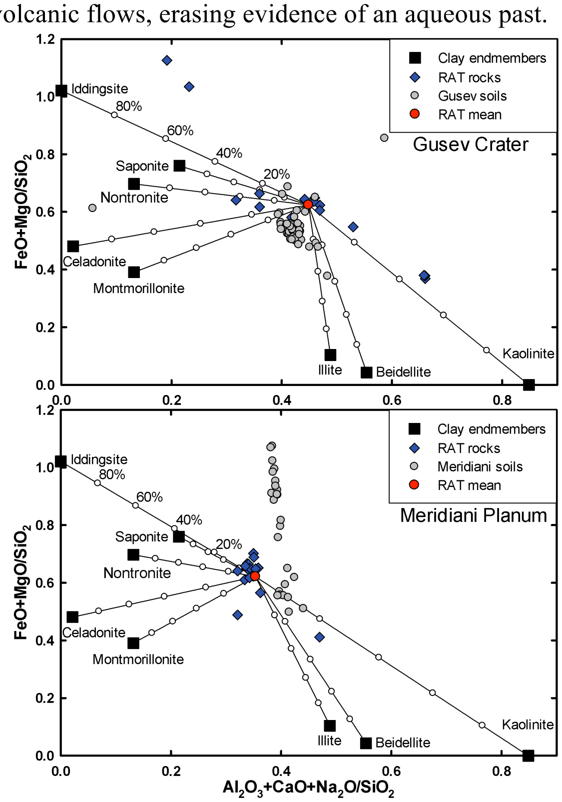
For six years the Mars Exploration Rovers (MER) Spirit and Opportunity have surveyed soil targets over long traverses in Gusev Crater and Meridiani Planum, resulting in the most detailed characterization of sediments beyond the Earth. Soils are produced largely by physical weathering unaltered basalts and may have complex provenance incorporating mixing on local, and global scales, trituration by impact gardening, and abrasion from aeolian processes. Evidence of aqueous alteration has been found in from of sulfate salts [3], goethite [4] and hematite [5], and chemical alteration from hydrothermal fluids [6], but are not as pervasive as expected. The purpose of this study is to estimate the phyllosilicate components in soils and evaluate the potential for aqueous alteration in soil formation and identify aqueous-limited alteration pathways.

Unresolved Phyllosilicates: Sulfur- and chlorine-rich silt-sized dust may contain remnants of Noachian phyllosilicates at quantities insufficient for detection by the MER rovers. Chemical mixing models have been developed to evaluate the dissolution of the easily weathered basaltic component olivine as FeO+MgO, the loss of feldspars as $CaO+Na_2O$, and the accumulation of Al_2O_3 as aluminum-bearing clays such as kaolinite. Uncertainties in protolith compositions can be minimized by plotting the mobility of soluble components relative to presumably immobile SiO_2 or TiO_2. The average composition of rocks abraded by the rock abrasion tool (RAT) is representative of the unaltered, mostly dust-free, igneous source for each landing site. Common clay minerals can be added to RATed rock means to model basaltic soils with alteration products.

As depicted in figure 1, most undisturbed Gusev soils can be compositionally explained as basalt with a 10-20% clay contribution of celadonite, illite, montmorillonite, or beidellite. Most undisturbed soils in Meridiani Planum cannot be formed from a basalt-clay mixture, indicating the source material may be compositionally distinct from local basalts.

The quantities of alteration components are evaluated independently with the Mini-Thermal Emission Spectrometer (Mini-TES). Spectra acquired for Gusev soils in from Sols 89-126 indicate 4 wt% phyllosilicates, lower than the modeled mixing composition for Gusev Crater. Reported Mini-TES results for Meridiani Planum soils are 5 wt% phyllosilicates [7], well above the chemical mixing modeled abundance.

Soils in Gusev Crater and Meridiani Planum do not contain large quantities of clay minerals that have been detected remotely in some other locations on Mars. Small quantities of clays may be present at the MER landing sites, not as locally altered products but as Noachian clays intermixed with dust deposits. Any clays formed locally were probably buried by younger volcanic flows, erasing evidence of an aqueous past.



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SEDIMENTARY PROVENANCE STUDIES ON MARS WITH AN EXAMPLE FROM THE BURNS FORMATION, MERIDIANI PLANUM. Scott M. McLennan, Department of Geosciences, SUNY at Stony Brook, Stony Brook, NY, 11794-2100, USA (Scott.McLennan@sunysb.edu).

Introduction: In order to evaluate the sedimentary history of Mars, it is necessary to constrain the provenance of sedimentary deposits of all ages. On Earth, a full suite of analytical methods, including major and trace element geochemistry, radiogenic and stable isotopes, mineralogy and microscopy can be brought to bear at all scales. However, analytical tools available for study of Martian sediments are considerably more limited. Available data include imaging with resolution to ~100 microns, major and a few trace elements, *in situ* spectroscopy, which constrains Fe-mineralogy reasonably well (Mössbauer) but other minerals less so (VNIR, TES), and orbital spectroscopy which, while gaining ever increasing resolution, cannot yet achieve anything approaching hand sample scale resolution.

In this presentation, some of the issues, constraints and insights associated with provenance analysis on Mars will be discussed, using the well-studied Burns formation at Meridiani Planum as an example.

Ultimate Provenance – The Martian Upper Crust: A fundamental point of departure between provenance studies on Earth and Mars is the nature of exposed crust contributing sediment. Although cannibalistic sedimentary recycling dominates immediate sediment sources, the vast proportion of terrestrial sediment is derived ultimately from 'granodioritic' upper continental crust, dominated by quartz, plagioclase and K-feldspar, with a lesser but still significant fraction from volcanic arcs. Only negligible amounts are derived from basaltic rocks. In stark contrast, Martian crust is composed almost entirely of basalts, dominated by plagioclase, pyroxene, olivine and Fe-Ti-oxides. Although there is regional variability, exposed crust on average has a moderately LIL-enriched basalt composition. Thus basalts represent the near exclusive ultimate provenance of Martian sedimentary rocks. The role of recycled sedimentary sources, although important for the Burns formation, is not constrained on a global scale.

Weathering Regimes: An important conclusion from returned data, laboratory experiments and geochemical modeling is that relatively acidic (controlled by the S-cycle rather than the C-cycle) and water limited conditions dominated aqueous weathering processes during much, if not all, of Martian geological time. Among the implications of these conditions are that normally insoluble Al and Fe^{3+} are relatively mobile and olivine and Fe-Ti-oxide dissolution processes are a common feature of aqueous weathering.

Sedimentary Differentiation Processes: On Earth, oceans act as a global chemical reactor that efficiently separates chemical constituents (e.g., carbonates, sulfates, chlorides) from the terrigenous components (e.g., quartz, clays). In the likely absence of oceans on Mars, at least during its post-early Noachian history, such sedimentary differentiation appears to be far less efficient. Accordingly surface soils and ancient sedimentary deposits that have been analyzed by Opportunity and Spirit (e.g., Burns formation; Peace class rocks) typically are mixtures of both terrigenous and chemical components (i.e., sulfates ± silica ± secondary oxides ± chlorides) with complex geological histories, thus complicating provenance studies.

The Burns Formation: The Burns formation is the most thoroughly studied sedimentary deposit on Mars. Composed of sulfate-cemented eolian sandstones, it has undergone a complex diagenetic history. Mineralogy is reasonably constrained but an unanswered question is how mineralogy relates to texture. For example, the rocks likely contain up to 25% amorphous silica but whether this is within grains, cement, or both is unknown. Geochemical mass balance indicates that grains are likely sulfate bearing and accordingly are interpreted as recycled sulfate cemented altered basaltic mud, possibly produced in a playa lake.

The chemical composition of the Burns formation, recalculated on a S/Cl-free basis, is similar to the Martian upper crust, apart from some minor and trace elements, which differ by up to a factor of 2. Elevated Ni could be due to a meteoritical component. However, this similarity on its own does not provide compelling constraints on provenance since there is no reason to suppose that chemical constituents (~60-70%) are derived from the same sources as siliciclastic constituents (~30-40%). Indeed, varying the amount of sulfate by up to ±15% does not significantly influence the basaltic character of the bulk composition.

The provenance of the terrigenous components can only be indirectly constrained. A combination of MiniTES and Mössbauer spectroscopy independently identified various chemical constituents within the Burns, including amorphous silica, hematite, jarosite and Ca- and Mg-sulfates. High levels of Cl indicate that chlorides are also present. When these constituents are removed by assuming simple stoichiometry, the composition of the remaining "residue" is consistent with a moderately weathered basalt with a primary composition also approximating average Martian crust.

A COMPLETE DEPOSITIONAL SYSTEM IN MELAS CHASMA, MARS. J. M. Metz[1], J. P. Grotzinger[1], D. Mohrig[2], A. McEwen[3], C. Weitz[4], [1]Geological and Planetary Sciences, California Institute of Technology, Pasadena CA, joannah@caltech.edu, [2]University of Texas, Austin, TX., [3]Lunar and Planetary Lab, University of Arizona, Tucson AZ, [4]Planetary Science Institute, Tucson AZ.

Introduction: Identification of complete source-to-sink systems on Mars is rare, because commonly parts of the system are not preserved, are eroded, or are covered by later deposition. Southern Melas Basin in Valles Marineris is an exception, as it could represent a complete erosional to depositional system, from the fluvially-incised source region in the surrounding highlands to the terminal sediment sink formed by the sublacustrine fans in the topographically lowest part of the basin (Figs. 1b, 2).

Fluvial incision of bedrock, interpreted as caused by runoff from precipitation [1,2], drains the ridges bordering the western and eastern parts of the basin (Fig. 1b). Sediments generated during erosion of the upland areas were transported by fluvial drainage systems to form a classic, cone-shaped alluvial fan at the western edge of the basin. Sediments which pass through the alluvial fan were deposited as clinoforms, which may record a potential shoreline or upslope channel levee part of the submarine fan system [3]. The clinoforms give way further down the topographic profile to a sublacustrine fan, very similar in morphology to the Mississippi submarine fan [4]. This ultimate depositional low in the system provides the terminal sink for the sediments. The presence of sublacustrine fans in Melas Chasma indicates that a significant body of water was present and stable at the surface of Mars for at least 10^2 to 10^4 years, which provides important constraints for past environmental conditions on Mars.

Data Sets: We utilized HiRISE, CTX, and CRISM images and Digital Elevation Models constructed from HiRISE stereo pairs to study two depositional fans in southwestern Melas Chasma.

Sublacustrine Fans: The fan complex near the western end of southern Melas Basin is composed of multiple lobes with dendritic finger-like terminations that branch off at high angles in the downstream direction (Fig. 1a). The surface of the fans are marked by numerous channels and has an average surface slope of ~1°. The morphology of these fans is distinct from other previously identified fans on Mars and appears most similar to terrestrial submarine fans.

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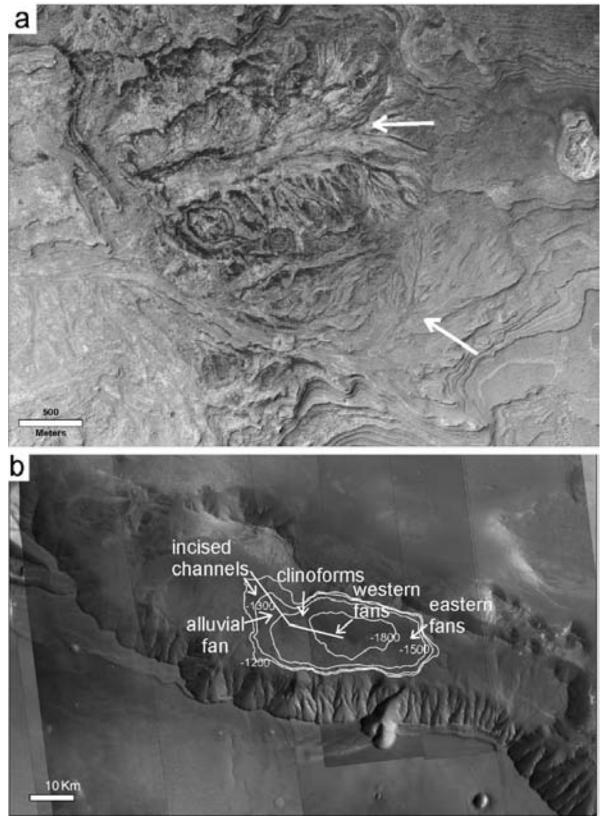

Fig 1. a.) Arrows highlight two depositional fans identfied in southwest Melas Chasma which have been interpreted as sublacustrine fans. b.) Features of a source-to-sink system in a small basin in southwest Melas Chasma. The white line indicates the topographic profile shown in Fig. 2.

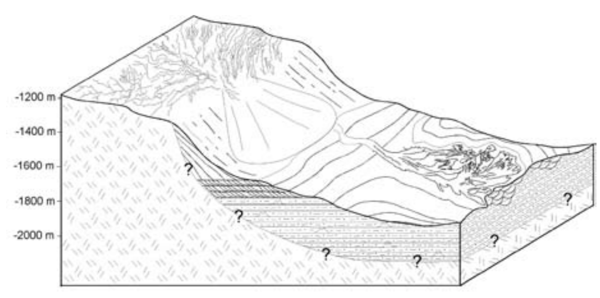

Fig. 2. Ideal schematic arrangement of environments including sublacustrine fans, clinoforms, alluvial fan and incised channels. Topography indicated by white line in Fig. 1b. The sublacsutrine fans occur in the topographically lowest part of the basin and represent the terminal sediment sink.

THE MINERALOGICAL EVOLUTION OF SEDIMENTARY SYSTEMS ON MARS. R. E. Milliken[1], [1]Jet Propulsion Lab/Caltech, MS 183-301, 4800 Oak Grove Dr., Pasadena, CA 91109 (Ralph.Milliken@jpl.nasa.gov)

Introduction: A major development in our understanding of Mars geology over the past several decades has been the clear detection and identification of sedimentary systems in the Martian rock record. Stratified deposits are present in terrains of various ages [1], deltas and fans have been observed in both closed and open basins [2-4], and minerals requiring the presence of water have been detected in these environments [3-7]. Of particular interest has been the observation that clay minerals and sulfates are separated in the ancient rock record both in space and time, and this has been used to suggest that Mars experienced a dramatic change in climate and weathering in its early history (>3 Ga) [8]. In order to fully test this hypothesis it is necessary to identify key stratigraphic sections on Mars that record these changes in mineralogy and in which the full mineral assemblages can be identified; thick, intact sedimentary sequences are a natural starting point for defining such 'reference' sections [9].

Clays on Ancient Mars: Phyllosilicates, primarily smectite, chlorite, and kaolin group minerals, have been detected in thousands of outcrops in Noachian-aged terrains on Mars using visible-near infrared reflectance spectra [5-6]. Recent studies have focused on the identification of Fe/Mg smectites in rocks in Mawrth Vallis, Nili Fossae, the southern highlands, and Gale Crater [5,9-12]. However, burial diagenesis on Earth typically results in smectite being converted to mixed-layered clays (e.g., corrensite) and ultimately illite or chlorite. Yet on Mars it is intriguing that some smectites are buried beneath several kilometers of rock and have not experienced this conversion [9], indicating that fluid flow may have been quite limited in some of these sedimentary environments [13]. Alternatively, some clays that have been previously identified as smectites may in fact be mixed-layered smectite-chlorite, which may indicate burial diagenesis [14].

In addition, many sedimentary environments on Mars, including the Eberswalde delta, exhibit only clay minerals as the alteration component. If the parent material is assumed to be basaltic in composition then one would expect smectites to co-exist with complementary salts (e.g., chlorides, sulfates, hydroxides, etc.) due to the excess in cations produced when forming smectite from basalt [7]. Therefore, current orbital data do not always provide the 'full picture' of mineral assemblages in what are otherwise recognizable sedimentary systems from a morphological perspective (e.g., the Eberswalde delta is in a closed basin but exhibits no evidence for evaporites).

These 'missing salts' and the apparent discordance in the rock record may be resolved if we can define stratigraphic sections on Mars that i) are continuous or contain clearly recognizable unconformities, ii) record variations in mineralogy and/or depositional environment with stratigraphic position, iii) are representative of local/regional processes that can be placed in a clear global context, iv) can be linked together in time and space to build a global stratigraphy for Mars. The identification of such reference sections is ultimately necessary to understand and independenty evaluate the climatic and geologic evolution of the red planet on a variety of spatial scales.

Until landers or rovers are capable of absolute age dating of the martian surface, it is reasonable to begin this process by examining thick sequences of sedimentary rocks, which arguably span more time, for which relative ages between units are clear. Gale Crater presents one such example, in which the lowermost strata contain clay minerals (nontronite) and sulfates, the overlying strata are dominated by sulfates, and the uppermost and thus youngest strata lack evidence of hydrated phases [9]. This evolution in the dominant alteration mineral assemblage through time is largely consistent with the hypothesis of Bibring et al. [8], who proposed that Mars transitioned from a climate favorable to clay formation to an acidic environment that favored sulfates, though Mg-sulfates at Gale do not require high levels of acidity to form.

Steps Forward: Determining which minerals and depositional settings (e.g., fluvial, lacustrine, alluvial, etc.) are recorded in martian sedimentary rocks is crucial for understanding climate evolution and identifying the primary volatile involved in crustal weathering on early Mars. As we continue to tackle this matter it is useful to be guided but not blinded by our terrstrial experience. The lack of plate tectonics and crustal recycling on Mars provides a unique opportunity to study the long-term stability of clay minerals and sulfates on timescales not accessible in the terrestrial rock record. In this aspect, ancient sedimentary systems on Mars may have just as much to teach us about evolution of the early Earth as our knowledge of Earth does about the geological evolution of Mars.

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INVERTED CHANNEL DEPOSITS AND ALTERED BASAL DEPOSITS IN THE RIM OF ISIDIS BASIN WITH IMPLICATIONS FOR THE DEPOSITS IN THE MIYAMOTO CRATER CANDIDATE LANDING SITE. H. E. Newsom[1], N. L. Lanza[1], A. M. Ollila[1], [1]Univ. of New Mexico, Inst. of Meteoritics, MSC03-2050, Albuquerque, NM 87131, USA, (newsom@unm.edu).

Introduction: Inverted channels often occur in impact craters, including Eberswalde, and Miyamoto [e.g., 1, 2]. By themselves, the inverted channels are important sedimentary targets, but underlying the inverted channels in some cases are polygonal fractured material that contains hydrous minerals and clay. One possibility is that this material represents fine-grained altered lake sediments and therefore represents a good astrobiology target for future missions.

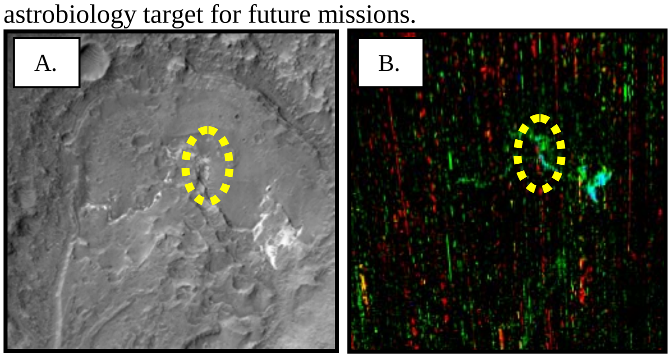

Fig. 1. Inverted channel complex in an erosional basin in a breached 60 km diameter crater on the edge of Isidis. (A.) Cropped CRISM (FRT0000B0CB_07_IF165S) visible image and (B.) IR image which show the Al-phyllosilicate signature (BD2210) of the underlying light toned material. Location of Fig. 2 is circled. Image ~ 3 km across.

Impact crater deposits: The southern rim of the Isidis basin includes evidence for fluvial erosion. A large 60 km diameter impact crater on this rim was proposed by Newsom [3] as a landing site for the canceled 2003 Mars lander. The crater is breached on the northern side with evidence for fluvial transport into Isidis. Recent CRISM and HiRISE images shows dramatic evidence in the center of the rim breach for the presence of an eroded basin. This 4.6 km long basin was filled with sedimentary deposits including polygonal fractured basal material that contains signatures of phyllosilicates and water, and an overlying inverted channel deposit (**Fig. 1, 2**). The stratigraphy and location of these deposits strongly suggests that the lower polygonal fractured rocks were deposited during or after a massive flood that created the rim breach from the release of a lake in the 60 km diameter crater. These geological constraints suggest that this lower phyllosilicate bearing material may consist of fine-grained lacustrine sediments, subsequently buried by the inverted channel deposit. Subsequent aeolian and/or fluvial activity has exposed the lower material.

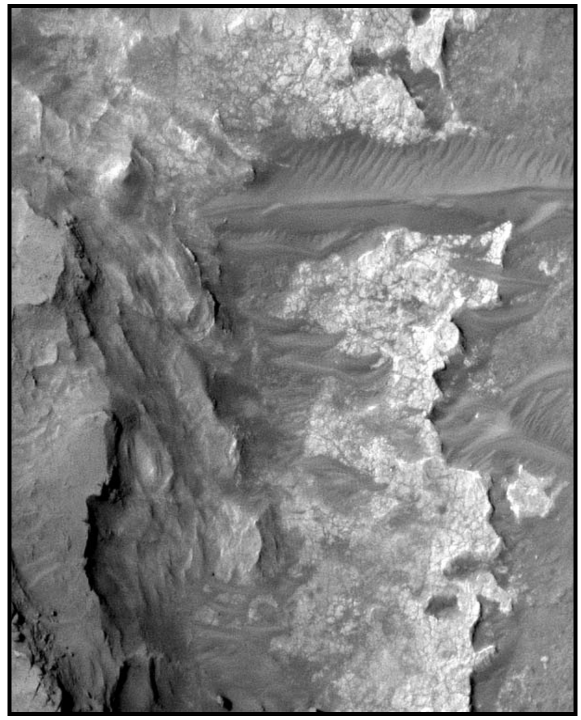

Fig. 2. Cropped HiRISE image (PSP_007727_1830) of the polygonal fractured phyllosilicate-bearing light toned layer below the inverted channel deposits on the left side of the image. Region shown is ~ 170 m across.

Implications for the Miyamoto Crater inverted channel and phyllosilicate-bearing deposits: The floor of Miyamoto crater has been proposed as a possible landing site for MSL [4, 5]. Miyamoto contains surprisingly similar, but more extensive, inverted channel deposits overlaying polygonal fractured light-toned phyllosilicate-bearing material with a high thermal inertia. Based on the evidence from Isidis, the Miyamoto material may also represent altered lake deposits, which could be a high priority target in the search for environments that preserve organic materials on Mars.

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GEOBIOLOGY AND SEDIMENTOLOGY OF THE HYPERSALINE GREAT SALT LAKE, NORTHERN UTAH, USA: ANALOGUES FOR ASSESSING WATERY ENVIRONMENTS ON MARS? Kathleen Nicoll[1] Laura L. Beer[2], [1]University of Utah, kathleen.nicoll@gmail.com [2]Colorado School of Mines, laurabeer@gmail.com.

Introduction: The hypersaline Great Salt Lake (GSL) of northern Utah, USA is a critical regional ecosystem that has not been examined in detail from a geobiological perspective. There are presently only a handful of studies on the biota of this shallow water closed-lake system [1]. Despite interest from industries mining the salt and harvesting the brine shrimp, relatively little is known about the lake's geochemistry, microbial diversity, metabolic activity, and mineralogy, and how these relate together with processes of biosedimentation and fossil preservation.

Objectives: We study the composition, architecture, and preservation of modern GSL microbial communities present using genomic (DNA sequencing) and microscopic techniques (SEM, EDAX).

Initial Results: Our examination of various sedimentary facies sampled in the modern GSL (figure 1) indicates that microbial communities occur in many of its environments. Microbial communities in the GSL are found in microbial mats, crusts, tufas, oolites, carbonate hardgrounds, stromatolites, open water, and benthos.

Traditional cultivation and isolation approaches on samples from the lake and surrounding features have yielded some Archaea, Bacteria, microalgae and cyanobacteria. Our ongoing phylogenetic studies of microbially-influenced sedimentary structures (MISS, after [2]) including biostromes, microbial mats, as well as benthic and pelagic regions of the lake, are yielding a tremendous amount of information through the application of high-throughput DNA sequencing techniques, including small sub-unit 16S ribosomal RNA (16S ssu rRNA) methods.

Conclusions and Implications: Our findings refute the idea that the GSL is "dead" – on the contrary, microbial diversity is a function of the prevailing conditions. Recent work on other microbial mats show that constituent cyanobacteria and other microorganisms secrete extracellular polymeric substances (EPS), which enhance the stability of the sediment [3], and contribute to sedimentation [4]. With this in mind, we endeavour to identify potential biomarkers present in GSL carbonate and siliclastic facies, and to examine their preservation and temporal persistence. Studying the GSL is especially valuable because it is an accessible extreme environment for testing hypotheses regarding biosedimentation, energy pathways, nutrient cycling and eukaryotic evolution on early Earth and Mars.

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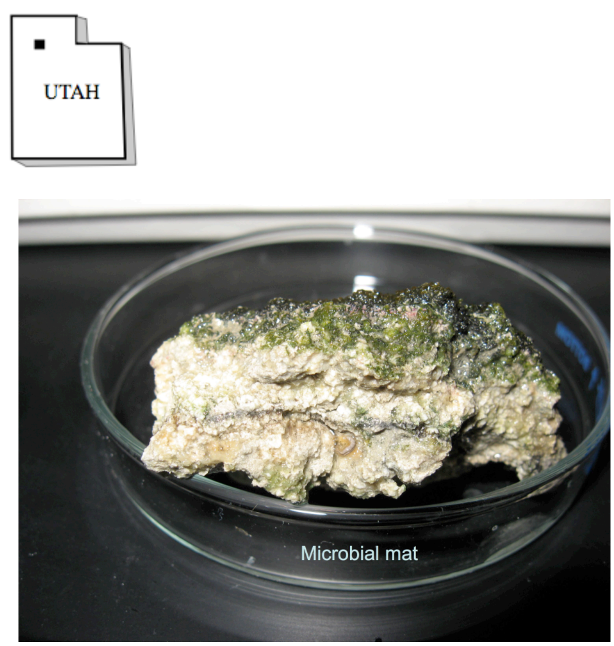
Figure 1: General location of our study area in GSL in Northern Utah. Below, photo of sampled modern microbial mat with MISS (Microbially-influenced sedimentary structures) that is yielding valuable genomic data.



BIOFILM-CATENAE IN SANDY TIDAL FLATS AND THEIR INFLUENCE ON PHYSICAL SEDIMENT DYNAMICS. N. Noffke, Old Dominion University, Ocean, Earth & Atmospheric Sciences, Norfolk, Virginia, USA, nnoffke@odu.edu

Microbial influences on marine sediments are generally understood as biogeochemical processes generating stromatolites. However, interaction of microbial mats with physical sediment dynamics plays also an important role [1]. In sandy settings, this biotic-physical interaction gives rise to highly characteristic 'microbially induced sedimentary structures - MISS'. The structures do not resemble at all stromatolites, but come in 17 main groups. They occur in siliciclastic tidal flats, sabkha and dune deposits since 3.2 billion years ([2]; [3] ; [4]. MISS have opened a new window for the exploration of early life on Earth. They may also serve as biosignatures for the search for life on Mars, especially in sandy aquatic deposits.

Modern microbial mats are constructed predominantly by cyanobacteria. The prokaryotes are excellently adapted to their environment. This presentation discusses, how benthic cyanobacteria respond to the long-term pattern of physical sedimentary processes.

Along transects from the low to the high water lines of the tidal flats, different types of microbial mats establish [5]; [4]. In the lower intertidal zone, biofilms overgrow the sands. Main biofilm-formers are coccoid cyanobacterial groups. In the upper intertidal zone, thin, endobenthic microbial mats develop. The mats are composed by the highly mobile filamentous species *Oscillatoria limosa*. In the lower supratidal zone, thick, epibenthic microbial mats can be found. These mats are formed by *Microcoleaus chthonoplastes*, a filamentous cyanobacterium well adapted to long periods of subaerial exposure. Such lateral successions are termed 'biofilm-catenae' [5].

Quantitative measurements documented that biofilms do not affect sedimentary processes. Biofilm-coated sand grains are swirled around by constant turbulence. The photoautotrophic cyanobacteria escape the lethal burial, because the microbial-mineral aggregates stay longer in suspension than non-colonized grains. They do not induce MISS. Endobenthic microbial mats stabilize sandy substrates 3 – 5 times compared to sterile sand. If buried, this cyanobacterium escapes quickly, and reestablishes a mat layer within a few hours. Epibenthic microbial mats stabilize sand up to 12 magnitudes.

The response by benthic cyanobacteria to the hydraulic conditions was quantified in field experiments using a portable MANZENRIEDER flume chamber [6].

This experiment produces a water current that crosses the microbial mat surface. A digital system analyses the first release of sand grains from the mat surface, the start of erosion of the microbial mat. The effect of the microbial mat on biostabilization of the sandy deposits was illustrated in a Shield's diagram. Endobenthic microbial mats colonize the uppermost millimeter of the sandy tidal surface and reduce the erosive forces of the currents significantly. The mat-covered sand withstands currents of up to 0.90 cm/s. The biostabilization effect is caused by the lower degree of roughness of the mat-interwoven depositional surface. Epibenthic microbial mats cover the tidal sands like a carpet. Their smooth surfaces reduce the erosive forces up to magnitudes of 12. As a consequence, such thick mats withstand currents of up to 1.60 m/s. This biostabilization effect prevents the direct influence of turbulent waters on the sand grains. This microbial effect can be expressed by a simple modification of the Shield's relation for sediment movement:

Q = r*u**2 / (r*s* - r*f*) *g* <u>*Dn*</u>,

where *u** is the shear velocity; r*f* is the density of fluid; r*s* is the density of sediment; *g* is the gravity constant; *D* is the actual grain diameter under the influence of biostabilization; and *n* is the exponent to which *D* is raised for the data to comply to the Shield's relationship. The results suggest to modify the quantification of physical sediment dynamics for the study of natural environments. With respect to Earth history, the quantification of those sedimentary processes allows to rise the hypothesis, that cyanobacteria have been at least 2.9 Ga around [7].

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SEDIMENT PREDICTION THROUGH BASIN ANALYSIS: An example from Acidalia Planitia. Dorothy Z. Oehler[1] and Carlton C. Allen[1]. [1]NASA - Johnson Space Center, Houston, TX 77058. dorothy.z.oehler@nasa.gov, carlton.c.allen@nasa.gov.

Introduction: Basin analysis is used on Earth to predict amount, age, and types of sediments likely in locations having limited subsurface data. Regional geology, aerial photography, and satellite data are the main tools for this type of analysis. We have used a similar approach for predicting sediment accumulations in Acidalia Planitia, Mars [1] and have applied that to interpretation of high-albedo mounds from the region.

We have incorporated Mars Orbiter Laser Altimeter (MOLA) data to assess the regional setting of Acidalia with regard to sources of sediments, catchment area, and depositional sites. We have coupled this with the mapping of the Acidalia mounds and with details of their geomorphology from Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) images. We used Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) data, thermal inertia, and regional gravity to help constrain our interpretations and our model of sedimentation.

Results: Chryse and Acidalia Planitiae (Fig. 1) have been proposed to be remnants of impact basins, formed ~4 Ga ago [2]. Together, they comprise an embayment [3] that was the focal point for sediment deposition from Hesperian outflow channels (Fig. 1).

Chryse is the proximal portion of that embayment. Channel deposits within Chryse are illustrated in Fig. 1. Acidalia is interpreted as the distal portion of the embayment. This is supported by occurrence of streamlined islands near the NE end of the Chryse Basin suggesting that water from the Hesperian floods spilled over into Acidalia [4-5]. In this distal position, Acidalia would have received the finer-grained fraction of sediments deposited during Hesperian flooding.

Within Acidalia, there are abundant high-albedo mounds. Mapping demonstrates 18,000+ of these and shows their spatial distribution to correspond to the southern portion of the Acidalia impact basin [1, 6]. HiRISE data add morphological detail that best supports an analog of terrestrial mud volcanism [1]. CRISM responses are consistent with this interpretation, as are estimates of thermal inertial and regional gravity [1].

Summary and Conclusions: Basin analysis suggests that Acidalia Planitia was the depocenter for accumulation of fine-grained sediments delivered by the Hesperian outflow channels. This is a unique setting on Mars in which especially large quantities of fluids and muds would have been concentrated. We propose that the profusion of mounds in Acidalia is a consequence this unique setting.

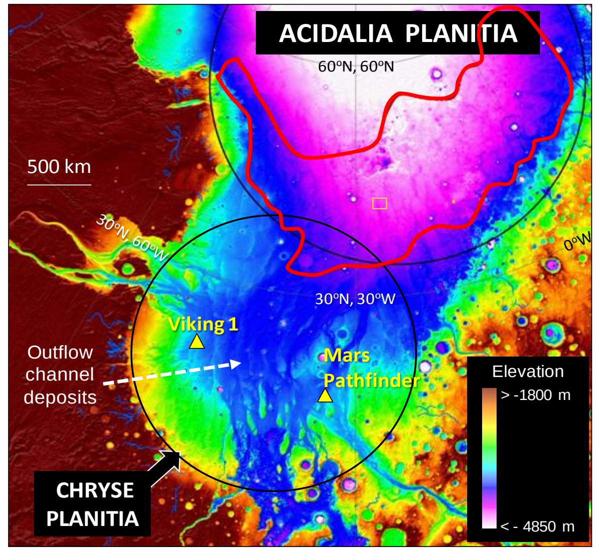

Fig. 1. Chryse-Acidalia embayment on stretched MOLA topography (polar projection). Black circles show proposed impact basins [2]. Red outline is area in which tens of thousands of mounds have been mapped.

The catchment area for the Chryse-Acidalia embayment includes a large portion of the Highlands. If organic materials were present in that catchment, they could have been carried with flood waters to the Chryse-Acidalia embayment. Since organics tend to be deposited - and preserved - with fine-grained sediments, buried sediments in Acidalia could contain remnants of such organic materials and these could include biosignatures of possible microbial life on Mars.

The basin analysis approach has resulted in new insight into the depositional history of Acidalia and that, in turn, has provided a regional context which supports comparison of the Acidalia mounds to mud volcanoes. Since mud volcanoes transport minimally-altered materials from depth to the surface, mud volcanoes in Acidalia may offer a means of tapping samples from deep zones that would otherwise be unreachable. Such samples may contain organic or mineralogical signatures of potential astrobiological significance [7]. Thus, the mounds in Acidalia may provide a new class of exploration target for Mars.

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Reconstructing fluvio-deltaic depositional systems on Mars: an approach using Martian orbital and Terrestrial analogue data. G. G. Ori[1 2] and F. Cannarsa[1], [1]IRSPS, Universita' d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy, ggori@irsps.unich.it, cannarsa@irsps.unich.it, [2] Ibn Battuta Centre, Unversite Cady Ayyad, Marrakech, Morocco

Introduction: Fluvial systems (not including outflow channels) are now well recognised on the surface of Mars. They exhibit both erosional and depositional reaches and cover large portion of the planets. Deltaic systems, as well, are widely observed on the planet. The presence of fluvio-deltaic systems is the evidence for a complex hydrological surface system with the occurrence of large bodies of standing water. It is remarkable that these fluvial systems have been depositional. Channel systems in the erosional realm have been observed on Mars since the Viking mission, but recently exhumed (inverted) channels have been observed. This means that fluvial systems constructed themselves in a floodplain and that alluvial plain probably existed.

Types of fluvio-deltaic systems: Erosional fluvial systems (network and isolated channels) are almost ubiquitous on Mars and they often are associated with deltaic features. These deltaic bodies are actually fan-deltas because directly connected to the erosional reaches of their feeding rivers [1]. These fan deltas can be very simple and form single or a few stacked bodies of Gilbert-type deltas [2]. In other cases (e.g. Eberswalde, Sabrina) they show a more complex deltaic plain and probably the delta front was subdivided in several mouth bars.

In a number of instances erosional rivers debouch in plains without any deltaic evidences. By analogy with several drylands, including Sahara, they probably passed into a dry plain via terminal fans, that is the distributary channel systems in low-gradient slopes that dry out downstream due to water evaporation and percolation [3].

The occurrence of exhumed (inverted) channels suggests the presence of more complex river – flood plain systems producing real alluvial plains [4]. These alluvial plain rivers must terminate with complex deltaic bodies resembling fluvial - or wave- dominated terrestrial deltas when debouching in bodies of standing waters. In case of inland basins they may terminate in systems resembling the terrestrial inland deltas.

Terrestrial analogies: Unfortunately, the sedimentological record of exposed depositional systems is largely incomplete. This is due to the strong wind erosion that these features underwent through the long Martian history [5]. In Sahara, large rivers and deltas formed during humid periods and they formed large fluvio-deltaic systems. However, during dry periods eolian activity removed almost completely the entire volume of fine (sand grade to mudstone) leaving only negative erosional morphologies, lags, and gravel deposits (Fig. 1). The only evidence in Sahara and adjacent arid and semi-arid areas (Arabia peninsula, Spain, etc.) of large alluvial plains and deltas are a few scattered exhumed channels both straight and meandering. This was also probably the fate of the fine-grained deposits of the rivers and delta systems on Mars.

A clear hint of this mechanism is shown in the deltaic plain of Eberswalde. Here there are evident meander belts. Meanders to be formed need cohesive muddy banks. Therefore, the presence of point bar bodies indicate that the deltaic plain was covered by a blanket of mud and fine-grained deposits at least as thick as the depth of meandering channels.

Summing up: erosional river systems are connected with fan deltas, alluvial plain systems probably where connected with more complex deltaic bodies, large part of the sedimentary record has been removed, Sahara and drylands may be used as proxies in deciphering the nature of the Martian fluvio-deltaic system.

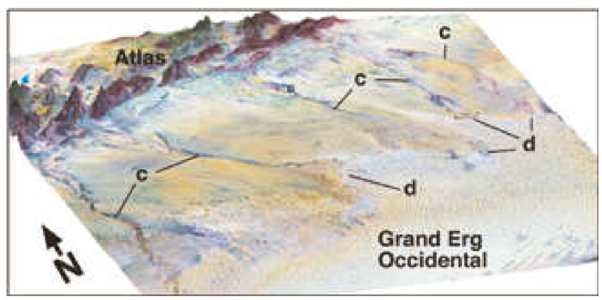

Fig. 1 Oblique view of the Atlasic Hamada with the palaeovalleys (c) flowing from the Atlas Mountains to the Grand Erg Occidental. Oued Namous is to the left. The palaeochannels are clearly visible and their distributary channel systems have their termini at the border of the erg. (d).

References: [1] Kraal E.R. et al. (2008) *Nature 451* (7181), 973-976. [2] Ori G.G. and Roveri M. (1987) *Sedimentology 34* (5), 845-859. [3] Ori G. G et al. (2007) *Sedimentary Processes, Environments and Basins*, Spec. Publ. Num. 38 IAS Editor(s): Nichols G. et al. DOI: 10.1002/9781444304411. [4] Holm D.A. (1960) *Science 132* (3437), 1369–1379. [5] Newsom et al. (2010) *Icarus, 205* (2010) 64–72.

HIGH RESOLUTION INVESTIGATION ON SURIUS VALLIS MOUTH AND THE SINUOUS RIDGES OF ARGYRE PLANITIA, MARS.
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Introduction: The basin of Argyre represents one of the oldest and largest impact craters of Mars. Located in the southern highlands of the planet (centered at about -55N 60W), it is formed by a mountainous ring about 1500 km large embaying a flat basin about 900 km wide.

Both the mountainous ring and the inner basin show several morphological features suggesting a very interesting geological evolution. According to several authors [1], [2], [3], [4] larger part of such features relates to a history in which the sculpting action of water and water ice appears to have been very effective in shaping the area. Glacial cirques, horns, rock glaciers, debris flows, gullies, fluidized debris aprons, fluvial channels have been observed and described in the Charitum Montes, which represent the southern portion of the mountainous ring of Argyre. Eskers, patterned ground, thermokarst, and fluidized ejecta are observed in the southern portion of Argyre basin. Some of such features, such as cirques, horns, eskers appear to be very similar to analogue terrestrial features. Three valleys debouches in Argyre Planitia from south. They are named Surius Vallis, Dzigai Vallis and Pallacopas Vallis. Although well developed deltas are not distinguishable at their mouths, other morphological features suggest a fluvial origin for such valleys [2].

Study area: We investigated a portion of southern Argyre Planitia proximal to Charitum Monthes, including the Surius Vallis mouth and the nearby sinuous ridges (Fig 1A). We used HiRISE, CTX, MOC, THEMIS, HRSC and MOLA data.

The study area is roughly characterized by two main typology of terrain: a rough-like terrain and a smooth-like terrain. The rough-like terrain (Fig. 1B) is characterized by a layered pattern, in which darker and brighter layers alternate. This terrain has been interpreted as formed in a proglacial and/or fluvioglacial environment, since at least part of sinuous ridges interpreted as eskers originate from this terrain and show the same layered pattern. Some evidences indicate possible multiple depositional activities, which could indicate cyclical climatic variations. The smooth-like terrain (Fig. 1C) usually occurs in areas comprised between two eskers. It is often characterized by polygonal pattern and layering is not observable. Locally, small portion of the smooth-like terrain outcrop on top of the rough-like terrain. This observation suggests that the smooth-like terrain overlaps and postdates the rough-like terrain.

In the proximity of the Surius Vallis mouth, a small delta is distinguishable. Evidences of this deltas were already observed in past by [2]. Now, CTX data show a more complex environment, in which the delta appears to partially overlap sinuous ridges.

Conclusions: These observations could imply that Surius Vallis deposits were emplaced, (at list at the final stage) successively to the emplacement of eskers, and successively to the wasting of the ice mass in which they were formed. This could explain the occurrence of smooth-like terrain overlapping the rough-like terrain as well. This hypothesis could also be consistent with the occurrence of a large depression comprised between two sinuous ridges: Cleia Dorsum and Hegemone Dorsum. In our model, in fact, Sinuous ridges could have acted as natural divides, preventing water coming from Surius Vallis to flow in this area, which has been preserved by flood(s).

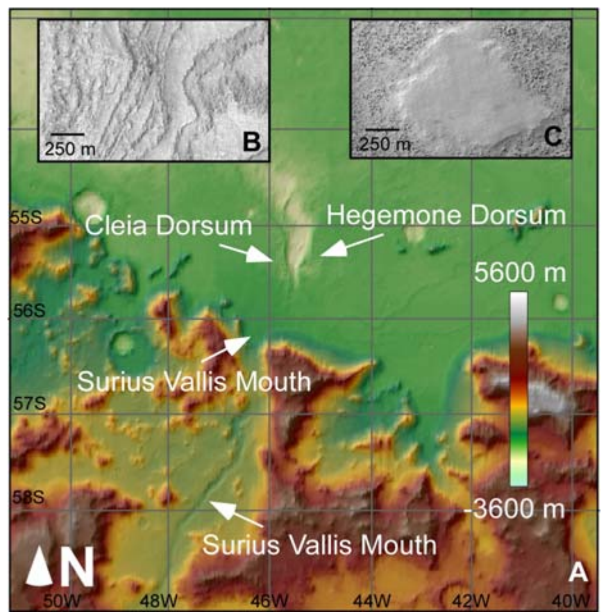

Figure 1. A) MOLA color-coded map of the study area. B) Sample of rough-like terrain (HiRISE ESP_011925_1245_RED). c) Sample of smooth-like terrain (HiRISE PSP_007007_1235).

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OCEAN SEDIMENTS IN THE NORTHERN PLAINS. T. J. Parker[1] and D. C. Barker[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, timothy.j.parker@jpl.nasa.gov, [2]University of Houston (University of Houston Geosciences, 4800 Calhoun Road, 77004).

Based on the highest-resolution image data available during the 1980s and 1990s, Parker et al. [1,2] hypothesized that the best explanation for the geomorphic features and contacts seen along the highland margin was erosion and deposition of material onto pre-existing terrain at a series of shorelines around the planet's northern lowland plains. These shorelines were inferred to indicate paleoclimate conditions that allowed liquid water to remain stable at the surface long enough for wind-driven waves to produce the features through wave refraction and longshore sediment transport. While the Arabia Level [3] does exhibit terracing in the modern very high-resolution images that is reminiscent of strandlines in terrestrial paleolakes, most of the other mapped levels do not. Instead, boundary morphology at the prominent, Deuteronilus Level [3] often exhibits lobate flow fronts and textures that resemble low-viscosity lava or debris flows. However, the MOLA topography does verify that the contacts are elevated by hundreds of meters to kilometers with respect to the northern plains interior to them, which does suggest that millions of cubic kilometers of volume was lost after emplacement of the marginal landforms.

Parker et al. [1] inferred marine conditions in a cooling climate based on the following observations: Starting at the Arabia Level and working plainward, plains textures transition from "smooth plains" between the Arabia and Ismenius Levels; to small-scale polygonally-patterned ground between the Ismenius and Deuteronilus Levels; to Thumbprint terrain (with bright conical hills interpreted as pingos) between the Deuteronilus and Acidalia Levels; to Mottled plains below the Acidalia Level. The reasoning was that: Smooth plains could indicate cold climate conditions hadn't ensued until the shoreline had receded and plains had been desiccated; small-scale polygons indicate ice-wedge polygons that formed by thermal cycling in a cold climate with water or ice present in the permafrost; closed-system pingos formed in a permanently cold climate after shoreline recession as near-surface groundwater water froze and concentrated remaining groundwater into lenses.

Additional landforms and plains morphologies identified recently [4] need also be considered in formulating a testable hypothesis commensurate with the newer, very-high resolution image data [e.g., 5]. We infer that an ocean would have been covered by debris and ice at least by Hesperian time (Arabia Level), and that it gradually receded due to loss via sublimation and redistribution elsewhere on Mars. The ice cover would have been frozen to the substrate at the shorelines, but floating as the bottom topography declined toward the plains interior. Fluvial rills identified at the Ismenius Level [1,4] could have formed via catastrophic disruption of this ice cover – perhaps due to an impact or landslide into the ocean. Similarly, when the ocean had receded to about the Deuteronilus Level, floods into the northern plains triggered a minor transgression to produce the lobate flow fronts as debris and ice was pushed upslope at the shoreline. Following cessation of the floods, the disrupted cover re-froze, this time producing pingos (and thumbprint terrain) as the debris/ice cover froze.

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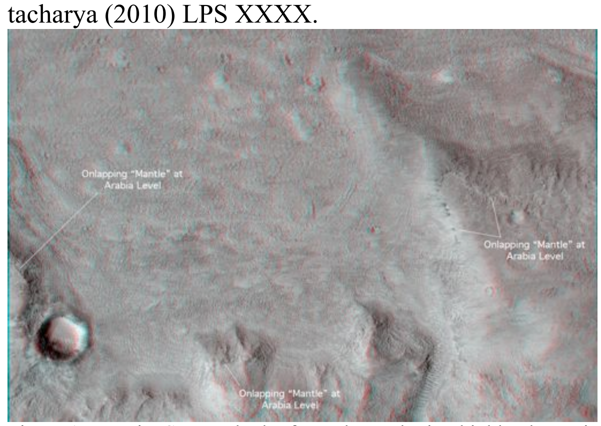
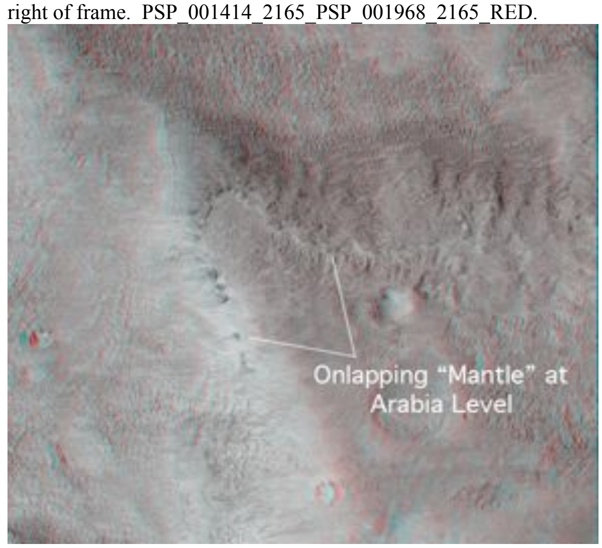


Figure 1: a. HiRISE anaglyph of mantle on sloping highland margin at Arabia Level in east Cydonia/NW Arabia. b: Detail of mantle at right of frame. PSP_001414_2165_PSP_001968_2165_RED.



SEDIMENTARY VOLCANOES IN THE CROMMELIN SOUTH CRATER, MARS. M. Pondrelli[1], A. P. Rossi[2], G. G. Ori[1] and S. van Gasselt[3], [1]IRSPS, Università d'Annunzio, Pescara (Italy), (monica@irsps.unich.it), [2]ISSI, Bern (CH), [3]Freie Universität, Berlin (DE).

Introduction: Mound-shaped morphologies are extremely common on Martian surface and have been ascribed to very different geological processes. The possibility that sedimentary volcanism could have played a role in the formation of some of these features have been also proposed [1, 2, 3, 4, 5, 6,7].

We report here the discovery of possible sedimentary volcanoes located in an unnamed crater located immediately south of the Crommelin crater.

Geological Setting: The stratigraphic succession of the Crommelin South crater (centered: 9W-4N) starts with the Plateau Sequence (Cratered unit) of Noachian age. The Equatorial Layered Deposits (ELD) nonconformably cover this unit. On top of the ELDs, the presence of metric to more than 100 m large mounds has been recognized.

Description: The mounds are located along the outer floor and the inner rim of the crater or are preferentially aligned along fractures. They include simple and coalescing complex mounds, both with and without central orifice (Fig. 1).

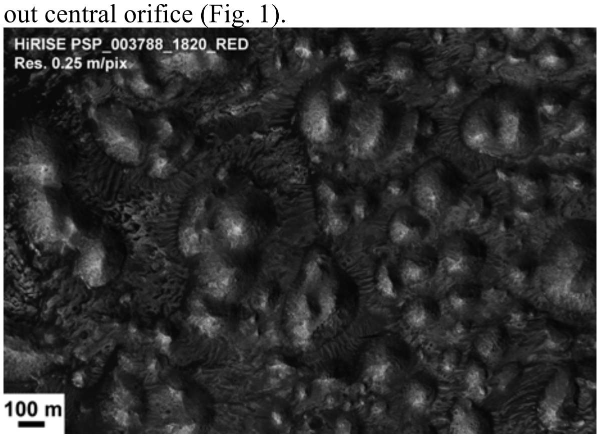


Fig. 1 – Complex and simple mounds.

Their height can be estimated about few tens of meters at most. About 50% of the mounds display a central orifice (Fig. 2) while others not. Orifices have small sizes, with an average area of about 170 m^2. The ratio between orifice, when visible, and mound areas is almost always less than 1%.

Mounds consist of poorly sorted either clast supported or matrix supported breccia. Layering, although faint, is locally emphasized by the presence of finer grained dark levels (Fig. 2).

Both the mounds and the ELDs are characterized by the presence of very similar bright material, fractured in polygons in the ELDs and breccia clasts in the mounds (Fig. 4). We hypothesize that the clasts represent reworked ELD bright layers material.

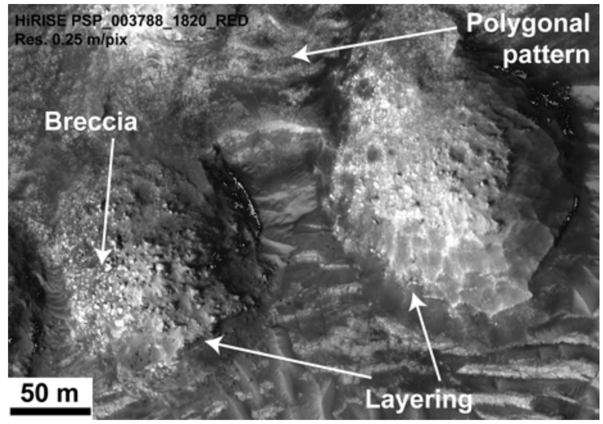


Fig. 2 – Mounds showing layering and breccia deposits.

Origin of the mounds: The fact that the mounds and the ELD consist of different deposits prevent from hypothesizing that the mounds could be remnants of a unit covering the present substrate. The morphology of the central orifices could suggest a formation following cratering but their constant presence on the topmost part of the mounds rule out this interpretation. The mound shape as well as the presence of an orifice could bear some resemblance with pingos, but the layering, the extensive brecciation, the lacking of radial fractures are strongly pointing against a pingo origin. A volcanic origin also appears to be unlikely for the complete lack of unambiguous volcanic landforms and deposits associated, within the basin, such as lava flows or dykes. Moreover, the material forming the breccia seems to consist of reworked ELD light toned layers deposits, and this strongly argue against a volcanic origin.

We propose that the mounds were formed as sedimentary volcanoes because of the general morphology, the distribution along fractures and the texture of the material. They would result from the emplacement of fluid-rich sediments moving upward due to overpressurization. Overpressure could have been related to endogenic processes or to overburden related to younger deposits (spring deposits? [8]).

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TIMING CONSTRAINS OF INTERIOR LAYERED DEPOSIT EMPLACEMENT IN VALLES MARINERIS

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Introduction*:*The discovery of layered deposits on Mars in Valles Marineris by Mariner 9 in the 1970, marked the beginning of sedimentological studies on Mars. The Martian grand canyon is partly filled by thick and central layered deposits called Interior Layered Deposits (ILD). Recent instruments (OMEGA and CRISM) brought mineralogical clues revealing sulfates rich deposits [1, 2]. Several hypotheses for their origin have been proposed, like lacustrine or eolian sediments [3,4], pyroclastic deposits [5,6,7], subglacial deposits [8] or spring deposits [9], or pre-Valles Marineris exhumed sediments [10]. In these hypotheses, the age is a crucial question. For some authors, the deposits predate the basaltic plateau of Valles Marineris and have been exhumed during the opening of the canyon [10]. For others, the deposits emplaced after or during the formation of Valles Marineris [4, 11, 12, 13]. In the present study, we investigated in different Chasmata of Valles Marineris the contact of the base and the top of ILD with the surrounding material such as the wallrocks and we performed crater counts on the top of ILD when possible. Landslides covering the deposits can also be used to retrieve a minimum age of ILD by counting craters.

Basal stratigraphic contact of ILD :

The base of the ILD is often hard to observe despite the high resolution coverage. The main reason is the presence of sand dunes, boulders or debris aprons that cover the foothill of the ILD and canyon walls. However, we observe the base of the light-toned layered deposits at different places.

We observe that the ILD are on the top of canyon floors in 2 canyons forming the head of outflow channels : Juventae Chasma and Capri Chasma. In these 2 canyons, the ILD sequence definitively onlaps the chaotic buttes forming the typical floor of outflow channels. This observation suggests an emplacement of the ILD after the outflow channels formation.

In the central canyons of Valles Marineris like Melas Chasma, the contact between ILD and the lava flows forming the walls of Valles Marineris is observed at ILD perched high on the walls of Valles Marineris [14]. There, high-resolution images display the thin light-toned layers lying unconformably above the suite of 10s m thick basaltic lava flows of the wall rock. The contact has been mapped at different elevations between -566 and +71 m suggesting that the ILD are draping the walls.

ILDs which occur in chaotic terrains (e.g. Aram Chaos) and in large craters (e.g. Gale crater) egally show stratigraphic relationships indicating that the ILD formed late in the geological sequence of events. In Chaotic terrains deposition of light toned layered deposits post-date the fracturing event forming the chaotic terrain.

Top of ILD:

The ILD are impacted by large craters that give a minimum age of 3-3.5 Gy. These impacts date the formation of the erosion of the ILD. This conclusion from crater count is comforted by the relative stratigraphy of the ILD mesa with Valles Marineris landsides. Some landslides overlap the flanks of ILD mesa like in Gangis Chasma or in Melas Chasma. These landslides have been dated by [15] and are more than 3 Gy years old.

Conclusions:

Gathering all these observations, the ILD of Valles Marineris should have formed after the canyon formation or at least after proto-canyons formation. However, their formation ended very early in the canyon history and their erosion into mesa ended at around 3-3.5 Gy.

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COMPOSITION OF TERRESTRIAL INVERTED CHANNEL DEPOSITS FROM THERMAL IR SPECTROSCOPY: IMPLICATIONS FOR MARTIAN EQUIVALENTS. E. B. Rampe[1], N. L. Lanza[2], C. Okubo[3], and T. G. Sharp[1], [1]School of Earth and Space Exploration, Arizona State University, Box 871404, Tempe, AZ 85281, Liz.Rampe@asu.edu, [2]Institute of Meteoritics, University of New Mexico, Albuquerque, NM; [3]U.S. Geological Survey, Flagstaff, AZ.

Introduction: Orbital data from Mars have identified several locations with positive-relief fluvial deposits, including Holden and Eberswalde craters and Juventae Chasma [1-3]. On Earth, inverted channel deposits (ICDs) commonly form by cementation of fluvial sediments and subsequent erosion of the surrounding terrain [4]. Cements are generally silica- and/or carbonate-rich and reveal important information about the aqueous history of the deposits. Thermal infrared (TIR) and visible-near infrared (Vis-NIR) spectroscopy are primary methods for determining the composition of the Martian surface. Amorphous silica has been identified in many locations on Mars through Vis-NIR spectroscopy, including ICDs in Juventae Chasma [3], but carbonates are generally absent on the surface. In this study, we test the ability of IR spectroscopy to identify the composition of cements in fluvial deposits by examining TIR emission spectra and spectral models of terrestrial ICD samples from the Cretaceous Cedar Mountain Formation near Green River, Utah [5,6].

Experimental Methods: TIR emission spectra of natural surfaces and fresh interiors of conglomerate, quartzite, and coarse-grained sandstone samples were measured at the Mars Space Flight Facility at Arizona State University using a Nicolet Nexus 670 spectrometer configured to measure emitted energy [7,8]. Spectra were scanned 150 times over the course of ~3 minutes, from 200-2000 cm^{-1} with 2 cm^{-1} spectral resolution. We modeled the mineralogy by linear deconvolution [9] using a spectral library containing common silicates, carbonates, sulfates, and oxides.

Results: TIR spectra of natural surfaces and fresh interiors show strong absorptions from SiO_2 phases (Figure 1). Spectral models indicate surfaces and interiors are mostly composed of quartz and/or a cryptocrystalline SiO_2 phase, primarily chalcedony. TIR spectra of the interiors and downward-facing surfaces of some samples have minor absorptions from carbonates; however, the upward-facing surface spectra of the same samples lack carbonate absorptions (Figure 1).

Discussion: TIR spectra and spectral models of natural surfaces and interiors of ICDs compare favorably to compositions determined by SEM, reported in a companion abstract [10]. Our data show TIR emission spectroscopy detects silica- and carbonate-rich cements if they are exposed at the rock surface. However, carbonate cements are not exposed on upward-facing surfaces of our samples because: 1) SiO_2 cements coat carbonate cements so that carbonates are not detectable; or 2) carbonate cements dissolve at rock surfaces.

Implications for Martian ICDs: This study suggests that TIR spectroscopy is an effective method for identifying silica-rich cements on Mars. However, if carbonate cements are present in Martian ICDs, they may not be exposed at the surface and would not be detected by TIR spectroscopy. This emphasizes the importance of ground truth investigations of these locations. Holden and Eberswalde craters are proposed landing sites for Mars Science Laboratory [11]. The instruments on board MSL could determine cement compositions, providing important information about past aqueous environments.

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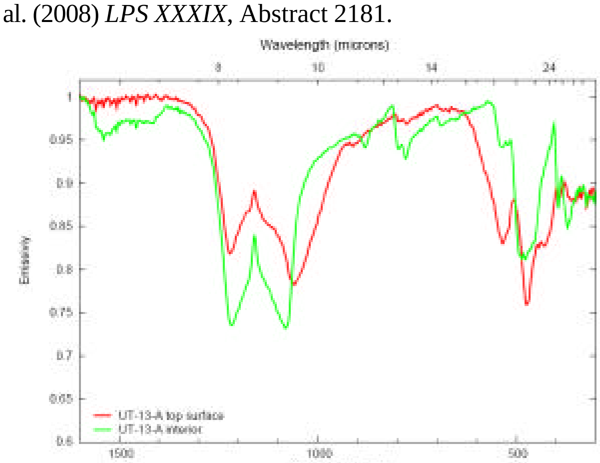

Figure 1. TIR spectra of a top surface (red spectrum) and interior (green spectrum). Doublets at ~1300-1000 cm^{-1} are from SiO_2 phases and the absorption at ~1600-1400 cm^{-1} in the interior spectrum is from carbonate.

SEDIMENTARY FEATURES WITHIN THE PROPOSED MARS SCIENCE LABORATORY (MSL) LANDING ELLIPSE IN EBERSWALDE CRATER. M. S. Rice and J. F. Bell III, Department of Astronomy, Cornell University, 406 Space Sciences Building, Ithaca, NY 14853, mrice@astro.cornell.edu.

Introduction: Eberswalde Crater (Fig. 1a) has been selected as a high-priority candidate landing site for the Mars Science Laboratory (MSL) mission based on the presence of a fan-shaped sedimentary rock unit interpreted as the lithified remains of a fluvial delta [1,2]. This feature provides the best known evidence for persistent fluvial activity on the surface of Mars. The proposed landing site is ~10 km east of the margin of the fan-shaped feature where the Eberswalde basin might have contained a lake [3]. Several sedimentary features have been identified within the landing ellipse [4,5], and here we investigate the stratigraphic relations between these features and the delta to help unravel the sequence of aqueous sedimentation.

Stratigraphic Units and Geologic Features: Our study uses a ~6 m/pxl MRO Context Camera (CTX) mosaic [6] and ~25 cm/pxl MRO HiRISE images [7].

Basal unit and meggabreccia. The basal unit represents the oldest materials in the study area and is characterized by sharp peaks and ridges. In places this unit is massive and texturally smooth, while other occurrences are highly fractured. Schieber [4] interpreted these outcrops as meggabreccia formed by a large, nearby impact. Some outcrops contain veins suggestive of breccia injection dikes [8].

Discontinuous light-toned unit. Veneers of discontinuous light-toned materials cover most of the Eberswalde basin and are overlain by a mantling unit and aeolian deposits. Pondrelli *et al.* [9] interpreted this unit as having been emplaced in the deepest part of what they considered to be an Eberswalde lake.

Mantling and aeolian bedforms. This unit consists of a dark, smooth material that occurs above the fractured and the discontinuous light-toned units. Small craters are preserved in this unit, and in many locations the smooth mantling grades into aeolian bedforms typically ~100 m in length with ~40 m spacing.

Fractured light-toned unit. Flat-lying, light-toned materials with extensive polygonal fractures outcrop in four major exposures within the landing ellipse. These exposures are stratigraphically below the layered light-toned unit, and could represent desiccation cracks in dehydrated clay-rich strata or sulfate minerals [4].

Inverted channels. Within the landing ellipse we find thirteen sinuous features with raised relief (*e.g.,* Fig 1b), with lengths ranging from 10 to 1000 meters. These are interpreted as inverted channels of fluvial origin [4]. Several narrow, elongated mesas observed within the ellipse may be remnants of additional inverted channels.

Layered light-toned unit and possible deltaic features. Three inverted channels within the ellipse terminate in lobe-shaped features comprised of light-toned, layered materials (*e.g.,* Fig. 1c). These materials resemble the light-toned layered unit at the Eberswalde delta margin; these might be erosional remnants of other deltaic materials [4]. Analysis of MRO CRISM spectra suggests that some light-toned layered materials contain phyllosilicates [10].

Conclusions: The variety of geologic materials within the proposed MSL landing ellipse, some of which might be aqueous sediments, adds to the science value of Eberswalde Crater as a high-priority landing site. MSL traverses *within the ellipse* could include exploration of sedimentary features of potential fluvial origin.

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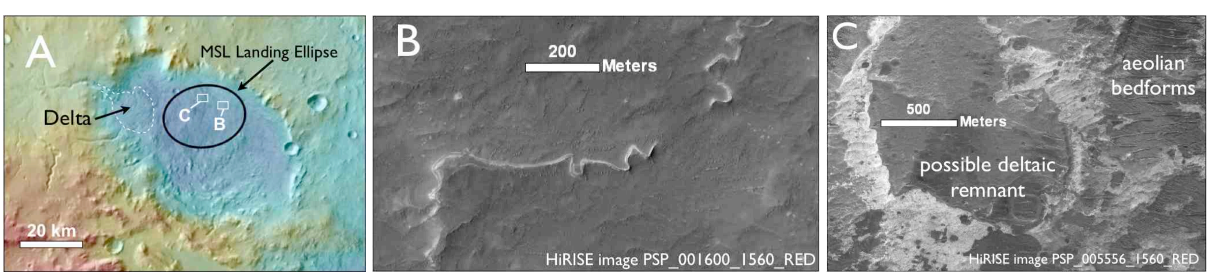

Figure 1. (a) MOLA topographic map of Eberswalde Crater showing locations of b-c within the landing ellipse; **(b)** sinuous, raised-relief channel; **(c)** possible deltaic remnant of light-toned layered material.

IN SITU SEDIMENTOLOGICAL STUDY OF THE CHEMICAL LITHOFACIES IN THE RIO TINTO AND JAROSO FLUVIAL SYSTEMS BY USING RAMAN SPECTROSCOPY. F. Rull[1,2], J. Martinez-Frias [1,2], Jesus Medina[1] and A. Sansano[1]. 1 Unidad Asociada UVA-CSIC al Centro de Astrobiología, Facultad de Ciencias, Universidad de Valladolid 47006 Valladolid (SPAIN), [2] Centro de Astrobiología, Carretera de Ajalvir Km4, 28850, Madrid (SPAIN) (rull@fmc.uva.es).

Introduction: Raman spectroscopy is a powerful technique for analysis of samples in either the solid, liquid or gas state without any preparation at the micro or macro scale. These capabilities are of great importance in the precise identification of mineral phases and their assemblages or in the identification of organic compounds. For these reasons Raman technique has been included as part of the Pasteur rover's payload in the Exomars mission. ExoMars is the first ESA flagship mission of the Aurora program that will send a rover to the surface of Mars in 2018 after the recent collaboration agreement NASA-ESA. The main aim of this mission is the search for past and present life on Mars. As part of this main aim to characterise the mineral products and indicators of biologic activities and to characterize mineral phases produced by water-related processes are of prime importance.

On Earth, fluvial environments are complex and dynamic systems which are conditioned by a considerable set of factors: climate, hydrology, geotectonic setting, rocks and soils, and also biodiversity. In this general framework, fluid-material interactions, involving clastic and chemical sediments, play a particular, but essential, role in the spatial-temporal architecture and evolution, at different scales, of the types of surface streams. Thus, in the context of Mars exploration, and considering the geomorphological and sedimentological features of the selected landing sites [1], it is important to examine specific sedimentary facies controls on the distribution of fluvial cementation, compaction and ratios of mineralization/alteration due to hydration-dehydration processes. The Tinto river and Jaroso ravine (Spain) are two extremely interesting fluvial stream systems, with and without water respectively, which have been proposed as potential Earth analogs [2,3] for the geological and astrobiological exploration of Mars. In the present work a comparative study of the chemical lithofacies in both environments has been performed at in the field and in the laboratory.

Experimental Raman spectra at the field were performed in-situ without any sample preparation at different places of the Rio Tinto area. The Raman spectrometer used was a portable i-Raman from *B&W TEC Inc*. adapted to work in field conditions. The optical head was attached to a mechanical device simulating the rover's arm to approach the samples with accuracy and stability. A baffle was used at the end of the optical head to minimize the solar light background. The excitation used was a 532nm wavelength laser with about 15mW power on the sample and a spot diameter of 100µm. Spectral resolution was ~5cm-1. Samples at the laboratory were analyzed with a portable Raman spectrometer developed in our group with the same spectral characteristics of the Raman Exomars instrument and coupled to a Raman optical head installed in a microscope stage.

Results In Figure 1 and 2 the Raman optical head taking in-situ spectra in evaporite samples at the Rio Tinto source and at the Jaroso Ravine are depicted with some of the spectra obtained. Results from the field and laboratory are analyzed and discussed in the framework of the different mineral formation processes at the two sites.

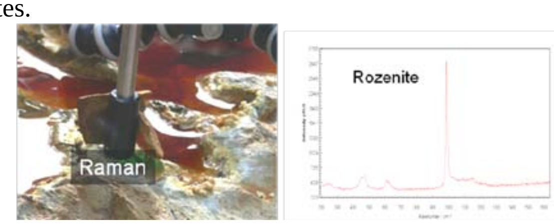

Figure 1. In-situ Raman analysis of evaporite minerals at Rio Tinto. Pure Rozenite is identified

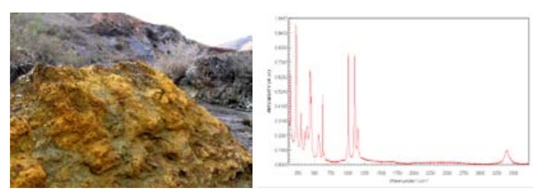

Figure 2. Massive deposit of Jarosite at Jaroso Ravine (World locality type of Jarosite) and Raman spectrum obtained

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Acknowledgements: This work was supported by the Ministerio de Ciencia e Innovación, Project AYA-2008-04520-ESP.

Environmental Context of Early Archean Stromatolites: Analog for Mars?

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Australian Archean stromatolites are arguably the best evidence for life on the early Earth, 3.5 billion years ago. These shallow-water sedimentary structures are plausible analogs for “biosignatures” on Mars, in that they are intimately associated with regularly layered deposits, crystalline sulfates, ferruginous materials, and small-scale cross lamination. But how useful is this comparison? Studies of the growth and environmental context of the stromatolites are the key to answering this question.

Stromatolites are self-organized mesoscale structures that result from various forms of accretionary growth in the generally vertical direction. Processes that contribute to stromatolitic growth include gravitational settling of sedimentary particles, surface-normal precipitation of mineral grains and fibers, upslope or downslope movement (diffusion) of previously deposited materials, and random natural effects best treated as noise (Grotzinger and Rothman, 1996). Most of these processes are equally characteristic of both abiotic and living systems and thus provide little or no evidence for a biogenic origin. However, sustained upslope diffusion is a process that is readily attributable to life but not to any other non-vital agents at anything larger than the atomic scale (Runnegar and Jögi, 2007).

The environmental context of stromatolitic structures provides another way to assess biogenicity. On Earth, early Archean stromatolites are commonly considered to have formed with gypsum, nahcolite ($NaHCO_3$), or aragonite evaporites, now pseudomorphed by barite ($BaSO_4$), quartz, and calcite (Buick, 2008; Tice and Lowe, 2004; Allwood et al., 2006); on Mars, prospective strata contain molds of sulfate crystals (possibly $MgSO_4.11H_2O$; Peterson and Wang, 2006) that have been attributed to evaporative processes (McLennan et al., 2005). Furthermore, an association of bacterial sulfate reducers with barite crystal growth surfaces has been claimed for the Australian Archean “evaporites” (Ueno et al., 2008; Shen et al., 2009). Our work on Australian Archean stromatolites and sulfates plus a new interpretation of Meridiani Planum “evaporites” (Niles and Michalski, 2009) suggests that early Earth may be a poor analog for early Mars.

Mars Sedimentology using Laser Remote Optical Granulometry (LROG). D. Sarocchi[1], R. Bartali[2], G. Norini [3,4] and Y. Nahmad-Molinari[5], [1] Instituto de Geología-Facultad de Ingeniería, Universidad Autónoma de San Luis Potosí, Av. Dr. Manuel Nava 5, Zona Universitaria, 78240 San Luis Potosí, Mexico. e-mail damiano.sarocchi@uaslp.mx, [2] Doctorado Institucional en Ingeniería y Ciencia de Materiales, Instituto de Fisica, Universidad Autónoma de San Luis Potosí, Zona Universitaria, 78240 San Luis Potosí, Mexico. [3] Dipartimento di Scienze Geologiche e Geotecnologie, Università degli Studi di Milano-Bicocca, P.za della Scienza 4, 20126 Milano, Italy [4] Computational Geodynamics Laboratory, Centro de Geociencias, Universidad Nacional Autonoma de Mexico, Campus Juriquilla-UNAM, Blvd Juriquilla 3001, 76230 Querétaro, Mexico. [5] Instituto de Física-Facultad de Ciencias, Universidad Autónoma de San Luis Potosí, Av. Dr. Manuel Nava 6, Zona Universitaria, 78240 San Luis Potosí, Mexico.

Introduction: We are showing a new optical method that allows to obtain remotely valuable information of sedimentary parameters [1],[6]. It is based on stereological analysis [2],[5] of high resolution CCD images, taken through a small aperture telescope (Figure 1). Image scale is obtained projecting on the outcrop three green laser beams forming an equilateral triangle with known size.

Figure 1. LROG System and Joya Honda outcrop in the background.

Distortion due to perspective and outcrop irregularities can be easily corrected in the image processing phase. Image analysis techniques are then applied to each picture in order to obtain information on deposit stratigraphy, texture and structures. Many sedimentary parameters can be precisely measured by means of LROG technique, the most important of them are: number and thickness of the sedimentary units; granulometric distribution and vertical granulometric profiles; clasts shape analysis and apparent fabric. The same technique allows to measure exactly the distance to the analyzed point.

We developed LROG techniques and actually using it to study inaccessible and consolidated deposits of volcanic sedimentary successions [3],[4]. The method proved to be very useful and provide better and more reliable results with respect to traditional sedimentological techniques. Moreover the method allows to obtain many images in a short time, and safely, because it is not necessary to stay too close to the outcrop neither to take samples. At a distance of 100 meters LROG allow to resolve clasts of 500 microns width. When comparing LROG granulometry with sieving technique the difference was as low as 10% (Figure 2). This discrepancy is basically due to sieving methodological limitation.

Remote high resolution sedimentology done with a small, lightweight, cheap, easy to use and low power instrument, placed aboard a robotic rover, could be a useful tool in exogeology research.

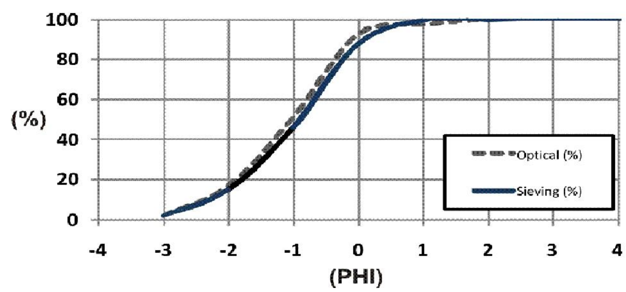

Figure 2. Optical and traditional granulometry comparative results.

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WATER-RELATED MINERALS IN AUREUM CHAOS, MARS. M. Sowe, L. Wendt, T. Kneissl, P.C. McGuire, and G. Neukum. Institute of Geosciences, Planetary Sciences & Remote Sensing, Freie Universitaet Berlin, Germany (mariam.sowe@fu-berlin.de).

Introduction: Collapsed plateau material, chaotic terrain, and Interior Layered Deposits (ILDs) characterize Aureum Chaos that is located east of Valles Marineris. As elsewhere on Mars, spectrometers on Mars Express (MEX-OMEGA), Mars Reconnaissance Orbiter (MRO-CRISM) and Mars Global Surveyor TES detected water-related minerals in association with ILDs [1-4]. We studied these minerals by utilizing MRO-CRISM data and co-aligned MEX-HRSC, MRO-HiRISE and MRO-CTX data since their extent indicates where water was present in the past (Fig. 1).

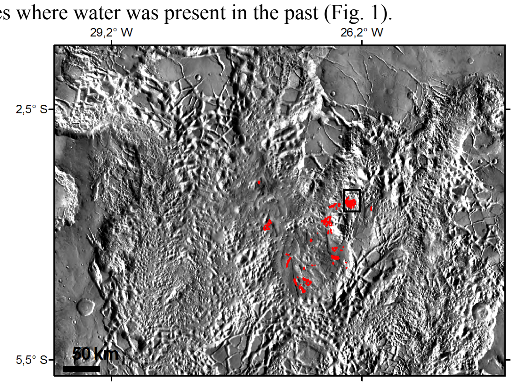
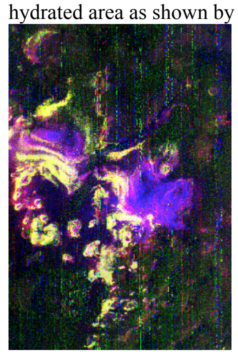


Fig. 1: THEMIS-daytime infrared shows the regions of major hydrated minerals and ferric oxides in red. Box indicates location of Fig. 2.

Methodology: CRISM data were analyzed with the CAT Software including atmospheric correction reflectance, removing bad bands, and artifacts [5]. Spectral indices were mainly used to identify minerals or mineral groups as described in [6]. We used the FRT Observations and HRL Targeted Observations which have the highest spatial resolutions (<36 m/px). Map-Projected MRDR were also applied. Data between 1 and 2.6 µm were used and combined with data in the visible range on selected observations. Mainly CRISM spectral indices [7] were used for identifying minerals (Fig. 2). However, iron oxides were found by the spectral slope between 1 and 1.3 µm as described by [8, 9]. Data of different resolutions were combined in a geographic information system but for our analyzes the best resolving data were used. **Stratigraphic relationship and extent:** The sulfates (local thickness ~50 m on average) crop out below a spectrally neutral cap rock, whereas monohydrated sulfate (MHS) underlies polyhydrated sulfate (PHS). PHS is detected at elevations below -3600 m, MHS below -4100 m, and phyllosilicate below -4000 m [10]. In some regions, weathered PHS (e.g. debris fans on scarps) to some extent covers MHS exposures. These regions have a massive, high-albedo texture which otherwise is observed in outcrops that show a MHS signature. Phyllosilicate is present below sulfates or occurs as windblown material but is not associated with ILDs. Iron oxide-rich material as found by CRISM is present in small occurrences within the hematite-rich region described by [1], but also in other spots either as erosional lack or bedrock in close spatial relationship with sulfates (mostly with MHS). The fact that ILDs are mainly buried by mantling deposits and show an abundant cap rock, overlying most of the sulfate-rich ILDs, may explain why sulfates were not found in all CRISM observations. However, the hydrated area as shown by CRISM is ~70 km².



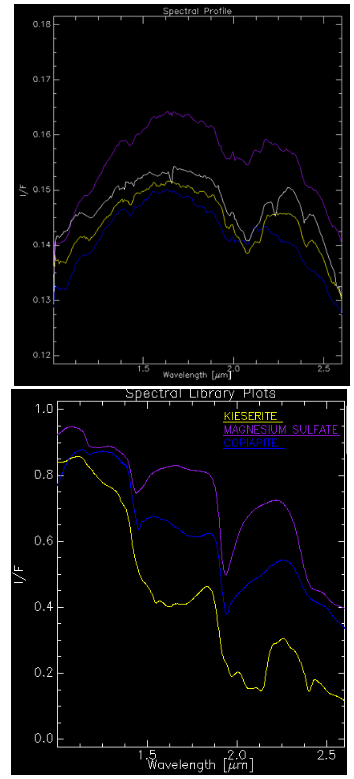


Fig. 2: (a) CRISM observation FRT 6181. Red: SINDEX, green: BD2100, blue: BD1900 [7]. Image is 20 km across. (b) Spectra indicate MHS (yellow), PHS (purple, blue) and a potential hydroxylated sulfate (white) which was found with MHS.

Conclusions: Low dip values and parallel bedding of ILDs indicate that they were formed by periodic, low-energy sedimentation [10]. Comparable mineralogies and morphologies were found in different regions of Valles Marineris [3] and may show that formation processes have been anyhow similar. The basin itself is dissected by subsided plateau material thus it provides multiple protected areas that might have served as sedimentary basins. Consequently, we do not consider a huge water-filled basin in which material would be deposited, but local ponds within the basin. Since Aureum Chaos is a closed basin, and a region of high hydrostatic head [11], groundwater activity could have contributed to the formation of the detected hydrated minerals. **Acknowledgement:** This research was partly supported by the Helmholtz Association through the research alliance "Planetary Evolution and Life", the German Science Foundation (DFG) through the Priority Program Mars and the Terrestrial Planets (DFG-SPP 1115, Project: Chronostratigraphy of Mars, grant: NE 212/8-3), and the German Space Agency (DLR), grant 50QM0301 (HRSC on Mars Express). **References:** [1] Glotch. and Rogers (2007), *JGR*, *112,* E06001. [2] NoeDobrea et al. (2008), *Icarus*, *193,* 516-534. [3] Sowe et al. (2009) *GSL subm.* [4] Wendt et al. (2010) *LPSC XLI*, #1699. [5] McGuire et al. (2009) *PSS, 57-7*, 809-815. [6] Parente (2008) LPSC XXXIX, #2528. [7] Pelkey et al. (2007) *JGR, 112*, E08S14. [8] Mangold et al. (2008) *Icarus, 194*, 519-543. [9] Le Deit et al. (2008) *JGR, 113* E07001. [10] Sowe et al. (2010) *LPSC XLI*, #2499. [11] Andrews-Hanna et al. (2007) *Nature*, *446*, 163-166.

STATISTICAL ANALYSIS OF BED THICKNESS DISTRIBUTIONS IN LAYERED DEPOSITS ON MARS.

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Introduction: This study examines the statistical characterization of bed thicknesses in a diversity of martian layered terrains with the broad goals of 1) providing an objective approach to their description and taxonomy, and 2) eventually helping to inform understanding of the depositional environments of proposed sedimentary rocks on Mars.

Methods: The three-dimensional orientation of bedding within each measured section is calculated from HiRISE Digital Terrain Models (DTMs, 1 m vertical resolution) using least squares regression. Topographic profiles are extracted from the DTMs parallel to dip direction along well-exposed, vertically continuous layered outcrops. Individual beds are identified by visual inspection of HiRISE images. The mean bed thickness and dip are calculated for each section, and we examine changes in bed thickness relative to the mean throughout the section. Deviations of the cumulative distribution of bed thicknesses from a typical power law distribution are compared at each location.

Initial Results- Terby Crater: We examine the layered sequence at the southern end of the western bench in Terby crater (Fig. 1A), located on the northern rim of Hellas basin. We find that beds in this section dip ~10º and have an average thickness of ~40 m, ranging from ~5 to over 150 m. These findings are in agreement with the estimations of Wilson et al. By comparison, layers measured in Holden crater have a mean bed thickness of ~1 m, and a dip of ~2º, yet the layered sequences in both Terby and Holden craters are interpreted as lacustrine in origin [1, 2]. Perhaps Terby crater contains other types of sedimentary deposits that would generate a higher degree of amalgamation, or simply a greater initial bed thickness. It is also possible that bed boundaries reflect diagenetic processes and do not record initial deposits. These effects will be considered during the course of the study. We also note that boundaries between individual beds that are not characterized by clear changes in albedo/tone may not be apparent in the visible images used for this study (HiRISE, CTX, MOC).

The cumulative distribution of bed thicknesses within this section shows significant deviation from a power-law distribution at the thin end of the distribution (Fig. 1B). The bending here is due to the underrepresentation of thin beds, likely because of an inability to resolve thin beds near or below the resolution of HiRISE images. However, it is also possible that the shape of the cumulative distribution is related to processes of erosion, bed amalgamation, and/or diagenesis that may be linked the depositional environment of this sequence. Continuing analysis within Terby crater, and at other layered deposits on Mars that have similar or diverse proposed depositional will provide additional context for these initial results.

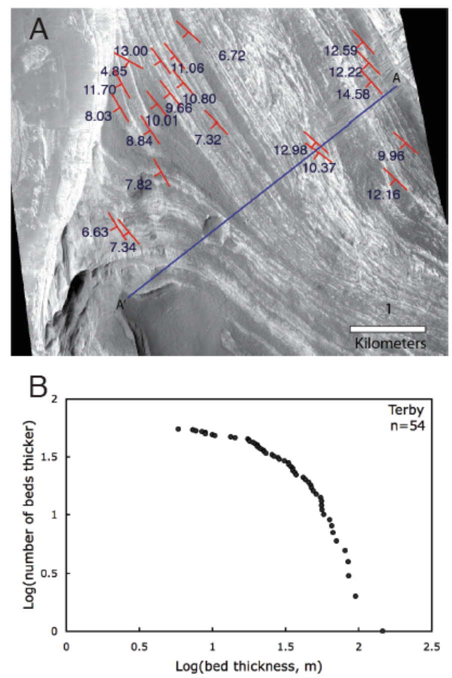

Figure 1. A) HiRISE image PSP_002572_1520. Strike and dip symbols represent the 3-D orientation of the beds. Bed thicknesses were measured along transect A-A'. B) Cumulative distribution of bed thicknesses along transect A-A'.

Implications: This study represents a first attempt at examining the statistics of stratigraphic layering on Mars, with the goal of determining whether these techniques can provide useful, semi-quantitative criteria for distinguishing sedimentary depositional environments on Mars. It complements the approach of Lewis et al., who assume a characteristic period for the strata and then calculate a power spectrum in the search for periodicity [3]. Statistical analysis of bed thickness distributions, coupled with morphologic and mineralogical interpretation has the potential be a powerful tool to characterize sedimentary rocks on Mars.

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SEDIMENT-ATMOSPHERE WATER EXCHANGE AND POLYGONAL CRACKS: LESSONS FROM WHITE SANDS NATIONAL MONUMENT, NM. D. Y. Sumner[1] and G. V. Chavdarian[2], [1]Geology Department, University of California, Davis, CA 95616, dysumner@ucdavis.edu.

Introduction: Water loss from cohesive sediments results in contraction [1-4]. When volume shrinks sufficiently that stresses exceed the tensile strength of the material, cracks form. The geometry of the cracks and resulting polygons reflects material properties and the history of water exchange between the sediment and the atmosphere [1-3,5]. Water content, transport, and exchange with the atmosphere affect the nucleation and propagation of cracks in hydrous sulfate dunes at White Sands National Monument, New Mexico [4].

Cohesion and Mineralogy: In White Sands dunes, capillary forces and gypsum cements give the sand sufficient cohesiveness to act as a uniform material with moderate tensile strength. With water loss, cracks form, defining dominantly five-sided polygons. Cracks extend to variable depths on the order of centimeters to more than half a meter.

Water Loss: Water loss is interpreted as the dominant cause for crack formation. Our measurements show that 5-10 cm below dune surfaces, the relative humidity remains 100% due to the evaporation and condensation of water in thin films on damaged grain boundaries. The amplitudes of daily temperature fluctuations, and thus absolute humidity fluctuations, decrease with depth, implying less evaporation/condensation cycling with depth in the dunes. Humidity contrasts between pores and the overlying atmosphere result in significant water loss from the dunes except during precipitation and frost/dew condensation. This water loss induces crack nucleation and propagation similar to that in some soils, where water evaporates producing negative pore pressures that increases effective stress, causing the soil volume to decrease and inducing cracking [3]. The volume decrease initially equals moisture loss. Later, capillary tension from moisture decreases sufficiently that air moves into pores and moisture loss is greater than the volume decrease [3]. We interpret upper surfaces of White Sands dunes to be in the second stage, whereas dunes are in the first stage at depth, and crack propagate downward.

Geometry: Geometry of crack triple junctions records the history of fracturing processes [1-3,6-7]. Cracks propagate perpendicular to the maximum tensile stress, and they release stress, changing the local stress field with maximum stress parallel to the crack [8]. Thus, when a crack terminates against an older one, triple junction angles tend to be 90°, 90°, and 180°. In contrast, ideal cracks propagating from a point show three 120° angles. Propagation of cracks with depth or repeated cracking and healing causes evolution of angles toward 120° [9]. At White Sands, polygonal crack networks have average triple junction angles of 92°, 117°, and 142° (N=165). This angular distribution can not be due to propagation of cracks with depth because these distributions are observed at the tops of dunes as well as slopes. Similarly, cracks at tops of dunes are unlikely to heal and reopen frequently enough for crack angles to evolve. Thus, we interpret crack angles as reflecting nucleation from points with inhomogeneities in stress causing variations in crack geometry..

Martian Sediments: Similar analysis of cracks in hydrous sulfate-rich sediments or sedimentary rocks on Mars [10-11] can provide insights into contraction and water loss processes. Fracture patterns range from dominated by 90° to dominated by 120° angles. These variations may reflect evolution of cracking patterns through repeated wetting and drying or variable contraction properties, either of which can provide insights into water cycling between sediments and the martian atmosphere.

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Fig. 1: Polygonal cracks in gypsum sand, White Sands National Monument, showing dominantly 120° triple junction angles. Image is about 50 cm across.

ORIGIN, EVOLUTION AND DEMISE OF THE EBERSWALDE CRATER LAKE

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Introduction: Since its initial discovery in 2003, the timing of the Eberswalde fan has been referred to as Late Noachian linked to a warm and wet climatic period [1,2,3]. Although it is recognized that the fan and drainage system was formed on a Noachian aged landscape, pinning the timing of its formation and demise remains elusive.

A stratigraphic chart was assembled from several studies that summarizes the relative timing of deposition between several adjacent craters . Placing the Eberswalde fan into this framework allows for an understanding of its evolution and relative timing within the context of the broader evolution of the Uzboi-Holden-Landon-Margaritifer drainage system. It is postulated that the Eberswalde fan may be Hesperian in age.

Origin: The Eberswalde fan and its drainage system is short lived [3,4] and is primarily spawned from a highland source terrain of the Holden Crater rim. It is a secondary system to the adjacent longer lived Uzboi-Holden-Landon-Margaritifer drainage system. Reconstruction of the lake levels and headland drainage suggest a local source that likely involved snowmelt. A Hesperian proposed timing, although younger than earlier estimates, is not definitive. It does fit a time of shift in climate and depositional response inferred within other segments of the broader drainage system.

Evolution: Several authors have described the depositional history illustrating 5 lobes of fan deposition [3,5,6,7]. Lake persistence estimates have ranged from short lived (yrs), with dry periods, to a long lived standing body of water of 1-2MM yrs [3,5,8].

Despite no clear evidence, by simply reversing the order of lobes 3 and 4 of Woods (2006), a simple 3 stage, initiation, peak and waning phase model arises. Under this scenario the peak phase lobes form during a declining water body. Episodic pulses of higher supply during this phase would raise lake level and account for the observed aggradational stacking patterns [6,7]. The waning phase is punctuated with brief high velocity floods that entered a highly depleted lake.

Demise: A headland source terrain of limited extent and replenishment likely led to the ultimate demise of the lake. Two elevation levels are observed for the headland drainage. The lower elevation system (~50m) drained a broader area but appears short lived. The upper elevation system (~400m) truncates the lower and appears longer lived. It is postulated that the different headwater elevations reflect retreat of a snowpack. It is assumed that atmospheric pressure declined to the point that conditons no longer supported a surface aqueous phase for the drainage and fan elevations.

Regional Stratigraphic Fit: The relative timing of events in Argyre, Hale, Bond, Holden and Eberswalde craters can be inferred and placed into a generalized stratigraphic framework. The lines of evidence for timing of features in each area are weak on their own, but collectively suggest a common pattern that might offer some constraint on the timing of the Eberswalde fan .

Relationship to Argyre : The later phase of inward flowing drainage and sedimentation at Argyre may be equivalent to the Eberswalde fan when both reflect a last gasp climate of surface aqueous favored conditions. A portion of Argyre lake deposition is earlier.

Argyre rim collapse may explain the displacement of lake water and the connection and catastrophic flow events through Uzboi during the Noachian. This process may also explain the shift from outward to inward flow for this crater.

Relationship to Hale and Bond : Deposition in these post Uzboi craters likely occupies the equivalent of the waning phase of Eberswalde fan deposition or younger. The absence of fluvial features in these craters is consistent with the termination of outflow from Argyre and a shift to a glacial and surface aqueous depleted setting [9].

Relationship to Holden : Eberswalde fan duration may correspond to the unconformity time period between lacustrine cycles or during the second cycle recognized in this crater. Similar crater histories [10] and flow decline within Uzboi canyon and Nirgal Vallis would fit the history and common demise of these two lakes[6].

Summary: Although the Eberswalde pre-fan history is unknown it is clear that the depositional and lake history was relatively short lived and formed during a waning phase of regional water supply. Eberswalde low may have been dry throughout most of its history.

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"SEQUENCE STRATIGRAPHY" OF POLAR DEPOSITS ON MARS: LESSONS LEARNED. K. L. Tanaka[1], C. M. Fortezzo[1], J. A. Skinner, Jr.[1], and E. J. Kolb[2], [1]U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, Arizona 86001 (ktanaka@usgs.gov), [2]Google, Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043.

Introduction: The polar regions of Mars exhibit relatively pristine sequences of mostly layered water ice and dust that form broad plateaus (Planum Boreum and Planum Australe). Recent and ongoing studies have utilized high-resolution imaging, multispectral, and radar sounding data obtained from orbiting spacecraft to determine the stratigraphic character of polar layered deposits (PLD) and how they may relate to orbitally driven climate variability [e.g., 1-12]. Here we focus on results achieved by adapting the sequence stratigraphy approach used to study sediments on Earth to mapping of the PLD. Results illustrate that this technique is vital for constraining and correlating geologic histories among various martian sedimentary sequences, which also occur in the cratered highlands, in canyons, and along the highland-lowland boundary.

Methodology: Sequence stratigraphy involves a mapping approach that provides a chronologic framework to rock strata, whereas the more common approach to mapping discriminates rock formations based on their material characteristics. The key structure that is mapped in sequence stratigraphy is the unconformity [13]. Unconformities may bound sequences of sediments that grade vertically and laterally in characterisitics such as mineralogy, bedding, and grain size, shape, and sorting [14]. Terrestrial sequence stratigraphy is applied to strata that record marine transgressions and regressions at multiple time scales due to climate-driven sea-level changes, basin subsidence, and changes in sediment supply [14]. The goals of mapping and analyzing sequences of layered deposits on Mars, at the poles and elsewhere, are commonly similar.

North PLD stratigraphy: We have delineated 5 Planum Boreum (PB) units, which from oldest to youngest are the rupes, cavi, and 1-3 units [12]. The PB rupes unit forms an ice-rich basal unit locally exceeding 1000 m in thickness and whose layers are tens to hundreds of meters thick; radar sounding data reveal its buried extent and topography, which is highly modified by erosion [6, 11]. Its crater density indicates that it was formed during the Hesperian (>3.5 Ga). Afterwards, the PB cavi and 1 units were emplaced forming sequences of ~meter-thick layers approaching 1500 m in total thickness, but their age is not well constrained (perhaps Middle to Late Amazonian, or several Ma to perhaps ~2 Ga). The cavi unit is sand rich and occurs locally and grades upward and laterally into the PB 1 unit, so there is no unconformity between them. Hundreds of local unconformities occur in the PB 1 unit, particularly in exposures of lower, marginal sequences. PB 2 and 3 units respectively represent relatively lithic- and ice-rich PLD, each no more than several tens of meters thick and superposed on partly eroded surfaces of underlying PB units. Bright residual water ice <1 m thick mostly superposed on unit PB 3 appears to be transient, and its behavior relative to recent climate is under investigation [e.g., 8, 15].

South PLD stratigraphy: The south PLD are made of 4 Planum Australe (PA 1-4) units of Amazonian age underlain by ice-rich Hesperian deposits of the Dorsa Argentea Formation. Each of these PA units are separated by unconformities and made up of meters-thick layers. The PA 4 unit is made up of CO_2 ice, whereas the other units are mostly water ice and dust. Several unconformities of possible regional extent have been mapped in the PA 1 unit. Crater dating of the PA 1 and 2 surfaces indicate that they are likely >100 Ma [16], and their onset could be much older.

Lessons learned: Major depositional breaks occur in both PLD, possibly due to pronounced changes in climate patterns, volatile supply, and other regional to global factors. Because an unconformity occurs just tens of meters below the top of the north PLD [3, 12], attempts to correlate detailed layering signatures below this break among various outcrops as well as to the orbitally driven climate record [1, 2] are highly suspect. Also, significant differences occur in how sequences of north and south PLD are delineated by unconformities. Thus, regional factors may be at play. By extension, other strata on Mars likely face the same obstacles in correlating various outcrops of similar appearance and setting and in constraining their ages.

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RECENT HYDRATED MINERALS IN NOCTIS LABYRINTHUS CHASMATA, MARS. P. Thollot[1], N. Mangold[1], S. Le Mouélic[1], R. E. Milliken[2], L. H. Roach[3], J. F. Mustard[3], [1]Lab. de Planétologie et Géodynamique, UMR6112, CNRS et Université de Nantes, 2 rue de la Houssinière, BP 92208, 44322 Nantes cedex 3, France, patrick.thollot@univ-nantes.fr, [2]Jet Propulsion Laboratory, Caltech, MS 183-301, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, [3]Dep. of Geological Sciences, Brown University, 324 Brook St., Box 1846, Providence, RI 02912, USA.

Introduction: Hydrated minerals on Mars are most commonly found in terrains dating to the first billion years of the planet's history. However, the identification of a Late Amazonian alteration layer has been reported recently by [1]. This study examines spectral and imaging data over Noctis Labyrinthus in search for other occurrences of hydrated minerals.

Data: Mineralogy was determined from data acquired by CRISM [2]. We looked for absorption bands diagnostic of hydrated minerals. We carefully ratio spectra of outcrops of interest to nearby dusty areas in order to remove column dependant noise and potential water ice clouds signatures.

Observations: CRISM data reveals hydrated minerals in 2 distinct chasmata of Noctis Labyrinthus, shown as North (NC) and South (SC) Canyon (Fig. 1).

Geologic context. NC floor is flat and bears HCP spectral signatures [3]. Several landforms can be observed that suggest a volcanic origin. The model crater age determined by [3] is <100 My.

SC features pyroxene bearing plains but no obvious volcanic landforms. Stratigraphy is exposed by a ~5x6 km large, ~400 m deep depression, surrounded by two tongue-shaped pyroxene-rich units, of which one features a light-toned layer surrounding its base.

Hydrated Mineralogy. Light-toned outcrops are present, and seem stratigraphically "sandwiched" between darker units. Absorption bands at 1.4, 1.75, 1.9 and 2.2 µm, allow us to differenciate a "blue" and a "green" unit based on spectral signatures of hydrated materials. As shown in Fig. 2, possible spectral matches for the blue unit include sulfates such as gypsum and bassanite while the green unit signatures suggest the presence of hydrated silica (opal).

In SC, several units appear spectrally distinct, with Fe/Mg sulfates interstratified between hydrated silica and/or Fe/Mg/Al phyllosilicates.

Discussion: NC geology and mineralogy bears resemblance to that of the chasma examined by [1]. Emplacement of the light and dark toned units may have occurred from airfall of volcanic ash. Interaction of ashes with volcanic gases such as SO_2 and a source of water would have formed hydrated sulfates and hydrated silica. These altered deposits may be linked to the surrounding volcanic activity, then suggesting a young alteration (<100 My).

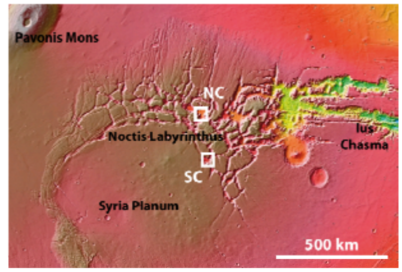

Fig. 1 Context of the study area (MOLA map)

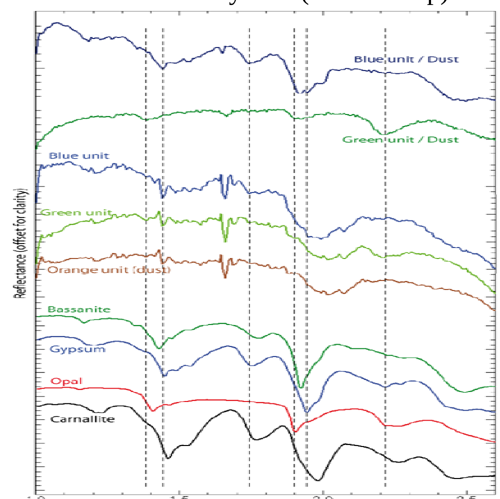

Fig. 2 CRISM spectra (blue, green, orange) and ratios (upper two spectra) compared to reference spectra [4] (lower four spectra). The 1.65 µm band is an artifact of CRISM data.

As the original deposits fill a late Hesperian chasma, their age is younger than that of most hydrated minerals on Mars, which date from the Noachian to early Hesperian [5], [6].

Conclusion: With respect to their formation process, recent alteration minerals in Noctis Labyrinthus chasmata may be different from widespread deposits observed elsewhere on Mars. Their recent age would imply that their formation did not require a martian climate that is different from that of today.

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ELEMENTAL DISTRIBUTIONS PRODUCED BY SORTING IN SILICICLASTIC SEDIMENTS: POTENTIAL FOR PROCESS INTERPRETATION. M. M. Tice[1], [1]Department of Geology & Geophysics, Texas A&M University, 3115 TAMU, College Station, Texas, 77843, tice@geo.tamu.edu.

Introduction: Some enrichments and depletions of elements associated with heavy minerals in Martian rocks and soils observed by lander alpha particle x-ray spectrometers (APXS) probably resulted from transport sorting [1]. Since many heavy minerals are composed of elements that are only trace components in most major rock-forming minerals (e.g. Ti in rutile, anatase, ilmenite, titanomagnetite, etc.; Zr in zircon; Fe in ilmenite, magnetite, titanomagnetite, hematite, etc.), transport-induced fractionations can be reflected in sediment elemental composition [2]. Moreover, sorting can produce heavy mineral enrichments or depletions lining laminations in a variety of sedimentary deposits [e.g. 3-6].

However, most compositional data for siliciclastic rocks are collected from relatively homogeneous material in order to infer source terrains or alteration processes. It is possible that patterns of spatial variability in rock composition arising from sorting processes could be used to infer information about transport and deposition supplementary to descriptions of sedimentary structures or physical grading. Compositional data could be particularly significant in rocks for which these traditional descriptions are difficult to obtain, especially fine-grained sedimentary rocks.

In order to investigate spatial patterns associated with elemental sorting produced by specific depositional processes, the distributions of compositionally distinctive heavy mineral grains were mapped in sandstone, siltstone, and mudstone slabs by x-ray fluorescence microscopy over areas up to 10 cm × 10 cm at 10 μm and 100 μm resolution. Samples included turbiditic sandstones and siltstones of the Brushy Canyon Formation (Middle Permian), deltaic interbedded sandstones and mudstones of the Fall River Formation (Cretaceous), and fluvial cross-laminated sandstones of the Bluejacket Sandstone (Middle Pennsylvanian).

Results and Interpretations: Massive/normally graded turbiditic sandstones (Bouma A divisions), although typically exhibiting size grading only toward to their tops, show characteristic upward decreasing Zr and Ti abundances throughout. This suggests that gradients in the abundances of both elements within individual beds may be useful for identifying the deposits of waning flows, even where physical grading is difficult to detect or absent. Ti abundances are maximum in finely laminated siltstones at turbidite tops (Bouma D divisions), suggesting an additional, hydraulically fine phase for Ti in these rocks.

Mudstone beds are enriched in Fe, Ti, and Al. Cross-laminations in all samples are marked by enrichments of Zr, Zr + Ti, Ti + Fe, or Fe + Al, probably reflecting shielding of small or flat grains by larger light mineral grains in separation bubbles on the lee sides of migrating ripples (Fig. 1) [5]. These elemental associations are consistent with overall grading patterns observed in turbidites and suggest that, in sediments with similar heavy mineral assemblages, elements are sorted from heaviest to lightest in the order Zr, Ti, Fe/Ti, and Al. Boundaries between cross sets are enriched in Zr, Ti, or both, reflecting trapping of the densest grains in the troughs of migrating ripples.

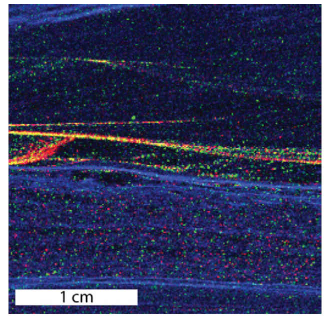

Figure 1. False-color map of Zr (red), Ti (green), and Fe (blue) in cross-laminated sandstone (Brushy Canyon Formation). Note sorting into characteristic assemblages of Zr, Zr + Ti, Fe + Ti, and Fe.

Conclusions: Spatial distributions of Zr, Ti, and Fe in sandstones, siltstones, and mudstones deposited in a variety of environments show consistent patterns of sorting reflecting shear velocities of the depositing flows. Current research is exploring the utility of this data for distinguishing between wind- and water-transported deposits and for quantitatively estimating such flow properties as shear velocity, volumetric sediment concentration, etc. These results may have application to interpreting physical sedimentary features on Mars by careful selection of APXS measurement spots, particularly if extended to different tectonic settings or basins with more mafic source terrains.

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MINERALOGY OF MARS ANALOG EXPLORATION TARGETS IN THE TODILTO FORMATION.

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Introduction: The Todilto Formation is a mid-Jurassic carbonate-sulfate evaporite sequence in NW New Mexico and SW Colorado [1,2,3]. Despite great extent (>150,000 km^2), the Todilto is thin (<37 m) and in general mineralogically simple, with basal limestone and upper carbonate plus Ca-sulfate (gypsum in outcrop, anhydrite where buried beneath the Colorado Plateau). The Todilto was emplaced by rapid marine flooding of the underlying Entrada Formation dune field [4]. Comparable flood events on Mars may account for some Ca-sulfate deposits seen from orbit [5].

Todilto Mineralogy: The basal limestone is laminated calcite with minor gypsum, kaolinite, and detrital quartz; thin bituminous laminae may occur along fissile partings (Figure 1). The overlying evaporite grades to a "chicken wire" fabric of gypsum nodules separated by septae of calcite and rarer dolomite.

Figure 1: Laminated basal Todilto; fine-grained calcite with detrital quartz (clear grains). Minor gypsum and kaolinite are associated with dark, bituminous bands.

Todilto outcrops are essentially calcite plus gypsum, but they locally include many other minerals. In the Grants uranium district uraninite is syngenetic in the basal limestone, along with ~26 other authigenic minerals [2,6] and including the type locality of santafeite, a Mn-vanadate [7]). The basal carbonate often has Fe-oxide and oxyhydroxide pseudomorphs after pyrite, an organically mediated sulfide that formed beneath microbial mats in Todilto playas [2]. Biological components were not trivial; where the Todilto is deeply buried, oil has migrated into underlying Entrada sandstone to form commercially productive deposits [8]. Even in weathered outcrops total organic carbon (TOC) in laminated Todilto carbonate may be ~1%, likely derived from algae and bacteria [1].

In general, unique mineralogy and high TOC are associated with carbonates and not with the gypsum. However, Fe-rich gypsiferous bodies can occur within contorted laminar calcite below the carbonate-sulfate transition (Figure 2). The dm-scale Fe-rich bodies preserve some pyrite, albeit mostly replaced by goethite pseudomorphs. The Fe-rich bodies do not preserve bituminous matter but the pyrite, out of equilibrium in its present association, is a vestige of microbial reducing environments.

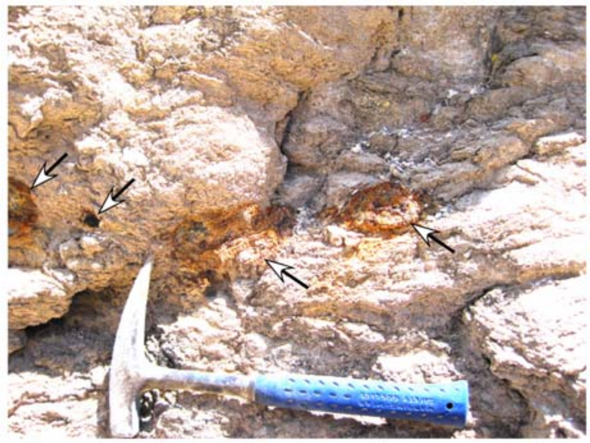

Figure 2: Fe-rich inclusions (arrows) in upper contorted, laminated carbonate facies of the Todilto Formation.

Exploration Targets: The simple composition of the Todilto is generally monotonous; in such a setting it is likely that exploration would zero in on features such as the basal layers or Fe-rich bodies shown here. The draw to these is in part because they simply stand out in imaging and in part because they represent contact or interface assemblages where initial low-salinity deposition or redox boundaries were present. Similar features might be encountered on Mars, although oxidation at the martian surface could destroy both bitumen and pyrite [9]. Nevertheless, Mössbauer data indicate a range of oxidation and suggest preservation of Fe-sulfide [10]; detection of bitumen or pyrite in evaporite sediments could provide pointers to past life.

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SURFACE DUST REDISTRIBUTION ON MARS AS OBSERVED BY THE MARS GLOBAL SURVEYOR.
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Introduction: The global redistribution of dust by the atmosphere is both geologically and climatologically important [1,2,3]. Dust deposition and removal at the surface represents ongoing sedimentary geology: a modern version of aeolian processes responsible for the concentration of vast dustsheets and potentially for ancient layered units at various locations on Mars. The varying amount of dust on the surface also has been hypothesized as a factor in controlling whether regional or global dust storms occur in a given year. Indeed, the atmosphere has a very short, sub-seasonal time-scale (or memory) and as such, any interannual variability in the climate system that is not simply ascribable to stochastic processes must involve changing conditions on the surface.

An excellent, multi-year dataset is provided by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) and the Mars Orbiter Camera Wide Angle imager (MOC-WA). This dataset allows investigation into the degree to which surface dust deposits on Mars change: over decadal time scales, over the course of the annual cycle, and as a result of global and regional dust storms. The MGS mapping orbit data set extends over 3 Martian years. These data sets include one global dust storm and smaller regional storms (one in the first TES mapping year and two in the third).

Data and Methods: We have used TES albedo measurements as a proxy for surface dust coverage, after validating this approach against the spectral Dust Cover Index [4]. We also use MOC-WA imagery to provide a qualitative verification of changes in surface dust coverage that we have inferred from changes in TES albedo. There are some limitations to our approach, including the masking of surface albedo by atmospheric scattering, and the inability to assess dust delivery or removal from a fully covered dusty surface (i.e., one that would not change in brightness).

Results and Discussion: We will present temporal profiles of surface albedo and atmospheric dust opacity for several study regions on Mars [1]. The collection of regions comprise both net sources and sinks of dust over the multiyear period of study. In addition, they illuminate some of the relationships between surface albedo and the occurrance of seasonal frost, atmospheric dust events, and global dust storms.

The MGS albedo data provide the ability to trace dust cover changes to specific atmospheric phenomena at a detailed level. These data show that the 2001 global dust storm caused widespread dust cover changes. Long-term responses to the 2001 storm varied. Areas that were darkened by the 2001 storm tend to show little or no recovery since, while areas that were brightened by the 2001 storm tend to recover over several years. This implies that dust redistribution may be cyclical, but with a multi-year time scale.

Other processes yielding significant albedo changes include seasonal cap-edge winds, seasonally varying regional winds, local/regional dust storms, and extratropical cyclones. Dust devils and ongoing, small-scale dust lifting do not appear to significantly modify the global patterns of dust cover. Finally, we argue that the apparent long-term darkening of the southern mid and high latitudes between the Viking and MGS eras is largely a consequence of the timing of image acquisition relative to global dust storms and surface dust "cleaning" by the seasonal ice cap and does not represent a decadal-scale, secular change. In fact, following the 2001 global dust storm, in late southern spring, the southern hemisphere was brighter in MGS than in Viking data.

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DENTICLES ON CHAIN SILICATE GRAIN SURFACES AND THEIR UTILITY AS INDICATORS OF WEATHERING CONDITIONS ON EARTH AND MARS. M. A. Velbel and A.I. Losiak, Department of Geological Sciences, Michigan State University, East Lansing, MI 48824-1115 U.S.A. (velbel@msu.edu).

Introduction: This paper reviews common low-temperature aqueous dissolution features on naturally weathered terrestrial chain-silicates and their applications to determining (paleo)environmental weathering characteristics, and then compares new measurements of some well-understood terrestrial textures with grain-surface textures of Martian surficial sediment.

Background: Pyroxene corrosion during terrestrial low-temperature aqueous alteration (weathering): Denticulated margins (also known in older literature as "sawtooth", "cockscomb" or "hacksaw" terminations) are a common feature of pyroxenes and amphiboles. Denticles are the remnants of undissolved material that originally represented the walls between elongate (almond-shaped) etch pits. This morphology is commonly produced during aqueous dissolution of chain-silicates, and occurs where a grain boundary, transmineral fracture or dislocation array transects the crystal at a high angle to the *z*-axis [1]. Terrestrial denticles are common in materials that experienced low-temperature aqueous alteration, including chemically weathered regoliths, soils in a variety of climatic and geomorphic settings, sediments and sedimentary rocks [1]. Some morphologic measures of chain-silicate corrosion during weathering (amplitude of denticulated terminations; size and shape of etch pits) have been successfully used to infer durations, rates, and (paleo)environmental climatic conditions of weathering and soil formation on terrestrial glacial parent materials [2].

Denticles on weathered terrestrial chain silicates [1-3] are similar in shape, size and distribution to features reported from recent Phoenix Microscopy, Electrochemistry, and Conductivity Analyzer (MECA) atomic force microscope (AFM) data. This contribution examines selected morphometric attributes of corrosion textures on naturally weathered terrestrial pyroxene to test two hypotheses: (1) Denticle geometry can be used to infer the composition of the parent pyroxene; (2) Morphologic attributes of the denticle in the Phoenix MECA AFM image are consistent with low-temperature aqueous corrosion.

Methods: Apical angles of denticles on naturally weathered terrestrial pyroxenes were measured from scanning electron microscopy (SEM) images.

Results: Apical angles on corroded pyroxenes can vary considerably among multiple denticles even in single images showing multiple identically oriented denticles on the same corroded pyroxene surface. Denticle apical angles in typically range over as much as 20° in single images; the maximum range observed for this study was nearly 50°. Different images of different but compositionally similar pyroxene grains have non-overlapping ranges of apical angles, even among images from the same parent material and weathering profile. Some images of corroded enstatite yield ranges of apical angles identical with some images of corroded augite, indicating that apical angle is not diagnostic of composition.

Discussion: Pyroxene is a chemically important mineral on Mars. It has been identified in Mars surface materials by instruments on the Mars Exploration Rovers and several Mars orbiters. Pyroxene dissolution is inferred to have contributed significantly to the solute composition of inferred Martian groundwaters. Pyroxene is also a major constituent of Mars meteorites, including nakhlites and many shergottites. The Phoenix MECA AFM imaged sawtooth features several microns in length, that strongly resemble denticles known to form by low-temperature aqueous corrosion of naturally weathered pyroxenes on Earth [1-3].

Denticles on pyroxenes are the corroded remnants of etch-pit walls. Pyroxene etch-pit walls are not crystal planes of the corroded pyroxene, and some are visibly curved. Such curvature of denticle surfaces complicates the measurement of apical angles. Furthermore, because of the large depth-of-field of SEM, variation of apparent angle is likely based on variable and non-uniform orientations of imaged surfaces. Consequently, there is presently insufficient basis for quantitative interpretation of denticle morphology, although qualitative comparison is still informative.

Conclusions: Ranges of some morphometric parameters of corroded terrestrial pyroxene surfaces are so large that measured angles could correspond to a wide range of pyroxene compositions and specific corrosion forms. Nevertheless, the similarity of aqueous weathering-related terrestrial chain-silicate denticles with features imaged on Mars is presently not inconsistent with inferences of a low-temperature aqueous origin of the Mars mineral denticles.

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Characteristics of Crater Floor Deposits in the Ares Vallis Region N. H. Warner[1], S. Gupta[1], S. Lin[2], J. Kim[2], J. P. Muller[2], J. Morley[3] [1]Dept. Earth Science & Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, UK, n.warner@imperial.ac.uk. [2]Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London, Holmbury St. Mary, Surrey, RH5 6NT, UK, [3]Centre for Geospatial Science, Sir Clive Granger Building, University of Nottingham, University Park, Nottingham, NG7 2RD, UK.

Introduction: Several medium to large diameter (D > 8 km) impact crater basins are present on the Late Noachian-Early Hesperian highland surfaces surrounding the Ares Vallis outflow channel [1]. Of these craters, some contain single, sinuous outlet channels which imply the past presence of crater lakes [2]. Additionally, several large diameter craters occur within the confines of the Ares Vallis outflow channel and show evidence for rim modification and breaching by floods. Using high resolution CTX, HiRISE, HRSC, and THEMIS images we have identified infilling deposits within both classes of craters. These materials show a variety of surface morphologies that may be linked to specific fluvial-lacustrine and periglacial processes.

Highland Craters with Outlet Channels: Four impact craters on the highland terrain surrounding Ares Vallis contain single, sinuous outlet channels and lack inlets or gullying on the interior crater walls. Furthermore, there is no evidence for modification of the highland craters by floods, indicating that these craters are located beyond the extent of past flood activity. Groundwater sapping into the crater basins is therefore the most likely mechanism for water infill.

CTX images of the infill material within the highland craters with outlet channels reveal smooth layered deposits that embay the interiors of the crater rims (thickness estimate = 300 m – 600 m). The surface of these deposits are marked by three distinct morphologies that include: (1) polygonally fractured terrain (Fig. 1) (2) smooth terrain and (3) smooth terrain with small conical mounds. Three out of four observed crater floors exhibit polygonal fractures that are concentrated at specific locations on the surface of the deposits. The polygons are ~ 30 m – 100 m wide and are similar in scale to purported de-hydration polygons identified on the floors of other former Martian crater lakes [3]. Smooth terrain is present within all the outlet channel craters, but often transitions to polygonal terrain where dust cover has been removed. One outlet channel crater, located at 5.5° N, 337.4° E, contains interior conical mounds that resemble either relic ice-cored pingos or rootless volcanic cones.

Ares Vallis Flood Modified Craters: Located at 2.5° N, 344.0° E is a 70-km-diamter impact crater that is cross-cut by the 1-km-deep eastern branch of Ares Vallis. Within the crater, the flood channel bisects layered deposits that exhibit lobate to oval flat-floored

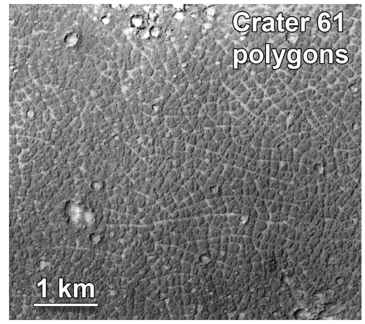

Fig. 1: CTX image of polygons on the floor of a crater with an outlet channel near Ares Vallis [2].

depressions on the surface. The morphology of these features is most consistent with thermokarst pits on Earth and Mars, which form by sublimation or melting of near-surface ice [4, 5]. HiRISE images taken from the interior of the depressions reveal poorly developed meter-scale layering with evidence of discontinuous and structurless bedforms. We hypothesize that flood deceleration within this broad channelized region of Ares Vallis deposited water-saturated flood sediments. Freezing of the water within the sediments and subsequent ice degradation may explain the formation of the thermokarst depressions [4].

Discussion and Conclusions: From crater statistics and relative relationships between the crater outlet channels and the Ares Vallis system we suggest that the highland craters in the region were infilled with water/sediment during the Late Noachian/Early Hesperian. However, drainage and outlet channel formation occurred only after a delay of 100 Ma – 900 Ma in the Late Hesperian/Early Amazonian.

In contrast, crater statistics and relative relationships with Ares Vallis outflow channels indicates that the infilling sediments and thermokarst-like depressions in the flood modified impact crater formed during the Late Hesperian, near 3.3 Ga – 3.0 Ga [4]. Interestingly, the timing of highland crater drainage corresponds closely to the regional formation of thermokarst terrains. This may indicate a genetic relationship between the features controlled by regional climate warming and melting of near-surface ice.

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FLUVIAL SEDIMENT ACCOMODATION AND MESOSCALE ARCHITECTURE—SOME NEGLECTED PERSPECTIVES. M. J. Wilkinson[1], [1]Jacobs Engineering, NASA–Johnson Space Center, 2224 Bay Area Blvd., Houston TX 77058, USA. justin.wilkinson-1@nasa.gov.

Introduction: Common assumptions in modeling martian fluvial sedimentation are that enclosed basins are a necessary constraint, with waterbodies such as lakes or seas within the basins. Two recent studies [1] reinforce the fact that these constraints are unnecessary for the accumulation of large fluvial sediment bodies on Earth. *Fluvial deposition on a slope* is the norm in terrestrial basins—requiring neither closed depressions nor waterbodies. The following terrestrial perspectives probably apply on Mars.

Fluvial sediment accomodation: Where other controls are lacking, accomodation for fluvial sediment accumulation is controlled in the longer term by the slope of stream profiles. Profiles tend towards a smooth concave parabolic form, beneath which fluvial deposition takes place—i.e. *under sloping stream profiles*, and in locations where basinal topography lies at altitudes lower than the profile (Fig. 1). The low-angle profiles of larger rivers project 100s km into lowland basins [1]. The associated sediment bodies in such basins, *unconfined* by valley walls, consequently cover very large areas (e.g. the Pilcomayo R. cone measures 210,000 km^2 [2]). Further, a distal confining wall—as in an enclosed basin—*is not a necessary constraint.* In hyperarid settings, accommodation can be increased locally since lower reaches of many desert rivers are *convex up* (steepening through loss of discharge [3]—dashed line, Fig. 1)—which implies a significant accommodation volume in an unconfined lowland.

Mesoscale architecture of fluvial sediment bodies in unconfined lowlands: Recent studies suggest that fluvial basin fills in unconfined settings are partial cones of low slope, and that large conical sediment bodies, still poorly recognized, are "the norm" in fluvially filled basins [1]. Larger basins are characterised by larger cones (100s of km long)—and are thus probably appropriate analogs for Mars. Such features are mesoscale (Group 9) architectural elements in Miall's hierarchy of fluvial bodies [4], intermediate in size between channel belts (Group 8) and "smaller basin fill complexes" (Group 10).

Mars: A survey of large cones (>100 km long) on Earth has revealed >150 such features. Perspectives from the study have allowed *prediction* of the location of a large relict cone (260 km, 85,000 km^2)—unsuspected by geologists from either remotely sensed imagery or numerous well-studied boreholes [5].

These perspectives should assist in identifying analogs on Mars. Indeed, possible examples of large sediment cones are modern Amazonis Planitia (and prior stages in its history) [6], and the feature at the mouth of Maja Valles. Large sediment cones have been suggested as loci of hydrous environments on Mars, based on a distal-cone aquifer in the Kalahari Desert [5].

Mesoscale fluvial cones, deposited on a slope, provide a model for fluvial deposition on larger martian plains—a parsimonious alternative without requirements for enclosed basins or waterbodies.

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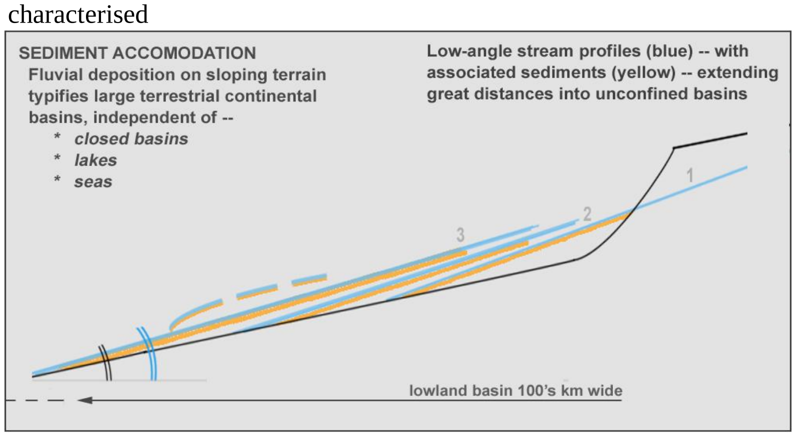

Fig. 1 Fluvial sedimentation on a slope (black line), i.e. without the influence of closed basins. Note lack of a distal topographic wall. Large accommodation volume relates primarily to the low slope of larger river profiles (nevertheless steeper than the underlying surface). 1–3: successive stages of fluvial sedimentation in a major lowland basin. Convex profile at desert stream end-point—dashed line. Vertical scale much exaggerated.

Stratigraphy of Al- and Fe-Rich Phyllosilicates in Southern Sinus Meridiani. S. M. Wiseman[1], R. E. Arvidson[1], R. V. Morris[2], F. P. Seelos[3], and J. C. Andrews-Hanna[4], [1]Washington University in Saint Louis, [2]NASA Johnson Space Center, [3]Johns Hopkins Applied Physics Laboratory, [4]Colorado School of Mines..

Introduction: In southern Sinus Meridiani, Noachian aged fluvially dissected, heavily cratered highlands are embayed by the Late Noachian/Early Hesperian sulfate- and hematite-bearing unit that was explored by the Opportunity rover [e.g., 1, 2]. Phyllosilicates have been detected in multiple locations throughout the southern highlands and are generally inferred to predate the formation of sulfate rich layered rocks [3]. Our new analysis of MRO data shows an unconformable contact between the younger sulfate-rich unit and the older phyllosilicate-bearing Noachian cratered terrain in southern Meridiani.

Stratigraphy and Mineralogy: Deeply incised channels in Noachian aged cratered terrain in southern Meridiani are separated by high standing interfluves in which light toned layers are exposed (Fig. 1a). Analysis of MRO CRISM, CTX, and HiRISE data reveals that at least two distinct layers are exposed in the upper portions of the interfluves. For simplicity, the lower layer will be referred to as Unit A and the upper layer as Unit B (Fig. 1a). Unit A consists of light toned indurated rock that exhibits spectral signatures of multiple hydrated phases. Unit B caps unit A and is also indurated. Unit A is exposed in areas where Unit B has been stripped via erosion. Remnants of Unit B occur as high standing knobs (Fig. 1a).

Unit A exhibits multiple textures and spectral signatures. The bulk of the unit has a weak to moderate 1.9 µm hydration feature (Fig. 1b, blue). Some areas within Unit A exhibit both a 1.9 and a 2.3 (Fe/Mg-OH) µm feature (Fig. 1b, magenta) indicative of Fe/Mg smectite (Fig. 1c, red spectrum). Al-rich phyllosilicates, which exhibit an Al-OH feature near 2.2 µm, are also detected in Unit A (Fig. 1b, green). Although exposures of Al-rich phyllosilicates are not extensive, spectra indicative of both montmorillonite and kaolin group minerals occur (Fig. 1c, green and black spectra). Areas from which Al-rich phyllosilicate spectra were extracted exhibit a distinctive morphology relative to areas dominated spectrally by Fe/Mg smectites in HiRISE images. Some portions of unit B exhibit a Fe/Mg-OH feature at 2.3 µm (Fig. 1b, red).

Discussion: An unconformable contact between younger sulfate- and hematite-bearing plains and older phyllosilicate-bearing cratered terrain occurs in Southern Sinus Meridiani. The phyllosilicate alteration likely occurred in a hydrologic regime dominated by meteoric water with a high water to rock ratio at moderate pH, whereas the sulfate-and hematite unit formed under ground water dominated evaporitic conditions with a lower water to rock ratio at low pH.

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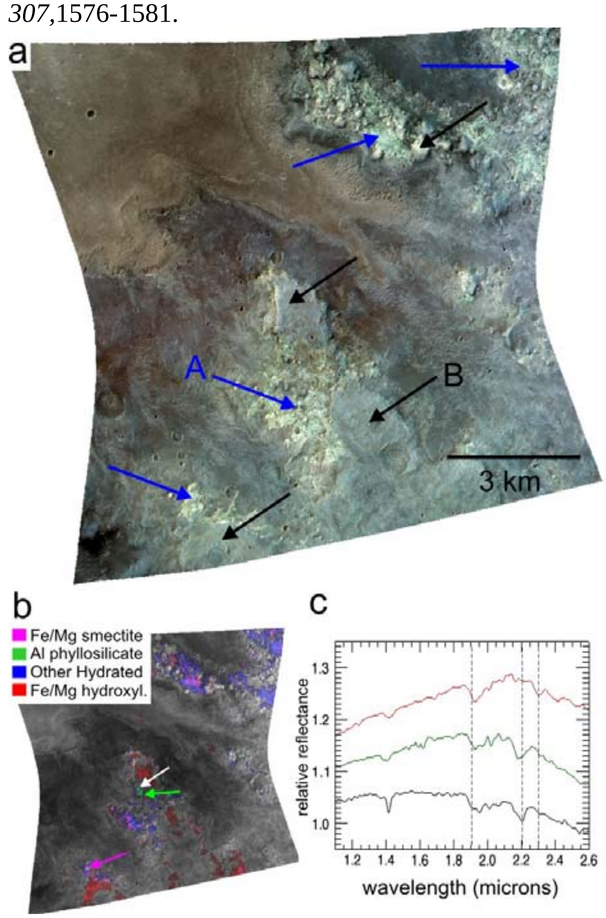

Figure 1. a) CRISM FRT000091C5 (-3.5°N, -5.4°E) false color composite (R=2.5, G=1.5, B=1.1 µm). Interfluves in the cratered terrain exbit light toned layers and are embayd by younger sulfate- and hematite-bearing plains (appear brownish). Blue arrows indicate unit A and black arrows unit B. b) CRISM false color parameter composite (R=D2300, G=D2200, B=D1900) overlain on a 1.1 µm albedo image. Blue areas exhibit an H_2O feature at 1.9 µm, red areas exhibit a Mg/Fe-OH feature at 2.3 µm, magenta areas have both 1.9 and 2.3 µm features, and green areas exhibit an Al-OH feature at 2.2 µm. c) CRISM relative reflectance spectra extracted from locations shown with arrows in part b.

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